Edwards Aquifer Recovery Implementation Program

Habitat Conservation Plan

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Prepared For

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B: Report of the Edwards Aquifer Recovery Implementation Program Science Subcommittee, "Evaluation of Designating a San Marcos Pool, Maintaining Minimum Spring Flows at Comal and San Marcos Springs, and Adjusting the Critical Period Management Triggers for the San Marcos Springs," November 13, 2008.

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S: SAWS ASR Work Group, "SAWS ASR Concept," February 2011.

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Chapter 2 Activities Covered by the Permit

2.1 Covered Activities

The Applicants seek incidental take coverage for four categories of activities that may result in incidental take of the fish and wildlife Covered Species: (1) the regulation and use of the Aquifer; (2) recreational activities in the Comal and San Marcos spring and river ecosystems; (3) other activities in, and related to, the Comal and San Marcos springs and river ecosystems; and (4) activities involved in and related to the implementation of the minimization and mitigation measures in these ecosystems.

The protection and regulation of the use Edwards Aquifer is the responsibility of the Edwards Aquifer Authority (EAA). The EAA also seeks coverage for the persons and entities it authorizes to use the Aquifer. The San Antonio Water System (SAWS), the City of San Marcos, and Texas State University seek incidental take coverage, as Applicants, for their pumping from the Aquifer authorized by the EAA.

The cities of New Braunfels and San Marcos and Texas State University have the authority to manage the spring and river ecosystems within their respective jurisdictions including many aspects of the use of the ecosystems for recreation. They are seeking incidental take coverage for these activities.

Each of the Applicants will be responsible for the implementation of minimization and mitigation measures as well as measures that contribute to the recovery of the Covered Species. In addition, Texas Parks and Wildlife Department (TPWD) will pursue creation of state scientific areas that will protect Texas wild-rice and habitat in the San Marcos Springs ecosystem during low flows and in the Comal Springs ecosystem to protect fountain darter habitat. TPWD also intends to participate in the implementation of other minimization and mitigation measures in both ecosystems. Incidental take coverage is sought for all of these activities.

The following is a brief description of the specific activities for which incidental take coverage is sought. Detailed descriptions of the measures that will be implemented to minimize and mitigate the impacts of the incidental take are set out in Chapter 5.

2.2 Edwards Aquifer Authority

Relative to the HCP, the EAA's primary statutory obligation is to authorize and manage the withdrawal of groundwater from the Aquifer. The EAA carries out its statutory powers through rulemaking.

The EAA seeks incidental take coverage for the EAA's programs that implement these statutory functions. In addition, the EAA seeks coverage for persons who are both authorized under the EAA Act and the EAA's rules to withdraw groundwater from the Aquifer within the jurisdictional boundaries of the EAA and in compliance with the Act and rules. It does not seek incidental take coverage for any federal facility which withdraws groundwater from the Aquifer for the benefit of the federal facility. Finally, EAA seeks coverage for the minimization and mitigation measures that either it will implement or for which it bears responsibility for having implemented

as identified in Chapter 5 of this HCP. The activities for which the EAA seeks coverage are described in more detail as follows.

2.2.1 Groundwater Withdrawal Program

2.2.1.1 In General

The EAA Act recognizes three categories of groundwater rights to withdraw and place to beneficial use water withdrawn from the Aquifer: (1) interim authorizations; (2) permits; and (3) exempt wells. Interim authorization rights are temporal groundwater rights that existed from the effective date of the EAA Act on June 28, 1996, for a limited period of time to provide a transitional bridge from the Texas common law to the statutory-based permit system established under the EAA Act. (*See generally* EAA Act § 1.17). Interim authorization rights became superseded upon entry of final orders by the EAA on applications for initial regular permits, or upon the failure of a well owner to timely file by December 30, 1996, a declaration for historical use for the well. (*See id* § 1.17(d)). The EAA does not currently recognize any interim authorization groundwater rights in the Aquifer. However, on rare occasions the EAA has had to place a well owner back on interim authorization status to address an unusual factual scenario, but does not anticipate in the future having to place a well owner back on interim authorization status.

The second category of Aquifer groundwater rights is groundwater withdrawal permits. These include Initial Regular Permits (and their derivative Regular Permits), Term Permits, Emergency Permits, and Recharge Recovery Permits. (*See id.* §§ 1.16, 1.19, 1.20 and EAA rules § 711.260). The final category of groundwater rights in the Aquifer are wells which are exempt from the permitting and metering requirements. (*See id.* § 1.33). The EAA's rules that implement its groundwater withdrawal program are found at Chapter 711.

2.2.1.2 Authorized Groundwater Withdrawals

Initial Regular Permits

Withdrawals under Initial Regular Permits, and derivative permits due to transfers of these permits which are known as "Regular Permits," are subject to the annual statutory cap on Aquifer withdrawals. In 2007, the Texas Legislature limited total withdrawals under all regular permits to 572,000 ac-ft/yr. (Section 1.14(c) of the EAA Act).

Although the EAA Act provides in Section 1.18 that the EAA may also issue Additional Regular Permits, this portion of the Act cannot be implemented because no additional water is available for permitting under the 572,000 ac-ft/yr cap established by the Legislature in 2007.

EAA seeks incidental take coverage for its authorization of the withdrawals under the cap and for the owners or lessees of the permits making the authorized withdrawals under the permits.

Term Permits

The EAA Act authorizes the EAA to issue Term Permits, which authorize the withdrawal of groundwater for a defined term, up to a maximum of 10 years. (EAA Act § 1.19). These permits are interruptible (*i.e.*, the right to withdraw pursuant to these permits must be interrupted during the term of the permit based upon statutorily-specified Aquifer or springflow levels). Further, withdrawals may be made pursuant to these permits only when Aquifer levels are

relatively high as measured at specified index wells - above 675 ft-MSL in the San Antonio Pool of the Aquifer, and above 865 ft-MSL in the Uvalde Pool or when springflow levels are relatively high (above 350 cubic feet per second [cfs] for Comal Springs and above 200 cfs for San Marcos Springs). Aquifer withdrawals made pursuant to Term Permits are not subject to or limited by the Aquifer-wide withdrawal cap that is discussed above in relation to Initial Regular Permits.

The EAA last issued term permits in 1997 although the EAA no longer has any records for these permits. These term permits are believed to have expired in 1998, and the EAA currently has no Term Permits shown to be outstanding in its permit data base. Current policy of the EAA is to not issue Term Permits. This policy is reflected in Section 711.102(b) of the EAA rules providing that "[u]nless the Board has issued an order authorizing applications for Term Permits to be filed with the Authority, Authority staff may not process any application received and must return the application to the applicant along with any application fee submitted." The Board has not issued such an order.

In the unlikely event the EAA changes policy and again issues term permits during the term of the ITP, the EAA, seeks incidental take coverage for the authorization of the withdrawals from the Aquifer and for the owners or lessees making such withdrawals pursuant to a Term Permit. The manner in which those withdrawals will be addressed is discussed in the Changed Circumstances provisions of Section 8.1.

Emergency Permits

The EAA Act authorizes the EAA to issue Emergency Permits to withdraw Aquifer water for the limited needs of preventing the loss of life, or to prevent severe, imminent threats to the public health or safety. (EAA Act § 1.20). Emergency Permits may be issued for a term of up to 30 days, but are renewable. A holder of an Emergency Permit may withdraw Aquifer water without regard to its effect on other permit holders. Aquifer withdrawals made pursuant to emergency permits are not subject to or limited by the Aquifer-wide withdrawal cap that is discussed above in relation to Initial Regular Permits.

Since its inception, the EAA has issued only one Emergency Permit in 2004 for 150 ac-ft to help remediate a sewer line spill in Salado Creek. This permit expired in July, 2004. By their nature, the EAA does not expect to issue Emergency Permits with any level of frequency.

In the event the EAA may encounter an emergency condition that justifies the issuance of an emergency permit during the term of the ITP, EAA seeks incidental take coverage for its authorization of any withdrawals under an emergency permit and for the owners or lessees making the authorized withdrawals under any emergency permit. The manner in which those withdrawals will be addressed is discussed in the Changed Circumstances provisions of Section 8.1.

Recharge Recovery Permits

The EAA has implemented this statutory authority in its rules to authorize the recovery from the Aquifer of groundwater that is in storage due to the recharge efforts of the Authority or another political subdivision. The EAA's Aquifer Recharge, Storage, and Recovery Program rules are found at subchapter J of Chapter 711. As presently implemented, Recharge Recovery Permits may be issued pursuant to Aquifer storage and recovery projects conducted to increase the yield of the Aquifer, protect springflows, and ensure minimum springflows of the Comal and San Marcos Springs. The EAA has developed Aquifer recharge, storage and recovery rules to allow

entities to conduct approved Aquifer storage and recharge activities. Aquifer withdrawals made pursuant to Recharge Recovery Permits are not subject to or limited by the Aquifer-wide withdrawal cap that is discussed above in relation to Initial Regular Permits.

EAA seeks incidental take coverage for its authorization of any withdrawals under Recharge Recovery Permits and for the owners or lessees of the water making the authorized withdrawals under any Recharge Recovery Permit. The manner in which those withdrawals will be addressed is discussed in the Changed Circumstances provisions of Section 8.1.

Exempt Wells

Exempt wells are those wells that are exempt from the duty to obtain a groundwater withdrawal permit from the EAA and to meter withdrawals. (EAA Act §§ 1.15, 1.16c, and 1.33). A well qualifies for exempt well status if: "(1) it is capable of producing no more than 25,000 gallons of water a day; (2) it will be used solely for domestic or livestock use; and (3) it is not within or serving a subdivision requiring platting; or (4) the well is located on and operated by, or for the benefit of, a federal facility, and prior to September 1, 2003, the EAA has not approved the transfer of ownership of an application for an Initial Regular Permit related to the well from the federal facility to another person." (EAA Rules §§ 702.1(b)(24) and 71.20). Further, Aquifer withdrawals made from exempt wells are not subject to or limited by the Aquifer-wide withdrawal cap that is discussed above in relation to Initial Regular Permits. However, the EAA requires owners of exempt wells to register the well. In so doing, the EAA can be sure that the well qualifies for exempt status.

It is estimated that in 2010, 13,605 ac-ft of withdrawals were made from domestic and livestock exempt wells.(EAA 2011b). The mean amount of water withdrawn annually from these exempt wells between 2000 and 2010 was calculated to be 13,700 ac-ft. (*Id.*). The total withdrawal by exempt federal facilities in 2010 was 5,126 ac-ft. (*Id.)* Thus, the total withdrawal from exempt wells in 2010 was 18,731 ac-ft.[1]

EAA seeks incidental take coverage for its determination that a well qualifies for exempt status and withdrawals from the Aquifer from a well that the EAA has determined to qualify for exempt status. Any "take" of federally listed species resulting from the withdrawal of water from the Aquifer by a federal entity is not included as a Covered Activity in this HCP. The manner in which any significant change in those withdrawals will be addressed is discussed in the Changed Circumstances provisions of Section 8.1.

[1] In the modeling of springflow, HDR assumed the total withdrawal from exempt wells was 20,203 ac-ft. *See* Section 5.8.1 below.

2.2.2 Permit Administration

2.2.2.1 Permit Transfers and Amendments

The ownership, point of withdrawal, purpose of use, place, of use, and maximum rate of withdrawal for a permit may be changed by a transfer or amendment process (EAA Rules Ch. 711, subch. L). The EAA seeks incidental take coverage for its authorization of withdrawals from the Aquifer pursuant to a change in permit under the EAA's permit administration rules in subchapter L of Chapter 711 and for owners and lessees making withdrawals under such a change in permit.

2.2.2.2 Conversion of Base Irrigation Groundwater

The groundwater withdrawal amount for an Initial Regular Permit issued for irrigation purposes is bifurcated between an "unrestricted" amount and a "base" amount, (EAA Act § 1.34(c); EAA Rules §§ 702.1(29) and (199)). The place and purpose of use of the "unrestricted" portion is generally transferable. The "base" portion, however, is not freely transferable and must be used in accordance with the place of use and purpose of use for irrigation as set out in the originally issued Initial Regular Permit. By rule, the EAA has authorized the "conversion" of "base" water into "unrestricted" in certain limited circumstances. Upon conversion, the purpose of use and place of use for the "base" water becomes as freely transferable as that for "unrestricted" water (EAA Rules §§ 711.338-.342). A conversion is authorized in only two circumstances: first, if the irrigator installs water conservation equipment such that less water is required for irrigation of the historically irrigated land (EAA Act § 1.34(b)); and, second, if the historically irrigated lands that provided the basis for the issuance of the Initial Regular Permit have been developed and are no longer farmed under the circumstances described in the EAA rules.

The EAA seeks incidental take coverage for its authorization of withdrawals pursuant to a conversion and for the owners or lessees of irrigation permits making withdrawals from the Aquifer pursuant to such a conversion.

2.2.2.3 Critical Period Management Program

In 2007, the Texas Legislature amended the EAA Act by passage of Senate Bill 3.[2] The legislation amends Section 1.26(b) of the Act to direct the EAA to adopt and enforce a Critical Period Management (CPM) plan with withdrawal reduction percentages whether according to the index well levels or the springflow at Comal or San Marcos Springs as applicable, for a total withdrawal reduction in critical period Stage IV of 40 percent of the permitted withdrawals under Table 2-1 for the San Antonio Pool and 35 percent under Table 2-2 for the Uvalde Pool:

TABLE 2-1
CRITICAL PERIOD WITHDRAWAL REDUCTION STAGES FOR THE SAN ANTONIO POOL

Critical Period Stage	Comal Springs Flow (cfs)	San Marcos Springs Flow cfs	Index Well J-17 Level MSL	Withdrawal Reduction - San Antonio Pool

[2] Senate Bill 3 (Act of May 28, 2007), 80th Leg. R. S. ch 1430, §§ 12.01-12.12, 2007 Tex. Gen. Laws 5848, 5901.

I	<225	<96	<660	20%
II	<200	<80	<650	30%
III	<150	N/A	<640	35%
IV	<100	N/A	<630	40%

cfs = cubic feet per second; MSL = mean sea level

TABLE 2-2
CRITICAL PERIOD WITHDRAWAL REDUCTION STAGES FOR THE UVALDE POOL

Critical Period Stage	Withdrawal Reduction Uvalde Pool	Index Well J-27 Level MSL
I	N/A	N/A
II	5%	<850
III	20%	<845
IV	35%	<842

MSL = mean sea level; N/A = not applicable

The legislation also stipulated that "[b]eginning September 1, 2007, the [EAA] may not require the volume of permitted withdrawals to be less than an annualized rate of 340,000 acre-feet, under critical period Stage IV." (EAA Act § 1.26(a)(d)). Further, "[a]fter January 1, 2013, the [EAA] may not require the volume of permitted withdrawals to be less than an annualized rate of 320,000 acre-feet, under critical period Stage IV unless, after review and consideration of the recommendations provided under Section 1.26A [of the Act] the [EAA] determines that a different volume of withdrawals is consistent with . . . maintaining protection for federally listed threatened and endangered species associated with the Aquifer to the extent required by federal law." (*Id*. at (e)).

The EAA seeks incidental take coverage for withdrawals from the Aquifer as may be reduced pursuant to the final CPM plan described above and in Section 5.1.4 of the HCP.

2.2.3 Minimization and Mitigation Measures

The following Covered Activities constitute minimization and mitigation measures and measures specifically intended to contribute to recovery under the HCP that will be implemented by the EAA. These measures are further detailed in Chapter 5.

- Support of USFWS refugia (Section 5.1.1)
- Voluntary Irrigation Suspension Program Option (Section 5.1.2)
- Regional Water Conservation Program (Section 5.1.3)
- Critical Period Management - - Stage V (Section 5.1.4)

- Expanded Water Quality Monitoring (Section 5.7.5)

2.3 City of New Braunfels

The Comal Springs, Landa Lake, and the Comal River are located within the boundaries of the City of New Braunfels. The City has the authority to manage the ecosystems of the Comal Springs, Landa Lake, and the Comal River within its geographical boundaries. These ecosystems are also used for recreational activities that are regulated in part by the City. Further, the City of New Braunfels diverts surface water from the Comal River.

As described below, the City seeks incidental take coverage for the recreational activities within its jurisdiction, the management of the ecosystems of the Comal Springs, Landa Lake, and Comal River and the diversion of water from the Comal River. Finally, the City of New Braunfels seeks coverage for the minimization and mitigation measures that it will either implement or have responsibility for having implemented.

These Covered Activities are described in more detail below and in Chapter 5.

2.3.1 Management of Public Recreational Use of Comal Springs and River Ecosystems

Public recreational use of the Comal Springs and River ecosystems includes, but is not limited to, swimming, wading, tubing, boating, canoeing, kayaking, scuba diving, snorkeling, and fishing. Related activities include operation of the wading pool at Landa Park on Spring Run 2, non-motorized vessels on Landa Lake, and all tubing, regardless of origin of the tuber or tube, on the Comal River from the confluence of the Dry Comal Creek to the confluence of the Guadalupe River. Where this recreational use is facilitated in any respect by the City of New Braunfels, including but not limited to the providing public access or outfitting services, the City of New Braunfels seeks incidental take coverage for impacts of these Covered Activities. Where this recreation is facilitated by commercial outfitting businesses, the City seeks incidental take coverage for these businesses through Certificates of Inclusion issued by the City of New Braunfels. (See Section 5.2.3). This Certificate of Inclusion process is voluntary, and outfitting businesses may obtain a Certificate of Inclusion in order to obtain incidental take coverage for their recreational activities. Regardless, for a recreator to be covered, the person must be in compliance with all local, state and federal laws and regulations. The failure of a person to comply with these regulations or one or more outfitters' lack of coverage pursuant to a Certificate of Inclusion in no way affects or alters the City of New Braunfels' incidental take coverage or requirements under this HCP and the Permit.

2.3.2 Management of Water Levels in the Comal River

The City of New Braunfels operates gates, culverts, and dam structures from Landa Lake to the Old Channel (three culverts), New Channel U.S. Geological Survey (USGS) Weir, Springfed Pool Inlet, Wading Pool Weir, Clemens Dam, USGS Weir (known as "Stinky Falls"), Golf Course Weir, and Mill Pond Dam (joint New Braunfels Utility and City of New Braunfels operation) to maintain constant flow in the Comal River, maintain constant elevations of large pools, and regulate flow regimes in the Old and New Channels during high and low flow events.

The City of New Braunfels also has a permit from TCEQ for 40 acre-feet of impounded water at Clemens Dam (City of New Braunfels Tube Chute). This permit is non-consumptive and establishes the constant level in the Comal River upstream of Clemens Dam to the confluence of the Old Channel and confluence of the Dry Comal Creek

The City seeks incidental take coverage for the operation of these structures including any incidental take that may occur during their operation such as by entrapment of a Covered Species.

2.3.3 Golf Course Diversions and Operation

The City of New Braunfels seeks incidental take coverage for the maintenance and upkeep of the Landa Park Golf Course adjacent to the Old Channel of the Comal River, including the use of plant protectants to maintain the golf course and the diversion of water from the Old Channel to maintain the golf course.

Irrigation water for the golf course is obtained via a single diversion from the Old Channel permitted by TCEQ (Permit 18-3824, Permit 18-3824A, Permit 18-3824B, and Permit 18-3826). The diversion is located approximately 200 yards upstream of Hinman Island Drive and considerably downstream of the Old Channel ERPA. The total water that is permitted for that diversion is 300 ac-ft/yr (200 ac-ft under permit 18-3824 and 100 ac-ft/yr for permit 18-3826). Permit 18-3826 is the more junior water right. The total diversion rate allowed under both permits combined is 2 cfs. Currently, the pump for the diversion is capable of diverting only 1 cfs. The surface water diversion will be operated in accordance with TCEQ rules including any TCEQ order to reduce or stop diverting water during low flows.

Historically, the City of New Braunfels Golf Course does not use its full permitted water rights for irrigating the Golf Course. From 2006 through 2010, an average of 115.4 ac-ft of water was diverted under both permits for golf course irrigation. To reduce dependency on Comal River water further, the City of New Braunfels is working with New Braunfels Utilities under a grant received by the Texas Water Development Board to develop and implement a reuse water system that will be used to maintain the golf course by supplementing or when feasible replacing the surface diversions used for irrigation purposes. The design process is underway.

2.3.4 Spring-Fed Pool Diversions and Operation

The City of New Braunfels seeks incidental take coverage for the impacts of its use and operation of the Landa Park Springfed Pool adjacent to the Old Channel of the Comal River. The City of New Braunfels is authorized to divert 8 ac-ft/yr of water from the Old Channel and impound it in the pool by TCEQ Permit 18-3826. Because the water is returned to the Old Channel, this diversion is permitted as a non-consumptive use. Maintenance operations (routine cleaning, algae removal, chemical application pursuant to label instructions, and filling/emptying) will be conducted according to the 2003 Comal Ecosystem Management Plan. (*See* Appendix N). Surface water diversions will be operated in accordance with TCEQ rules as established by Permit 18-3826.

2.3.5 Boat Operations on Comal River and Landa Lake

The City of New Braunfels seeks incidental take coverage for the boats it operates on the Comal River and Landa Lake related to research, enforcement, litter collection, and maintenance activities.

2.3.6 Infrastructure Maintenance and Repair

The City of New Braunfels seeks incidental take coverage for the routine, minor repairs of infrastructure and facilities associated or located on City of New Braunfels property that is adjacent to or directly affects the Comal Springs and River ecosystem. Routine,

minor repairs include activities such as repairs to access points or stairways adjacent or leading to the springs or river, but in any event would not involve activities requiring a USACE § 404 permit or authorization.

2.3.7 Minimization and Mitigation Measures and Measures that Contribute to Recovery

The following Covered Activities constitute minimization and mitigation measures as well as measures specifically designed to contribute to recovery under the HCP that will be implemented by the City of New Braunfels. These measures are further detailed in Chapter 5.

- Flow-split Management in the Old and New Channel (Section 5.2.1)
- Native Aquatic Vegetation Restoration and Maintenance (Section 5.2.2)
- Management of Public Recreational Use of Comal Springs and River Ecosystem (Section 5.2.3)
- Decaying Vegetation Removal and Dissolved Oxygen Management (Section 5.2.4)
- Control of Harmful Non-Native and Predator Species (Section 5.2.5)
- Non-Native Snail Removal Program and Gill Parasite Monitoring (Section 5.2.6)
- Prohibition of Hazardous Materials Transport Across the Comal River and Its Tributaries (Section 5.2.7)
- Native Riparian Habitat Restoration (Section 5.2.8)
- Reduction of Non-Native Species Introduction and Live Bait Prohibition (Section 5.2.9)
- Litter Collection and Floating Vegetation Management (Section 5.2.10)
- Management of Golf Course Diversions and Operations (5.2.11)
- Management of Household Hazardous Wastes (Section 5.7.5)
- Impervious Cover/Water Quality Protection (Section 5.7.6)

2.4 City of San Marcos

The City has the authority to manage the ecosystems of the San Marcos River and Springs within its jurisdiction. These ecosystems are also used for recreational activities that are regulated in part by the City. The City of San Marcos also is authorized to pump water from the Aquifer.

The City seeks incidental take coverage for the recreational activities within its jurisdiction, the management of the ecosystems of the San Marcos River and Springs, and the permitted use of the Aquifer. Finally, the City of San Marcos seeks coverage for the mitigation and minimization measures that it will either implement or have the responsibility of implementing.

These Covered Activities are described in more detail below and in Chapter 5.

2.4.1 Management of Public Recreational Use of San Marcos Springs and River Ecosystems

Public recreational uses of the San Marcos Spring and River ecosystems include, but are not limited to swimming, wading, tubing, boating, canoeing, kayaking, golfing, snorkeling, SCUBA diving, and fishing. The City of San Marcos seeks incidental take coverage for its management of public recreation and for the individuals who recreate in accordance with all applicable laws and regulations.

2.4.2 Boat Operations on San Marcos River

The City of San Marcos seeks incidental take coverage for its operations related to enforcement, research, litter collection, and maintenance activities on the San Marcos River. No motors allowed except trolling motors.

2.4.3 Infrastructure Maintenance and Repair

The City of San Marcos seeks incidental take coverage for routine, minor repairs of infrastructure and facilities associated with or located on City of San Marcos property that are adjacent to or directly affect the San Marcos Springs and River ecosystem. Routine, minor repairs would include activities such as repairs to access points along the river, but would not involve activities requiring a USACE § 404 permit or authorization.

2.4.4 Minimization and Mitigation Measures and Measures that Contribute to Recovery

The following Covered Activities constitute minimization and mitigation measures and measures that are intended to contribute to recovery that will be implemented by the City of San Marcos. These measures are further detailed in Chapter 5.

- Texas Wild-Rice Enhancement and Restoration (Section 5.3.1)
- Management of Recreation in Key Areas (Section 5.3.2)
- Management of Vegetation and Litter below Sewell Park (Section 5.3.3)
- Prohibition of Hazardous Materials Transport Across the San Marcos River and Its Tributaries (Section 5.3.4)
- Reduction of Non-Native Species Introduction (Section 5.3.5)
- Sediment Removal below Sewell Park (Section 5.3.6)
- Designation of Permanent Access Points/Bank Stabilization (Section 5.3.7)
- Control of Non-native Plant Species (Section 5.3.8)
- Control of Harmful Non-Native and Predator Species (Section 5.3.9)
- Native Riparian Habitat Restoration (Section 5.7.1)
- Septic System Registration and Permitting Program (Section 5.7.3)
- Minimization of Impacts of Contaminated Runoff (Section 5.7.4)
- Management of Household Hazardous Wastes (Section 5.7.5)

- Impervious Cover/Water Quality Protection (Section 5.7.6)

2.5 Texas State University

Portions of the San Marcos River and the San Marcos Springs are located within the jurisdiction of Texas State University. The University has the authority to manage the ecosystems of the San Marcos River and Springs within its jurisdiction. These ecosystems are used for educational and research purposes by the University, for recreational activities by the students, faculty and staff of the University and for public service activities. The University is authorized to pump water from the Aquifer and to divert water from Spring Lake and San Marcos Springs.

The University seeks incidental take coverage for the educational, research, recreational, and public service activities within its jurisdiction, the management of the ecosystems of the San Marcos River and Springs, the permitted use of the Aquifer, the diversion of water from the springs, and the use of the San Marcos Springs and River. The University seeks coverage for the minimization and mitigation measures that it will implement or have responsibility for having implemented.

The Covered Activities are described in more detail below and in Chapter 5.

2.5.1 Management of Public Recreational Use of San Marcos Springs and River Ecosystems

Public recreational use of the San Marcos Spring and River ecosystems include, but are not limited to swimming, wading, tubing, boating, canoeing, kayaking, golf, diving, snorkeling and fishing. Covered activities include recreation in accordance with all applicable laws and regulations.

2.5.2 Vegetation Management

2.5.2.1 Management of Submerged and Floating Aquatic Vegetation in Spring Lake

Texas State University currently harvests submerged vegetation from Spring Lake with a harvester boat and manually cuts vegetation from around spring openings, the underwater archaeological site, along the wall by the River Systems Institute, and in the fountain area. All vegetation is removed in order to enhance viewing from the River System Institute's glass-bottom boats and prevent entanglement of plant material in the boat propeller.

2.5.2.2 Management of Aquatic Vegetation and Litter from Spring Lake Dam to City Park

Lower flows in the San Marcos River increase the likelihood of vegetation mats forming on top of Texas wild-rice plants which may interfere with flowering and reproduction, block sunlight and interfere with photosynthesis, and slow current velocity (Power 1996). Additionally, the San Marcos River is heavily used for recreation from Spring Lake Dam to IH-35. Texas State University will remove floating vegetation mats and litter from the River to enhance the aesthetics and enjoyment of recreational activities, such as tubing, swimming, canoeing, and fishing, in areas from Spring Lake Dam to City Park.

2.5.3 Diving Classes in Spring Lake

Texas State University provides educational activities within Spring Lake and the San Marcos River in accordance with all applicable laws and regulations. The University has designated an area of 2140 square meters as its Dive Training Area in Spring Lake; this area was the site of the underwater show of the Aquarena Springs theme park for over 40 years. The natural and cultural resources in this area have long been disturbed, hence diving activities occurring here will have minimal impact, if any, on listed species. To minimize the impacts of its classes and programs on the habitat in Spring Lake, any individual diving outside of the Dive Training Area has to complete the Diving for Science class.

Texas State University seeks incidental take coverage for these educational activities. Current educational activities include the following Covered Activities:

2.5.3.1 Diving for Science Program

This program trains volunteers to SCUBA in a manner that protects listed species in Spring Lake. Upon completion, the volunteers help with various projects in the lake, but always under supervision. This Program is required for anyone diving outside the Dive Training Area in Spring Lake.

2.5.3.2 Continuing Education SCUBA Classes

Texas State University allows the use the designated Dive Training Area (approximately 2,140 m^2) for a maximum of ten check-out dives by dive shops at the end of each semester for their beginning and advanced SCUBA classes. These divers will not be allowed to dive outside of this area.

2.5.3.3 Texas State University SCUBA Classes

Texas State University will offer basic and advanced SCUBA classes with multiple sessions occurring year-round. All of these classes are taught only in the Dive Training Area.

2.5.4 Research Programs

Research is a primary component of Texas State University's activities in Spring Lake. All research proposals will be reviewed by the staff of the River Systems Institute to ensure there is no impact on Covered Species or their habitat in Spring Lake. If take cannot be avoided it will be minimized by educating the researchers as to the area where the species are located and measures to minimize any potential impacts as described in Section 5.4.8. Any diving support to a research study in Spring Lake will be provided by individuals who have completed the Diving for Science Program.

2.5.5 Diversion of Water from Spring Lake

Texas State University has surface water right certificates from the TCEQ, as described below.[3] Texas State University seeks incidental take coverage for the use and operation of the authorized diversions.

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[3] *See also* Section 5.4.5 and Figures 5-3 and 5-4.

2.5.5.1 Spring Lake (Certificate 18-3865)

Texas State University has a 100 ac-ft/yr irrigation water right. A pump house located adjacent to golf course green #8 diverts an average of 26 ac-ft/yr of water for the purpose of irrigating the 70-acre Aquarena golf course. The permit limits the diversion rate for the diversion to 1.33 cfs.

The University also has a 534 ac-ft/yr industrial permit with a maximum permitted diversion rate of 600 gpm. Over the last five years, it has used an average of 103 ac-ft/yr of this industrial permit for two chiller plants (East Chill Plant and Cogen Plant). The water is pumped from an intake site located just below the Spring Lake dam. The permit limits the diversion rate for the diversion to 1.33 cfs.

Texas State University has a 513 ac-ft/yr municipal water right; a 31,262 ac-ft/yr hydroelectric water right; and a 700 ac-ft/yr water right to operate an artificial waterfall. The permit for the hydroelectric plant and artificial waterfall is for non-consumptive use with the water being returned to Spring Lake near the point of diversion. The diversion rate for the 513 acre-foot right is limited by the permit to 2.22 cfs. The University has not exercised these rights and has no present intention to exercise these rights. However, Texas State University may consider exchanging these rights for additional irrigation or industrial rights if future growth requires additional water resources.

In addition, the University is authorized to impound 150 ac-ft/yr in Spring Lake.

The rate of diversion from Spring Lake for consumptive use water under TCEQ Certificate No 18-3865 is limited to a total of 4.88 cfs.

2.5.5.2 San Marcos River (Certificate 18-3866)

Texas State University has a 40 ac-ft/yr irrigation right that is not currently being used. The diversion is located on the San Marcos River at Sewell Park. The permit requires Texas State to reduce the diversion to 20 ac-ft/yr when flow in the River falls below 128 cfs. The permit limits the rate of diversion for this water right to 1 cfs. The University also has a 60 ac-ft/yr industrial permit used to fill and replenish seven off-channel reservoirs (old fish hatchery ponds) for biological research and related educational purposes. Over the last five years, Texas State University has used an average of 36 ac-ft/yr to replenish these ponds. The permit limits the rate of diversion for this water right to 2.22 cfs. The water is diverted at a pump house located in Sewell Park.

The total rate of diversion for consumptive use water from the San Marcos River under TCEQ Certificate No 18-3866 is limited to 3.22 cfs.

2.5.6 Management of Golf Course and Grounds

Texas State University seeks incidental take coverage for the impacts of its maintenance of a nine-hole golf course located adjacent to Spring Lake. Management practices include application of fertilizer and pesticides, mowing, and landscaping.

2.5.7 Boating in Spring Lake and Sewell Park

Texas State University seeks incidental take coverage for the impacts of its boating activities in Spring Lake and Sewall Park. Texas State University occasionally conducts canoeing/kayaking classes in Spring Lake and Sewell Park. Classes in Spring Lake occur in the glass-bottom boat runs, and the classes downstream of Spring Lake will use the area between Sewell Park and Rio Vista Falls. Additionally, the glass bottom boat and glass bottom kayaks operate in Spring

Lake. Canoes and kayaks will also occasionally be used for research and maintenance projects in Spring Lake and in the River.

2.5.8 Minimization and Mitigation Measures

The following Covered Activities constitute minimization and mitigation measures and measures specifically intended to contribute to recovery that Texas State University will have the responsibility for implementing. These measures are further detailed in Chapter 5.

- Texas Wild-Rice Enhancement and Restoration (Section 5.4.1)
- Control of Recreation in Key Areas (Section 5.4.2)
- Management of Vegetation (Section 5.4.3)
- Sediment Removal in Spring Lake and Sewell Park (Section 5.4.4)
- Diversion of Surface Water (Section 5.4.5)
- Sessom Creek Sand Bar Removal (Section 5.4.6)
- Diving Classes in Spring Lake (Section 5.4.7)
- Research Programs in Spring Lake (Section 5.4.8)
- Management of Golf Course and Grounds (Section 5.4.9)
- Boating in Spring Lake and Sewell Park (Section 5.4.10)
- Reduction of Non-Native Species Introduction (Section 5.4.11)
- Control of Non-Native Plant Species (Section 5.4.12)
- Control of Harmful Non-Native and Predator Species (Section 5.4.13)

2.6 San Antonio Water System

The San Antonio Water System (SAWS) is a water purveyor to residences, businesses and other end users in the City of San Antonio and parts of Bexar and surrounding counties. SAWS is authorized by the EAA to pump water from the Aquifer. SAWS has access or otherwise controls approximately 46 percent of the permitted water rights to pump from the Aquifer. As part of its operation, it stores water pumped from the Aquifer in an Aquifer Storage and Recovery facility (SAWS ASR) located in Southern Bexar County. The SAWS ASR is an underground storage reservoir in the Carrizo sand aquifer in Southern Bexar County. As a SAWS Water Management Project it is designed to store Aquifer water when demand is less than available supply. The stored water is returned to San Antonio for use during critical period when demand is high.

SAWS seeks incidental take coverage for the impacts of its pumping from the Aquifer and for its use and operation of the SAWS ASR.

2.6.1 Minimization and Mitigation Measures

The following Covered Activities constitute minimization and mitigation measures and measures specifically intended to contribute to recovery that will be implemented by SAWS. These activities are further detailed in Chapter 5.

- Use of the SAWS ASR for Springflow Protection. (Section 5.5.1).

- Phase II Expanded Use of the SAWS ASR and Water Resources Integration Program Pipeline. (Section 5.5.2).

2.7 Texas Parks and Wildlife Department

To minimize the impacts of recreational activities on Texas wild-rice and other Covered Species habitat, Texas Parks and Wildlife Department (TPWD) in support of the HCP created State Scientific Areas in the San Marcos Springs ecosystem effective May 1, 2012. This Scientific Areas are designed to protect Texas wild-rice by limiting recreation in these areas during low flow conditions. *See* Section 5.6.1 TPWD also will pursue the creation of state scientific areas in the Comal Springs ecosystem for the protection of existing fountain darter habitat and additional habitat created by the City of New Braunfels. (*See* Section 5.2.2.2). TPWD seeks incidental take coverage for the implementation of the regulations creating these state scientific areas.

2.8 Adaptive Management Process

The Applicants anticipate the need for three levels of decisions (Section 6.1.3) relating to the AMP during the term of the ITP: (1) Routine Adaptive Management Decisions; (2) Non-routine Adaptive Management Decisions; and (3) Strategic Adaptive Management Decisions. As part of the AMP, the Applicants also will conduct applied research at the Applied Research Facility at the San Marcos NFHTC. The Applicants seek incidental take coverage for the management, oversight, and implementation of measures developed in the AMP.

Chapter 3 Environmental Setting and Baseline Conditions

3.1 Climate

3.1.1 Regional Description

The prevailing climate of the HCP Study Area varies from subtropical steppe in the western region to subtropical subhumid in the central region and to subtropical humid in the eastern region. (Larkin and Bomar 1983; *see* Figure 3-1). The subtropical steppe is characterized by semi-arid to arid conditions. Subtropical subhumid climate is typified by long, hot summers and short, mild winters, while subtropical humid climate exhibits higher humidity and slightly milder summers. Regional prevailing winds are generally southerly, except during winter, when they are frequently from the north. Latitude, elevation, and proximity to the Gulf of Mexico influence the climate of the region.

The average annual temperature in the study area is about 68° F (20° C), with average annual high temperatures of 78–84° F (26–29° C) (Figure 3-2). Summertime temperatures commonly exceed 100° F (38° C) with average monthly high temperatures ranging from 90° F (32° C) to 97° F (36° C) (Larkin and Bomar 1983). Winters are generally mild with average monthly low temperatures ranging from about 36° F (2° C) to 60° F (16° C). Temperatures fall below freezing about 20 days each year (NOAA 2010).

Average annual precipitation within the region varies from about 20 inches in western Kinney County to about 40 inches in Calhoun County (Figure 3-3); however, in some years the region may receive as much as 50 inches or as little as 10 inches of precipitation (National Oceanic and Atmospheric Administration 2000). Average annual precipitation over the Edwards Aquifer during the period of 1934-2009 ranged from about 21.9 inches in the western region to 34.2 inches in the eastern region. During this period, San Antonio averaged 30.4 inches of precipitation. (EAA 2010b). Historically, precipitation is highest during May and September. Stalled cool fronts and summer tropical storms may result in increased precipitation amounts.

It is reported that the potential incidence of high-magnitude flooding is greater for the Balcones Escarpment area of central Texas than for any other region of the United States. (Caran and Baker 1986). In part, this is due to the climatic provenance of central Texas; the area lies within a convergence zone of high and low pressure air masses. Additionally, tropical storms and hurricanes penetrate into the area from the Gulf of Mexico producing some of the areas heaviest rainfalls. (Patton and Baker 1976). Once rainfall hits the ground, runoff absorption rates become a function of landscape physiography. Along the Balcones Escarpment, valleys are

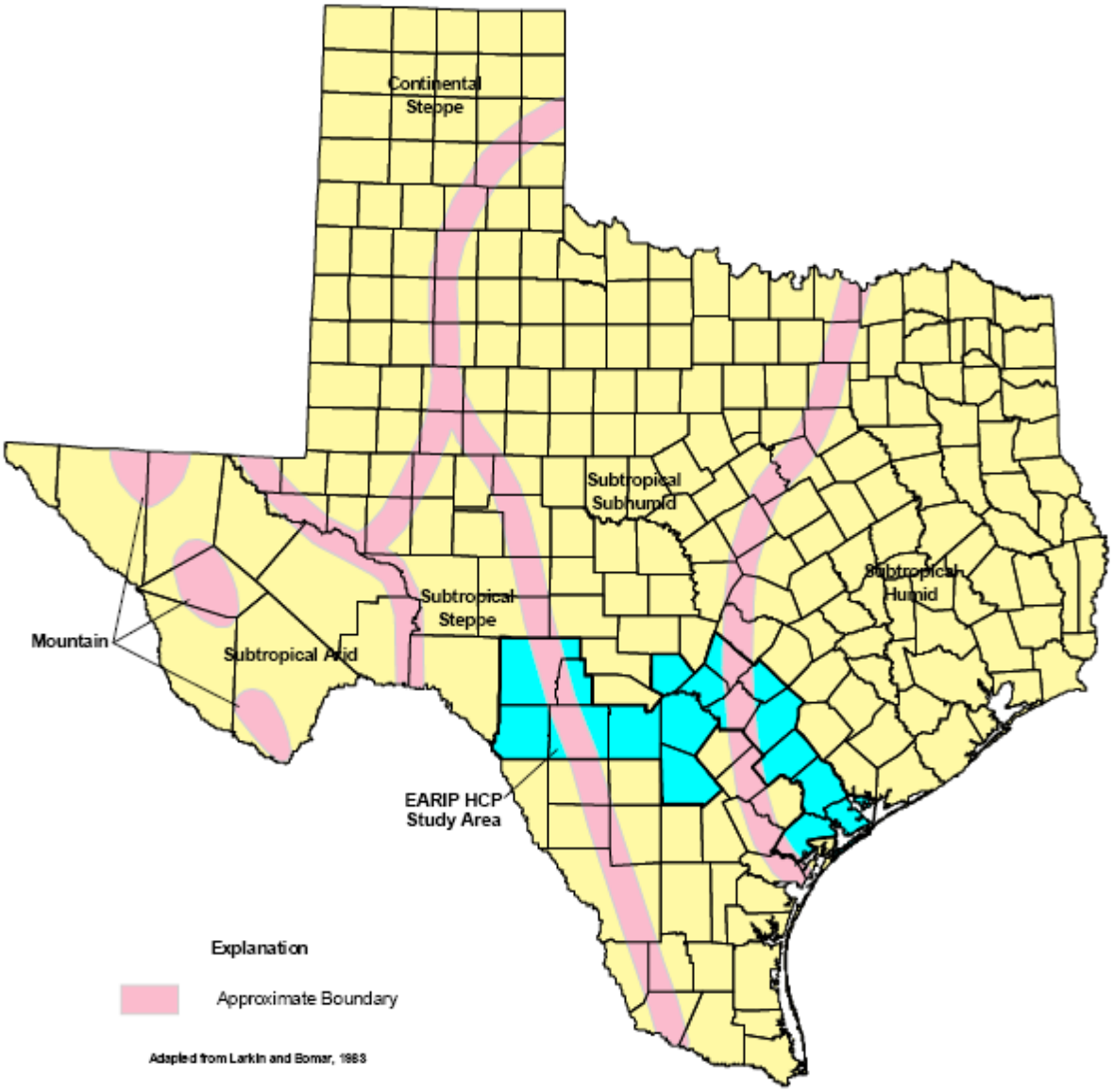


Figure 3-1
Climate Regions of Texas

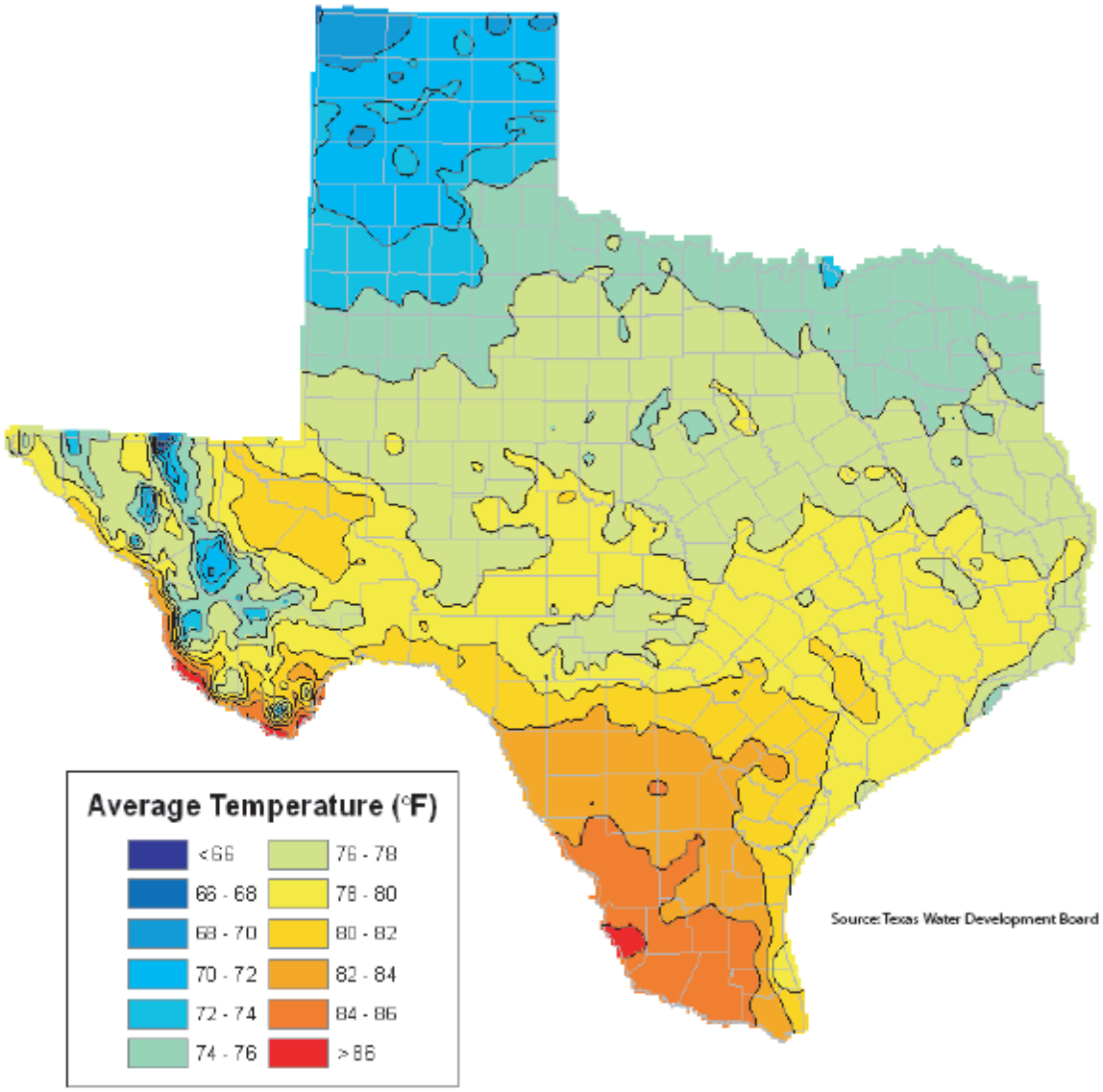


Figure 3-2
Annual Average High Temperature, 1971-2000

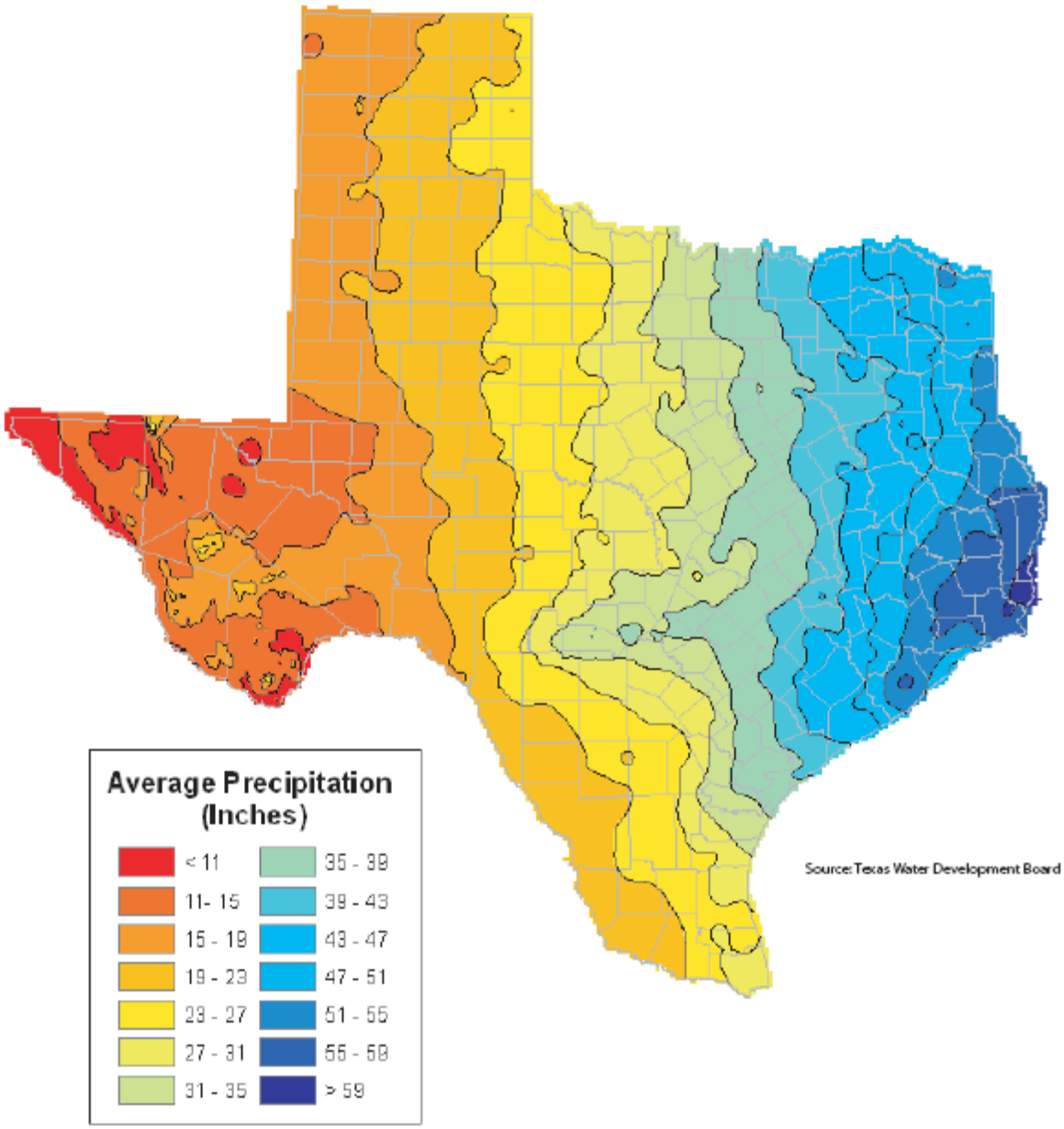


Figure 3-3
Average Annual Precipitation in Inches, 1971-2000

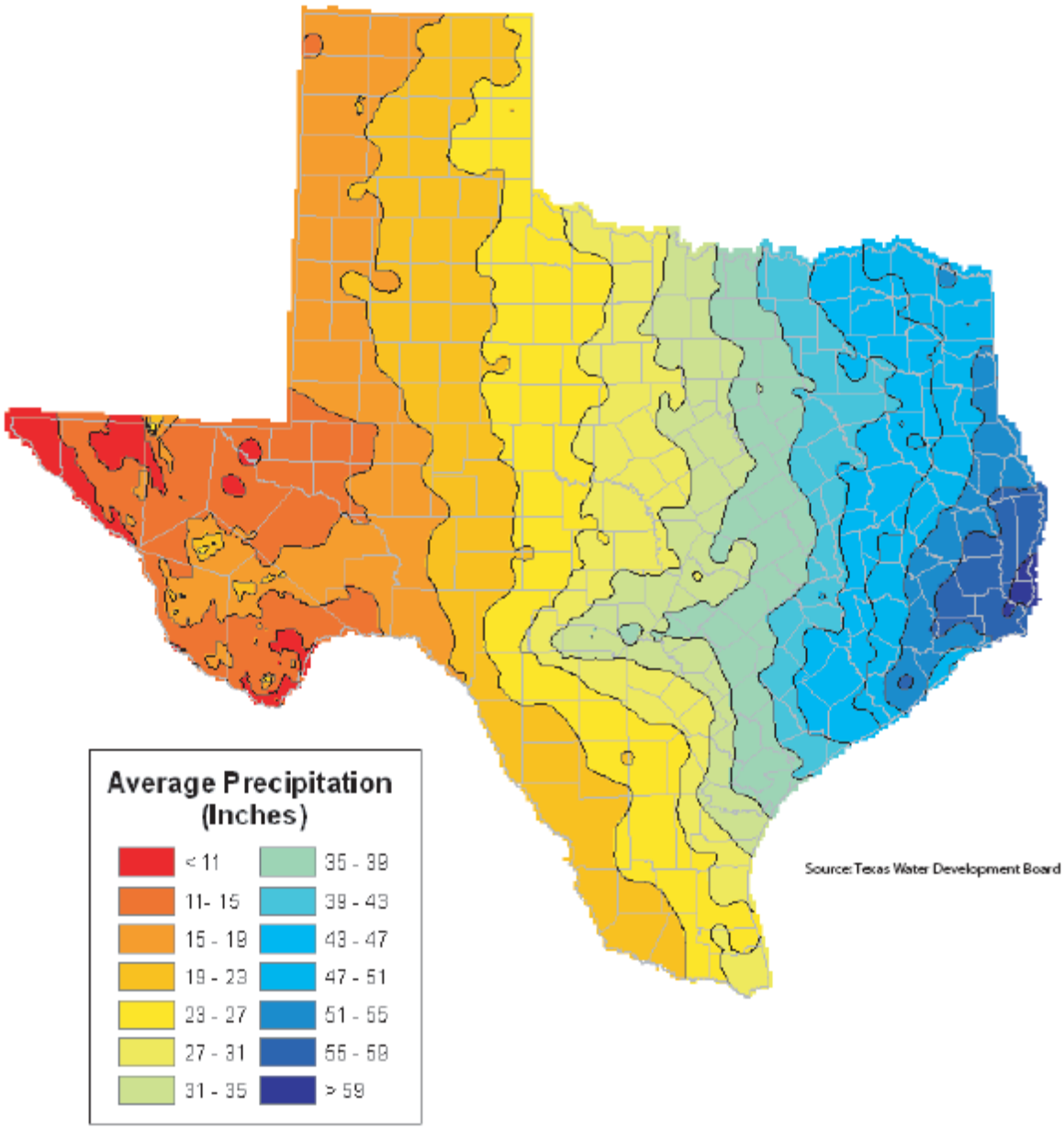


Figure 3-3
Average Annual Precipitation in Inches, 1971-2000

narrow, slopes are sparsely covered by vegetation, and the surface is variably exposed bedrock or overlain by thin upland soils. Below the Escarpment, on the Blackland Prairies, soils with low-absorption rates. (Caran and Baker 1986; Patton and Baker 1976). Interacting together, these infiltration capacity severely limit factors greatly increase runoff and drainage discharge.

Regional surface water features are subject to evaporation, especially during hot summer months. Average regional monthly gross lake-surface evaporation ranges from approximately 2.5 inches in January to over 9 inches in August. (Larkin and Bomar 1983). Evapotranspiration percentages vary throughout the region, with an average of approximately 85 to 90 percent of regional precipitation lost through evapotranspiration. (USGS 1995).

3.1.2 Frequency of Tropical Storms

Tropical storms, including hurricanes, hit the Texas Gulf Coast at a frequency of about 0.67 storm per year. (Brown *et al*. 1974). Occasionally these storms move inland while dissipating, resulting in severe weather over the region. As moisture-laden air masses move inland from the Gulf of Mexico and are forced to rise at the Balcones Escarpment, they mix with low pressure fronts from the north or west. Such systems can result in some of the largest storms ever recorded in the United States. High winds, excessive rainfall, hail, and tornadoes may result from these tropical storms. Flash flooding is common after thunderstorms that produce large amounts of precipitation in a relatively short period of time. One such instance was flooding associated with Hurricane Amelia in August 1978. Between August 1 and 3, 1978, more than 48 inches of rain fell on a ranch in Medina County, the highest three-day precipitation total ever recorded in the United States. (Caran and Baker 1986).

3.1.3 Climate Change

3.1.3.1 Regulatory Background

The Council on Environmental Quality in the Executive Office of the President (CEQ) recently provided draft guidance for Federal agencies in analyzing the environmental effects of greenhouse gas (GHG) emissions and climate change as part of the assessment of the effects of a proposed action on the environment in accordance with Section 102 of NEPA and the CEQ Regulations for Implementing the Procedural Provisions of NEPA, 40 C.F.R. parts 1500-1508. This draft guidance was provided in a February 18, 2010 memorandum (CEQ 2010).

A summary of the existing and potential future effects of climate change on the affected environment are discussed below. Compounding effects of climate change to impacts of the Covered Activities on the affected environment of the HCP Plan Area are discussed in this Chapter.

The U.S. Climate Change Science Program (CCSP) has concluded that the global climate is changing. Effects of this change on the existing environment has been evaluated in a 2008 U.S. national scientific assessment (National Science and Technology Council 2008) which integrates, evaluates, and interprets the findings of the CCSP and draws from and synthesizes findings from previous assessments of the science, including reports and products by the Intergovernmental Panel on Climate Change (IPCC).

The conclusions in the National Science and Technology Council assessment build on the vast body of observations, modeling, decision support, and other types of activities conducted under the auspices of CCSP and from previous assessments of the science, including reports and products by the IPCC, CCSP, and others. This assessment and the underlying assessments

have been subjected to and improved through rigorous peer reviews. According to CCSP's Synthesis and Assessment Product (SAP) 4.3 (Backlund *et al*. 2008), it is very likely that temperature increases, increasing carbon dioxide levels, and altered patterns of precipitation are already affecting U.S. water resources, agriculture, land resources, biodiversity, and human health, among other things. *SAP 4.3* also concluded that it is very likely that climate change will continue to have significant effects on these resources over the next few decades and beyond.

Numerous lines of evidence robustly lead to the conclusion that the climate system is warming. The IPCC (2007a) stated in its Fourth Assessment Report:

> *"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level."*

3.1.3.2 Temperature and Precipitation Trends in Texas Based on the Historical Record

Regional data for North America confirm that warming has occurred throughout most of the United States. The U.S. Historical Climate Network of the National Climatic Data Center found that for all but 3 of the 11 climate regions, the average temperature increased more than 0.6 degrees Celsius (°C) between 1901 and 2005 (NOAA 2007). According to data compiled by the National Climatic Data Center (2010) over the period of record 1895 to 2010, temperature in Texas has increased at a rate of about 0.1 degree Fahrenheit per decade or about 1 degree Fahrenheit over the past century, while precipitation during this same period has decreased at a rate of -0.03 inch per decade or about 0.3 inch over the past century.

3.1.3.3 Future Temperature Projections

In order to project future changes in the climate system, including temperature, precipitation, and sea level at global and regional scales, academic institutions and government-supported research laboratories in the United States and other countries have developed a number of computer models that simulate the Earth system and that are based on the various emissions scenarios described in the National Science and Technology Council's *Scientific Assessment* (NSTC 2008). The IPCC helps coordinate modeling efforts to facilitate comparisons across models, and synthesizes results published by several modeling teams.

- By mid-century (2046 to 2065), the choice of scenarios involving greenhouse gas emissions becomes more important for the magnitude of the projected global average warming, with average values of 1.3, 1.8, and 1.7°C from the models for scenarios B1 (low emissions growth), A1B (medium emissions growth), and A2 (high emissions growth), respectively (Meehl et al. 2007). By the end of the century (2090 to 2099), projected global average surface warming varies significantly by emissions scenario. The full suite of the IPCC's Special Report on Emission Scenarios (SRES) (IPCC 2000) provide warming for 2090 to 2099 relative to 1980 to 1999 with a range of 1.8 to 4.0°C with an uncertainty range of 1.1 to 6.4°C. The IPCC found that all of North America is very likely not only to warm during this century, but to warm more than the global mean warming in most areas (Christensen et al. 2007). An increase in surface evaporation is expected to accompany the projected widespread increase in temperature.

- According to CCSP's Synthesis and Assessment Product (SAP) 4.3 (Backlund et al. 2008), it is very likely that temperature increases, increasing carbon dioxide levels, and altered patterns of precipitation are already affecting U.S. water resources, agriculture, land resources, biodiversity, and human health, among other things. SAP 4.3 also concluded that it is very likely that climate change will continue to have significant effects on these resources over the next few decades and beyond.

3.1.3.4 Precipitation Projections

Overall, future model projections show that global mean precipitation increases with the warming of the climate (Meehl *et al*. 2007), but with substantial spatial and seasonal variations. Other conclusions provided by recent climate studies include:

- A widespread increase in annual precipitation is projected by the IPCC over most of the North American continent except the southern and southwestern part of the United States and over Mexico

- Some models project drying in the southwestern United States, and more than 90 percent of the models project drying in northern and particularly western Mexico. In western North America, modest changes in annual mean precipitation are projected, but the majority of models indicate an increase in winter and a decrease in summer. Models show greater consensus on winter increases to the north and on summer decreases to the south.

- Recent analyses (Milly et al. 2005; Karl et al. 2008) shows that several atmosphere–ocean general circulation models project greatly reduced annual water availability over the southwestern United States and northern Mexico in the future.

- "Climate model projections … indicate that larger streamflow … declines are expected in the West, where the balance between precipitation and evaporative demand changes will be dominated by increased evaporative demand. However, because of the uncertainty in climate model projections of precipitation change, future projections of streamflow are highly uncertain across most of the United States." (Lettennmaier et al. 2008).

While caution should be used as global climate projections move to more regional and localized levels, such projections may still provide insights into future trends. Climate projection data developed and used by the IPCC have been further refined and downscaled by the Lawrence Livermore National Laboratory (LLNL) Green Data Oasis (LLNL *et al*. 2010) to simulate climate projections on a regional level. Such data allows the evaluation of potential climate change on habitat of threatened and endangered species (Darby 2010). Projected change in precipitation for Texas from 2009 through 2050 using IPCC SRES CCSM Scenario B1 Scenario (low greenhouse gas emissions) as downscaled by the LLNL Green Data Oasis and portrayed by Darby (2010) is illustrated by Figure 3-4.

Sea level rise could affect the southeastern Texas coast along the Gulf of Mexico. With increases in global ocean temperatures, the IPCC (2007a) projects sea level rise of between 0.59 and 1.9 ft. by the end of the century (2090 to 2099) relative to the base period (1980 to 1999). The projected rate of sea level rise off the low-lying U.S. South Atlantic and Gulf Coasts (which includes portions of the HCP Planning Area) is predicted to be higher than the global average.

3.1.3.5 Projections of Extreme Events

Models suggest that climate change will alter the prevalence and severity of many extreme events such as heat waves, cold waves, storms, floods, and droughts. Projections of global temperature from the IPCC (Meehl *et al*. 2007) show that it is very likely that heat waves will become more intense, more frequent, and longer lasting in a future warm climate, whereas cold episodes are projected to decrease substantially. Meehl and Tebaldi (2004) and Meehl *et al*. (2007) found that the pattern of future changes in heat waves, showing the greatest increases in intensity over western Europe, the Mediterranean, and the southeastern and western United States is related in part to circulation changes resulting from an increase in greenhouse gases. The IPCC (Meehl *et al*. 2007) projected a tendency for drying in mid-continental areas during summer due to higher temperatures, indicating a greater risk of droughts in those regions.

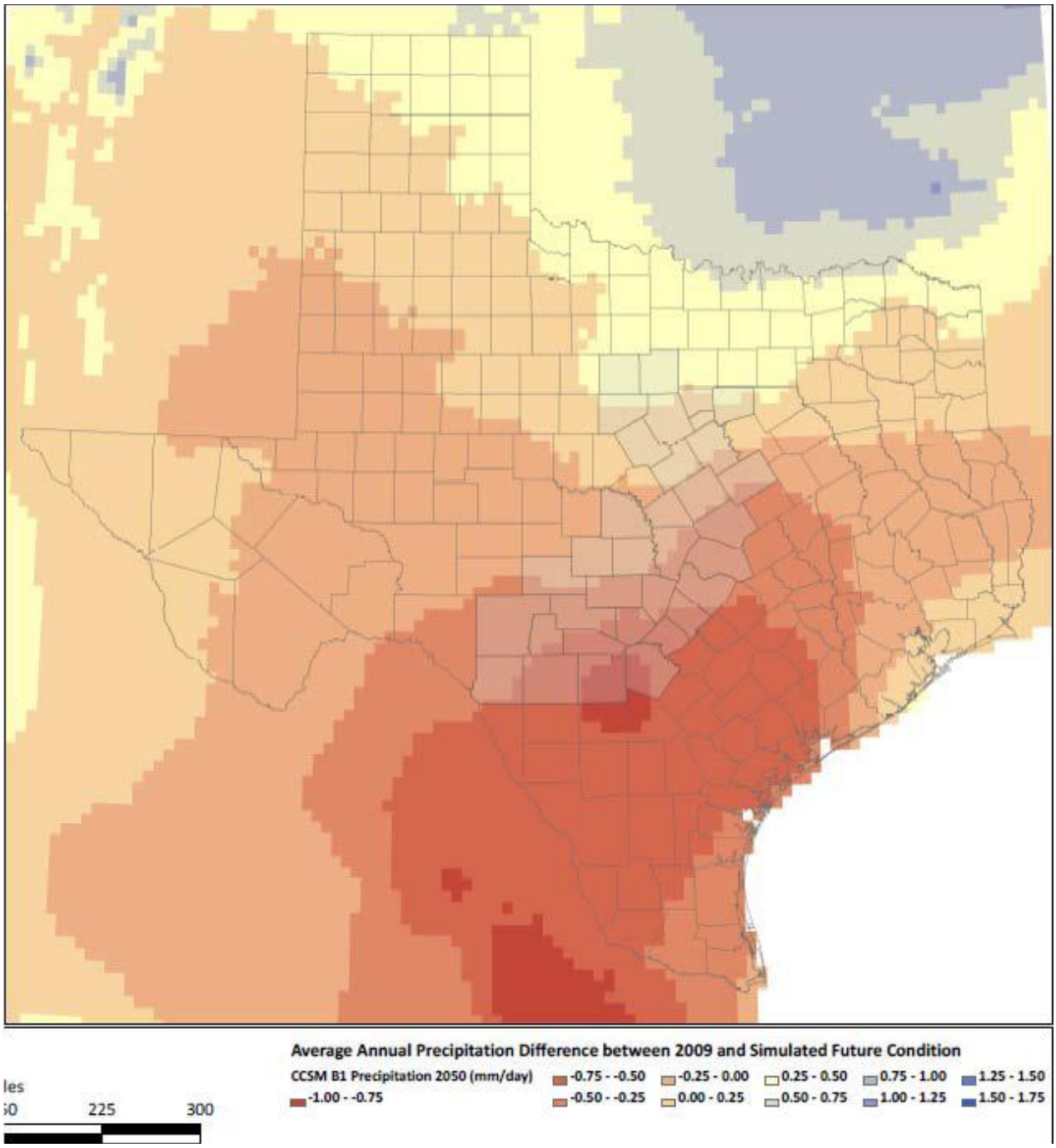


Figure 3-4. Projected precipitation differences between 2009 and 2050 based on IPCC SRES CCSM Scenario B1 (low greenhouse gas emissions)
SOURCE: (Darby 2010)

3.1.3.6 Climate Change Impacts

IPCC studies suggest a number of components of the human environment, including water resources, will be impacted by climate change, resulting in a number of implications:

- All IPCC regions show an overall net negative impact of climate change on water resources and freshwater ecosystems (high confidence).
- The IPCC (Kundzewicz et al. 2007) concluded with high confidence that semi-arid and arid areas are particularly exposed to the impacts of climate change on freshwater.
- Projections for the Ogallala aquifer region show that natural groundwater recharge decreases more than 20 percent in all simulations with different climate models and future warming scenarios of 2.5°C or greater (Field et al. 2007).

3.1.3.7 Global Implications

The IPCC (Kundzewicz *et al*. 2007) reached several conclusions concerning the effects of global climate change on water resources:

- Climate change affects the function and operation of existing water infrastructure as well as water management practices (very high confidence).
- Adverse effects of climate on freshwater systems aggravate the impacts of other stresses, such as population growth, changing economic activity, land use change, and urbanization (very high confidence).
- Regionally, large changes in irrigation water demand as a result of climate change are likely (high confidence).
- Current water management practices are very likely to be inadequate to reduce the negative impacts of climate change on water supply reliability, flood risk, health, energy, and aquatic ecosystems (very high confidence).
- In the United States, many competing water uses will be adversely affected by climate change impacts on water supply and quality. Climate change impacts on water supply and quality will affect agricultural practices, including the increase in irrigation demand in dry regions and the aggravation of nonpoint source water pollution (e.g., pollution from urban areas, roads, or agricultural fields) problems in areas susceptible to intense rainfall events and flooding. (Field et al. 2007).
- Drawing on these studies, the IPCC concluded that climate change will constrain North America's over-allocated water resources, increasing competition among agricultural, municipal, industrial, and ecological uses (very high confidence). (Id.).
- Climate change has the potential not only to affect settlements directly, but also to affect them through impacts on other areas linked to their economies at regional, national, and international scales. In addition, it can affect a settlement's economic base if it is sensitive to climate, as in areas where settlements are based on agriculture, forestry, water resources, or tourism (IPCC 2007b).

- In the United States, the most vulnerable areas are likely to be Alaska, coastal and river basin locations susceptible to flooding, arid areas where water scarcity is a pressing issue, and areas whose economic bases are climate-sensitive (Field et al. 2007).

3.1.3.8 Regional Implications

Climate change could impact groundwater resources by affecting recharge, pumping, natural discharge, and saline intrusion. (Mace and Wade 2008). They suggest that climate change will more adversely affect karstic aquifers, such as the Edwards Aquifer, that recharge locally from streams and rivers in comparison to aquifers where recharge is increased through pumping and the capture of intermediate and local groundwater flow paths. A warmer, dryer climate will increase demand for water to support agriculture, municipal, and industrial use. This will result in greater demand for both surface and groundwater. Decreases in surface water supply due to climate change may also increase demand for groundwater use. (Kundzewicz *et al*. 2007; Mace and Wade 2008). Natural aquifer discharge to springs and seeps is affected by recharge to the aquifer, discharge by pumping, and changes in groundwater gradients as affected by plants, including phreatophytic species that demand higher amounts of water. In coastal areas, groundwater and dependent resources may be affected by rising sea levels. As sea level rises, salt water moves inland, decreasing the areal extent of the aquifer and possibly affecting water quality in nearby wells. This is particularly important for shallow aquifers, especially karstic ones. (Mace and Wade 2008).

3.1.3.9 Potential Climate Change Impacts to the Edwards Aquifer

Mace and Wade (2008) and Loáiciga *et al*. (1996) suggest that the Aquifer is probably Texas's most vulnerable aquifer and groundwater resource with respect to climate change and variability In addition if there is a long-term drying of the climate in south-central Texas, area groundwater users can expect to be under more drought restrictions.

Loáiciga *et al*. (2000) studied the climate change impacts on the Edwards Aquifer. Climate change scenarios were created from scaling factors derived from several general circulation models to assess the likely impacts of Aquifer pumping on the water resources of the Aquifer. Aquifer simulations using the *GWSIM IV* groundwater model indicate that, given the predicted growth and water demand in the Edwards Aquifer region, the Aquifer's ground water resources appear threatened under $2\times CO_2$ (*i.e.*, doubling of CO_2 levels) climate scenarios. Their simulations indicate that $2\times CO_2$ climatic conditions could exacerbate negative impacts and water shortages in the Edwards Aquifer region even if pumping does not increase above its present average level. The historical evidence and the results of this research indicate that without proper consideration to variations in Aquifer recharge and sound pumping strategies, the water resources of the Edwards Aquifer could be severely impacted under a warmer climate.

Mace and Wade (2008) also used the *GWSIM-IV* groundwater model to evaluate effects of climate change. They scaled monthly recharge from 70 percent to 130 percent of the historical values to account for climate change and used pumpage defined by the critical period management rules in SB 3. Results indicated that for the period of 1947-1960, artesian flow at Comal Springs would cease despite critical period management. Modeling results further suggested that Aquifer pumping may have to be reduced by about 40,000 ac-ft/yr to maintain minimum springflows if recharge declines 30 percent.

3.1.4 Frequency of Droughts

The *Glossary of Meteorology* defines droughts as *"periods of abnormally dry weather sufficiently prolonged for the lack of water to cause a serious hydrologic imbalance."* A number of different indices of drought, evaluating precipitation, temperature, and soil moisture data, have been developed to quantify drought, each with its own strengths and weaknesses. Two of the most commonly used are the Palmer Drought Severity Index and the Standard Precipitation Index.

Serious droughts have been recorded in some parts of Texas in every decade since 1900. Droughts result from lower than normal precipitation levels; however, years with above average precipitation totals may still experience conditions of low water availability, especially after dry periods when increased groundwater pumping results in a shortage of water. Therefore, reporting the *annual average amount of rainfall* does not represent the occurrence of droughts or the impacts that droughts have on the Aquifer and the living organisms dependent upon it. Averaging the rainfall data tends to mask the duration and intensity of droughts. In addition, the lack of long-term rainfall data for the area hampers long-term analysis of droughts in the region. (Mauldin 2003).

Droughts vary significantly in duration and intensity. At least five droughts of extended duration and extreme intensity have occurred since 1931 in the Plan Area. (Riggio *et al*. 1987).

Numerous droughts of shorter duration and less intensity have also been recorded. In 1987, Riggio *et al*. conducted a comprehensive analysis of droughts using monthly rainfall data at many sites from 1931 to 1980. They defined droughts by the quantity and duration of rainfall events. Precipitation data were normalized to account for differences in rainfall between arid west Texas and humid east Texas. Between 1931 and 1985 the frequency of occurrence of the three-month drought in the Edwards Plateau region varied from 62 to 70 occurrences, depending on location. During the same period, the frequency of occurrence of the six-month drought varied between 32 and 40 occurrences. (Riggio *et al*. 1987). Less than 24 occurrences of the 12-month drought were recorded between 1931 and 1985 (Riggio *et al*. 1987). Although droughts are cyclic in nature, they are not consistent in frequency.

The six-year drought that occurred from 1951 through 1956 is considered the drought of record for the Aquifer as it was the most severe drought recorded according to documented aquifer records maintained since 1934. This drought resulted in the only known cessation of artesian flow at Comal Springs in 1956, for 144 days (Longley 1995). To better understand the drought of record and how it relates to the long-term climate of the Aquifer, a study utilizing dendrochronology was conducted on existing data bases to evaluate historic drought patterns in the Aquifer region (Mauldin 2003). Dendrochronlogy is the use of tree-ring analysis to evaluate historic climatic conditions. It is an established, critical element of climate research (Blasing and Fritts 1976; Robinson 1976; Stahle *et al*. 1985; Stahle and Cleaveland 1988; Cook *et al*. 1999). An extensive data base of tree-ring data for the southwest was used in the analysis (Cook 2000). Data collected from existing data-bases was correlated with the Palmer Drought Severity Index (PDSI) for a 280-year period (1700–1979). The PDSI is a standard measure of soil moisture conditions used to classify drought frequency, intensity and duration. It has a range of -4.0 to 4.0, with an average year falling between -0.5 and 0.5. Droughts are defined as -1.0 through -4.0. Over the 280-year period studied, 25.7 percent of the years were drought years. (Mauldin 2003).

Although there are insufficient scientific techniques to accurately predict droughts, several conclusions may be drawn from this best available data. Droughts are not uncommon to the Aquifer region; however, they are usually short in duration and are generally not too intense.

During the 280-year period (1700 through 1979), the Aquifer region experienced 40 droughts of various lengths. The duration of the average drought was 1.8 years, while droughts that lasted only 1 year were more common. Long-term droughts, defined as those exceeding 3 years in duration, occurred only four times, and three of those were in the 1700s. The fourth, long-term drought was the drought of record (1951–1956), which lasted 6 years. The drought of record was the most intense long-term drought (-2.32 average PDSI, peaking about -3.1); however, six other droughts were more intense for shorter durations (PDSI > -3.1). (Mauldin 2003). Therrell (2000), also using tree-ring analysis, concluded that the drought of record was the most prolonged period of sustained drought in the past 347 years. The drought of record represents only 2.1 percent of the 280-year period analyzed and only 2.5 percent of the 40 droughts.

However, there is evidence that much more severe droughts have occurred in North America prior to the instrumental record of roughly the last 100 years (Lettenmaier *et al*. 2008). When records of drought for the last two millennia are examined, the major twentieth century droughts appear to be relatively mild in comparison with other droughts that occurred within this time frame. (International Drought Information Center 2010). Although there are still a few high resolution (offering data on annual to seasonal scales), precisely dated (to the calendar year), tree-ring records available that extend back 2,000 years, most of the paleo-drought data that extends back this far are less precisely dated and more coarsely resolved. These records reflect periods of more frequent drought, or drier overall conditions rather than single drought events, so it is difficult to compare droughts in these records with twentieth century drought events. However, the twentieth century can still be evaluated in this context, allowing an assessment of whether parts of the twentieth century or the twentieth century as a whole were wetter or drier than in the past with these records. Several studies illustrate some paleo-drought records for the past 2,000 years. For instance, Woodhouse and Overpeck (1998), using paleoclimatic indicators (primarily tree rings), find that many droughts over the last 2,000 years have eclipsed the major U.S. droughts of the 1930s and 1950s, with much more severe droughts occurring as recently as the 1600s. Although the nature of future drought stress remains unclear, for those areas where climate models suggest drying, such as the southwest including the western half of Texas (Seager *et al*. 2007), extreme droughts as or more severe than those encountered in the instrumental record are more likely (Burke *et al*. 2006). More recent (Cleaveland and Votteler 2011, in preparation) dendrochronology studies focused on the Aquifer region have reached similar conclusions for a 500-year time sequence beginning in 1500. The drought ending in 1956, as evaluated using 5-, 10-, and 20-year averages, ranks as either the second or forth driest period during the past 500 years. As actual rainfall is the driver in Aquifer recharge, and, therefore, spring flows, total rainfall during 1- to 10-year periods may better reflect the likelihood of decreased springflows such as that which occurred during the drought of record.

3.1.5 Likelihood of a Repeat of the Drought of Record

In response to concerns about the likelihood of a reoccurrence of a significant drought that could adversely affect the spring systems during the term of the Permit, the potential for a repeat of the drought of record was analyzed from three perspectives: the long-term regional rainfall pattern based on tree-ring data, the regional pattern of rainfall from the instrumental rainfall records, and a probabilistic analysis based on the characteristics of the historic instrumental data.

3.1.5.1 Long-term Regional Rainfall Pattern (1500 to 2010)

Based on a recent evaluation using tree-ring data as a proxy for annual rainfall, Cleaveland and Votteler (in preparation) have provided a depiction of the climate in the Edwards Aquifer region of Texas during the past 500 years. They identified the pattern of significant drought events in Divisions 6 and 7, which correspond to the Edwards Aquifer contributing zone and recharge zone respectively for this period. Significantly, the period ending in 1956 was the second driest 5-year period, the fourth driest 10 year period, and the second driest 20-year period in both Divisions, indicating that it was a significant, event of low frequency during this period.

3.1.5.2 The Regional Rainfall Record (1895 to 2010)

Figure 3-5 displays the regional rainfall record from 1895 to 2010.

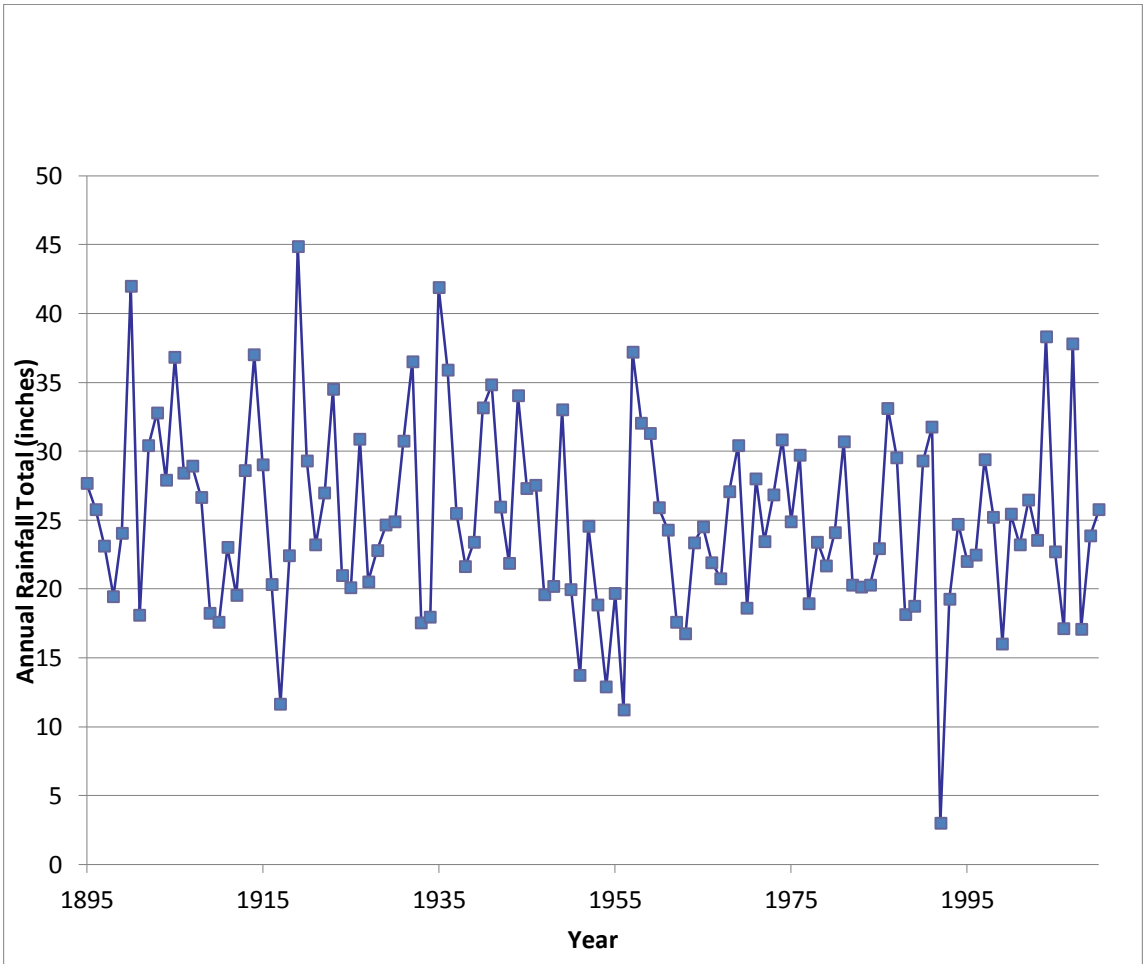


Figure 3-5. Division 6 Rainfall

3.1.5.3 Probabilistic Assessment of Recurrence of the Drought of Record

Although not necessarily intuitive, annual rainfall totals are essentially random with little evidence for between year associations (Hershfield 1963; Guttman 1989). The distribution of annual rainfall totals is often nearly normal (or Gaussian) (Hirshfield 1963), but also can be

represented by other statistical distributions. Guttman (1989) recommends evaluation of the data of interest prior to making assumptions as to the appropriate statistical descriptor.

Rainfall data for the period from 1895 to 2010 (Table 3-1; Figure 3-6) were evaluated as to their approximation to a normal distribution. The mean rainfall during the period was 25.37 inches per year (s.d. = 6.575) with a minimum of 11.22 inches in 1956.

TABLE 3-1
ANNUAL RAINFALL RECORDS FROM TEXAS CLIMATE DIVISION 6

Year	Annual Rainfall (inches)	Year	Annual Rainfall (inches)	Year	Annual Rainfall (inches)
1895	27.68	1934	17.95	1973	26.84
1896	25.79	1935	41.91	1974	30.86
1897	23.11	1936	35.93	1975	24.90
1898	19.48	1937	25.48	1976	29.75
1899	24.04	1938	21.65	1977	18.96
1900	41.98	1939	23.39	1978	23.43
1901	18.12	1940	33.16	1979	21.68
1902	30.44	1941	34.83	1980	24.11
1903	32.80	1942	25.98	1981	30.70
1904	27.91	1943	21.88	1982	20.29
1905	36.84	1944	34.04	1983	20.16
1906	28.43	1945	27.32	1984	20.29
1907	28.93	1946	27.53	1985	22.96
1908	26.65	1947	19.61	1986	33.13
1909	18.26	1948	20.21	1987	29.53
1910	17.61	1949	33.03	1988	18.14
1911	23.02	1950	19.97	1989	18.76
1912	19.54	1951	13.74	1990	29.29
1913	28.59	1952	24.58	1991	31.77
1914	37.02	1953	18.84	1992	30.00
1915	29.05	1954	12.89	1993	19.27
1916	20.36	1955	19.68	1994	24.71
1917	11.67	1956	11.22	1995	22.03
1918	22.43	1957	37.23	1996	22.46
1919	44.89	1958	32.05	1997	29.42
1920	29.33	1959	31.30	1998	25.24
1921	23.20	1960	25.90	1999	16.02
1922	26.98	1961	24.30	2000	25.44
1923	34.49	1962	17.62	2001	23.20
1924	20.97	1963	16.78	2002	26.48
1925	20.11	1964	23.35	2003	23.56
1926	30.89	1965	24.53	2004	38.31
1927	20.54	1966	21.93	2005	22.72
1928	22.81	1967	20.74	2006	17.12
1929	24.65	1968	27.07	2007	37.81
1930	24.91	1969	30.43	2008	17.09
1931	30.73	1970	18.64	2009	23.87

1932	36.53	1971	27.99	2010	25.76
1933	17.53	1972	23.47		

SOURCE: http://www.nass.usda.gov/Statistics_by_State/Texas/Charts_&_Maps/cwmap1.htm

The distribution of this data was assessed using Microsoft Excel 2010 and the SYSTAT 11 statistical software package. The annual rainfall data was compared with a number of statistical distributions but fit best with and were not significantly different from a normal distribution. (*See* Figure 3-6).

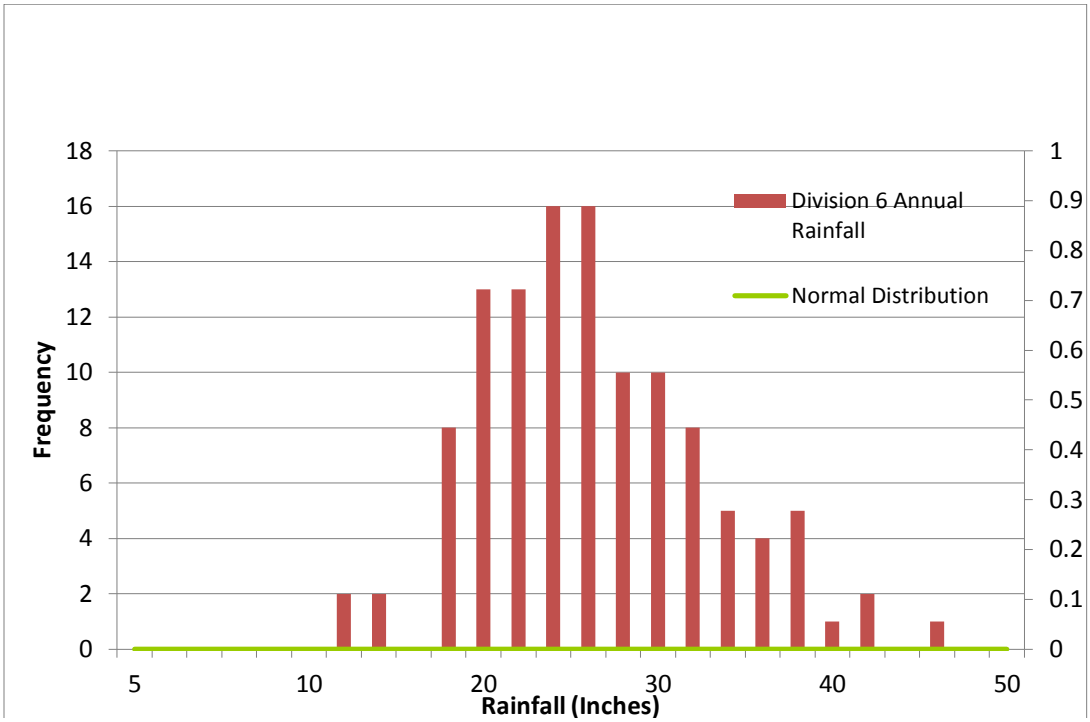


Figure 3-6. Division 6 Rainfall Frequency Distribution

Because the 1956 drought of record was the result of a multi-year sequence of drier than average years, the 1895-2010 rainfall data set was also examined by calculating three, five, seven, and ten-year running averages. (Figures 3-7 through 3-10). Each of these sequences was also normally distributed. With this analysis, it was not possible to identify which sequence (three, five, seven, or ten-year would be the best descriptor of what occurred in the drought of record, therefore all of the sequences were evaluated.

While the rainfall in 1956 was the lowest annual total for the entire period (11.22 inches), it does not stand out significantly from other years. (*See* Figure 3-6). However, the three, five, seven, and ten year sequences ending in 1956 each are distinguishable in the period, particularly the five and seven-year sequences.

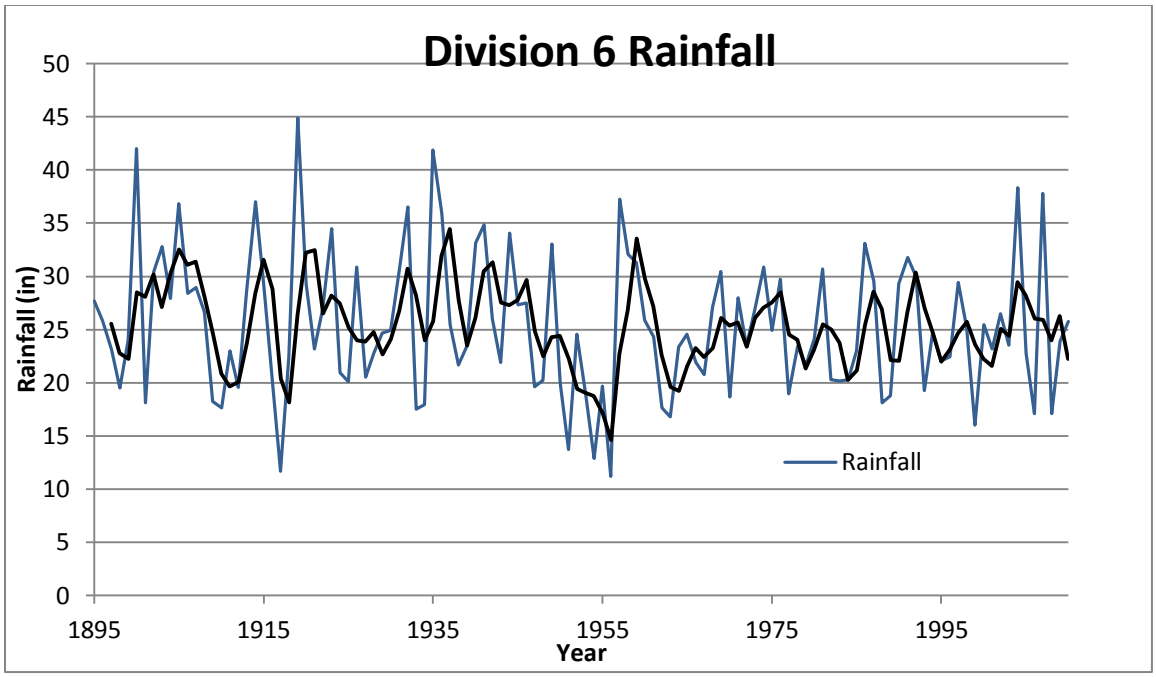


Figure 3-7. Three-year moving average rainfall 1895–2010

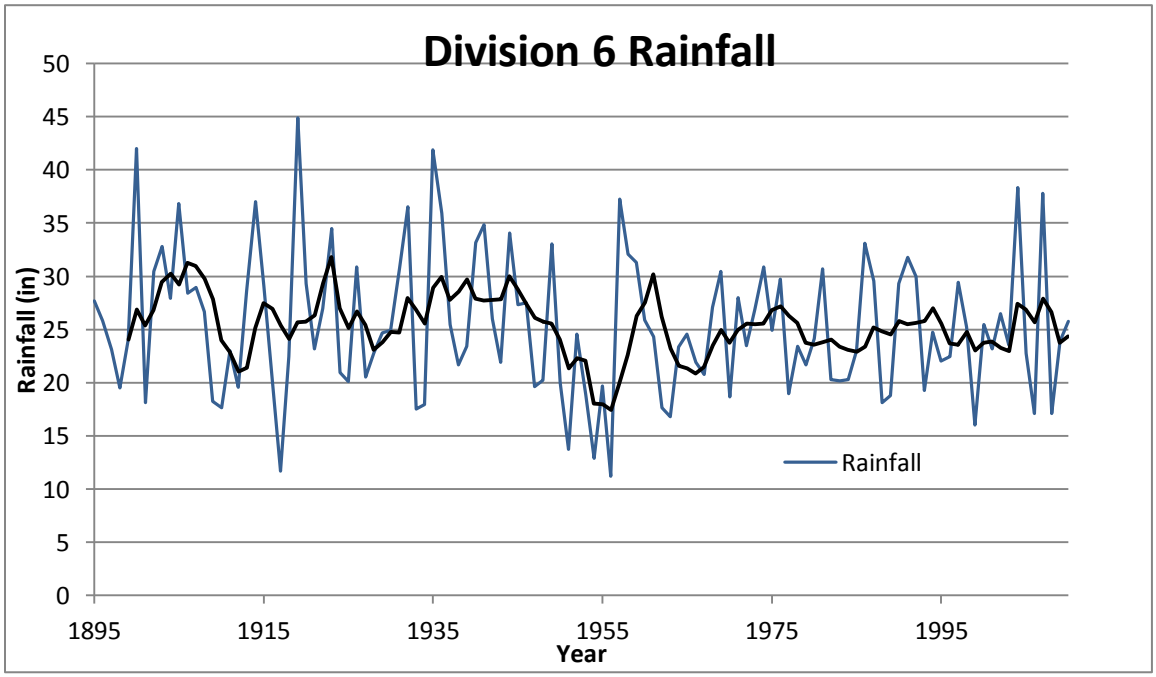


Figure 3-8. Five-year moving average rainfall 1895–2010

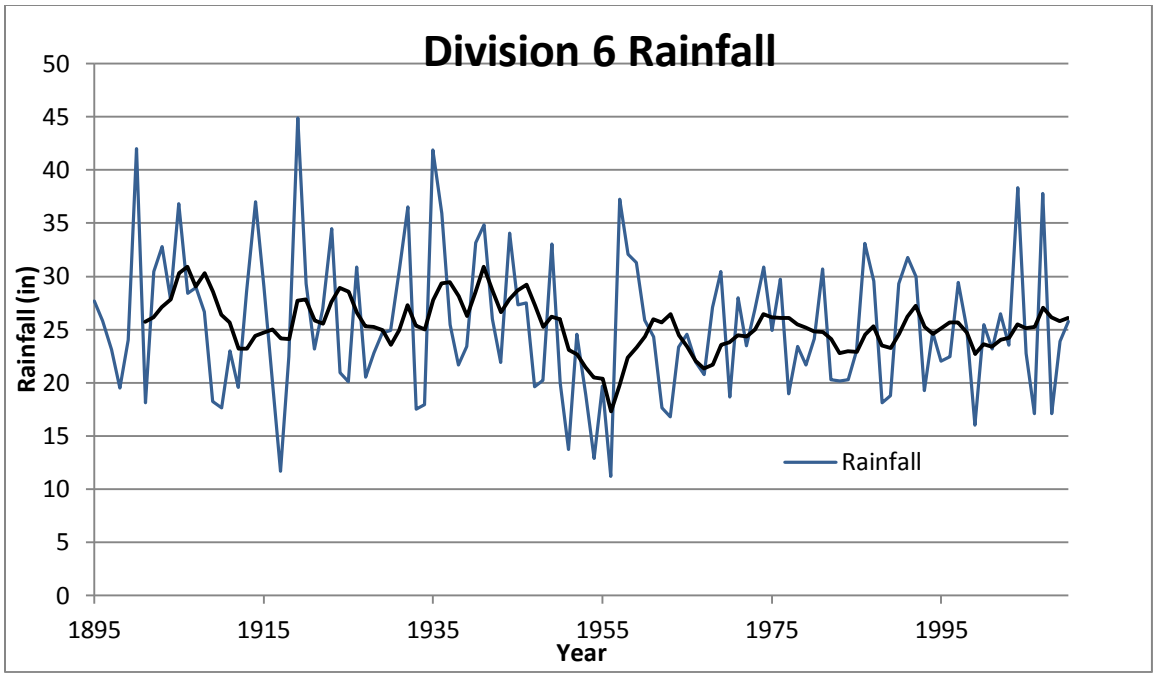


Figure 3-9. Seven-year moving average rainfall 1895–2010

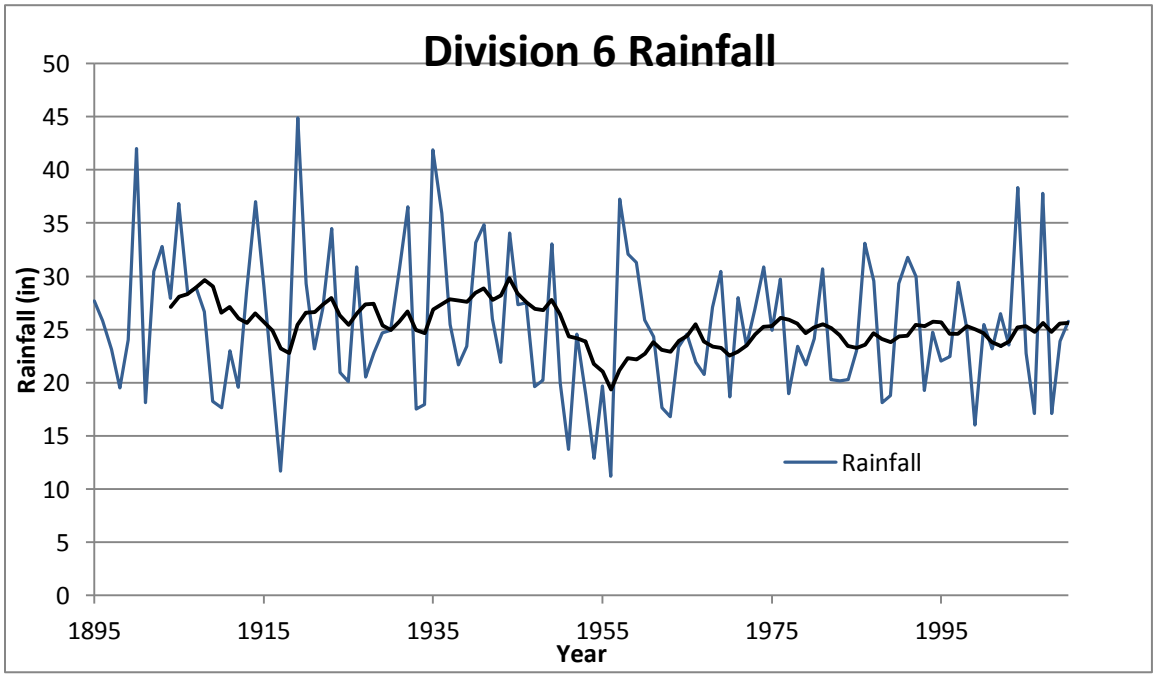


Figure 3-10. Ten-year moving average rainfall 1895–2010

From the normal distributions for each of these sequences (from the individual yearly totals and the three, five, seven, and ten year totals), the cumulative probabilities for the drought of record were calculated based on the normal distributions (Table 3-2).

TABLE 3-2
PROBABILITY OF DROUGHT OF RECORD BASED ON 1895-2010 ANNUAL RAINFALL TOTALS

Number of Years in Drought Sequence	Mean for drought of record (inches)	Calculated Cumulative Probability* P(rainfall< drought of record)
1	11.20	0.0161
3	14.60	0.00211
5	17.44	0.00219
7	17.27	0.00034
10	19.38	0.00119

*Calculated from 1895-2010 rainfall data.

From this it can be inferred that if the overall climatic regime during the past eleven years were to continue into the near term future, the probabilities of a recurrence of a year as dry as 1956 is approximately 1.6 percent in any given year. The probabilities of three- or five-year periods as dry as the drought of record are approximately 0.2 percent, and the probabilities of seven- or ten-year periods as dry as the drought of record are 0.1 percent or less. (Table 3-3).

TABLE 3-3
CALCULATED AND MODELED PROBABILITY OF RECURRENCE OF DROUGHT OF RECORD

Number of Years in Drought Sequence	Mean for drought of record (inches)	Calculated Cumulative Probability* P(rainfall< drought of record)	Monte Carlo Modeled Cumulative Probability for Future Periods**		
			8 Year (2010-2018)	15 Years (2010-2025)	25 Years (2010-2035)
1	11.20	0.0161	0.094	0.16	0.241
3	14.60	0.00211	0.011	0.026	0.038
5	17.44	0.00219	0.009	0.009	0.041
7	17.27	0.00034	0	0	0.005
10	19.38	0.00119	0.001	0.007	0.017

*Calculated from 1895-2010 rainfall data.

**Based on 1,000 iterations.

3.1.5.4 Effects of the Drought of Record on Comal Springs

The severity of the drought of 1956 and its impact on water levels at Landa Lake are unique in the hydrologic record for central Texas. The most critical period of low flow at Comal Springs was during the summer months of 1956, when the springs ceased artesian flow. Landa Lake went from being “full” in early June, to being “dry” in August of that year. A description of what occurs at Comal Springs when water levels drop has been previously described, (LBG-Guyton Associates 2004), and is summarized below.

Spring runs #1 and #2 stop flowing at Landa Park well water elevation of 622 feet above median sea level (ft-MSL), when total Comal Springs flow is about 130 cfs. Spring run #3 stops flowing at Landa Park well water level of 620 feet MSL, which is also the current lake level, as controlled by the dam. Total Comal Springs flow at this point is about 50 cfs. Spring runs #1 and #2 went dry during the summer of 1953 and from the summer of 1954 until January 1957, and spring run #3 stopped flowing during the summer of 1955, and also from May until December 1956. Although flow stops from spring runs #1, #2, and #3 at a Landa Park well level of 620 ft-MSL, there was still flow out of Landa Lake due to spring discharge from the other spring runs into the lake itself. When the water elevation at the Landa Park well declined to about 619 ft-MSL, total spring discharge went to zero. During 1956, spring discharge was zero for 144 consecutive days, from June 13 to November 3. At this point, flow stopped at the New Channel dam, but water was still able to flow though the culvert to the Old Channel. Below a Landa Park well elevation of approximately 618 ft-MSL, the elevation of the lake bottom immediately upstream of the culvert prevented flow from reaching the Old Channel culvert. Spring discharge could presumably still occur at water levels as low as the lowest lake-bottom elevation of 613 ft-MSL. However, for such discharge to occur, an outlet at that elevation would need to be constructed that would discharge to a location (such as Old Channel) at a lower elevation.

Large parts of the lake bottom emerged at a lake elevation of 618 ft-MSL. The north end of the lake, north of Spring Island, also emerged at about 618 ft. Although there were some deeper pools at the north end, flow from north to south was probably interrupted. Figures 3-11a and 3-11b are photographs of the southern end of Landa Lake that were taken sometime in the summer of 1956. The water level in the individual pools within the lake appeared to be about 617–618 ft-MSL. The lowest level of Landa Park well (613.34 ft-MSL) was reached August 21, 1956. The deepest pool, just south of Spring Island had a bottom elevation of 613 ft-MSL, and newspaper clippings indicate that there may have been 6 inches of water left in the deep pools.

3.1.5.5 Effects of the Drought of Record on San Marcos Springs

A description of what occurs at San Marcos Springs when water levels drop has been previously described (LBG-Guyton Associates 2004) and is summarized below.

San Marcos Springs is at the end of a flow system for the Aquifer that includes most of the outcrop, streams, and the Blanco River in Hays County. The springs receive recharge from this area, and they often exhibit a rapid flow response to storm events in this region. San Marcos Springs also appears to receive a regional base flow of about 50 to 100 cfs that bypasses discharge at Comal Springs. Although San Marcos Springs did not go dry during the drought of record in the summer of 1956, spring discharge declined to 47 cfs. Seasonal water level rises and increased flows in the artesian section of the Aquifer (San Antonio pool), however, do not

FIGURE 3-11a: Summer 1956 photo of southern end of Landa Lake, on western shore looking north toward the escarpment. Photo date unknown. Water level elevation in pools is about 617 to 618 ft. Photo provided by George Ozuna of USGS (LBG-Guyton Associates 2004)

FIGURE 3-11b: Summer 1956 photo of southern end of Landa Lake, on western shore looking southeast toward the flow-through pool. Photo date unknown. Water level elevation in pools is about 617 to 618 ft. Photo provided by George Ozuna of USGS (LBG-Guyton Associates 2004)

always result in increases in discharge at San Marcos Springs. The increased flow is in large part captured as increased discharge at Comal Springs. All of the spring discharge at San Marcos is through spring complexes in the bottom of Spring Lake. There are few, if any, subaerial springs, as occur at Comal Springs. Although some of the springs have distinct orifices where discharge can be measured, most of the spring discharge appears to be through rock rubble or sand boils in large flat sand plain areas. The southern springs appear to discharge groundwater from the regional flow system, while the northern springs receive their discharge from the more localized recharge zone in Hays County. Discharge rates in the southern springs would be expected to be far more stable under varying flow conditions than the northern springs, which should be more variable in proportion to total spring discharge values.

3.1.5.6 Effect of Drought on Hueco Springs

Following Barr (1993), only recent drought and springflow data are presented here. The larger of the two springs, Hueco I, typically exhibits constant flow but has been documented to stop flowing during severe droughts (Ogden *et al*. 1986), such as in 1984. However, Hueco I did not stop flowing during the drought occurring in 1989–1991. Hueco II is an intermittent spring that typically stops flowing during the driest months of the year. (Barr 1993).

The Applicants do not own or have jurisdiction over these springs or the surrounding ecosystems.

3.1.5.7 Effect of Drought on Fern Bank Springs

No long-term data exist for this site; however, a single-family owned the spring site from the late 1800s until 2009. In 2008, the landowner claimed that the spring never ceased flowing during that time, including the drought of the 1950s. The Applicants do not own or have jurisdiction over these springs or the surrounding ecosystems.

3.2 Aquifer-fed Springs

Texas originally had 281 known major non-saline springs, and, of those, only four were defined as first-magnitude springs, having a flow of over 100 cfs. These four consist of Comal Springs, San Marcos Springs, Goodenough Springs, and San Felipe Springs. Goodenough and San Felipe springs are located in Val Verde County, west of the Edwards Balcones Fault Zone Aquifer, and Goodenough has since been inundated by the impoundment of Amistad International Reservoir. (Brune 1975). Comal and San Marcos springs remain the largest springs in Texas, and flow from these springs is supplied principally by the Aquifer. Other spring outlets of the Aquifer within the jurisdiction of the EAA include Leona Springs, San Pedro Springs, San Antonio Springs, Hueco Springs, and Fern Bank Springs. (*See* Figure 3-12). Total annual discharge from the six most significant springs shown in Table 3-4 during the period of record 1934 to 2009 has varied from 69,800 ac-ft in 1956 to 802,800 ac-ft in 1992 with an average annual discharge of 385,700 ac-ft. (EAA, 2010b).

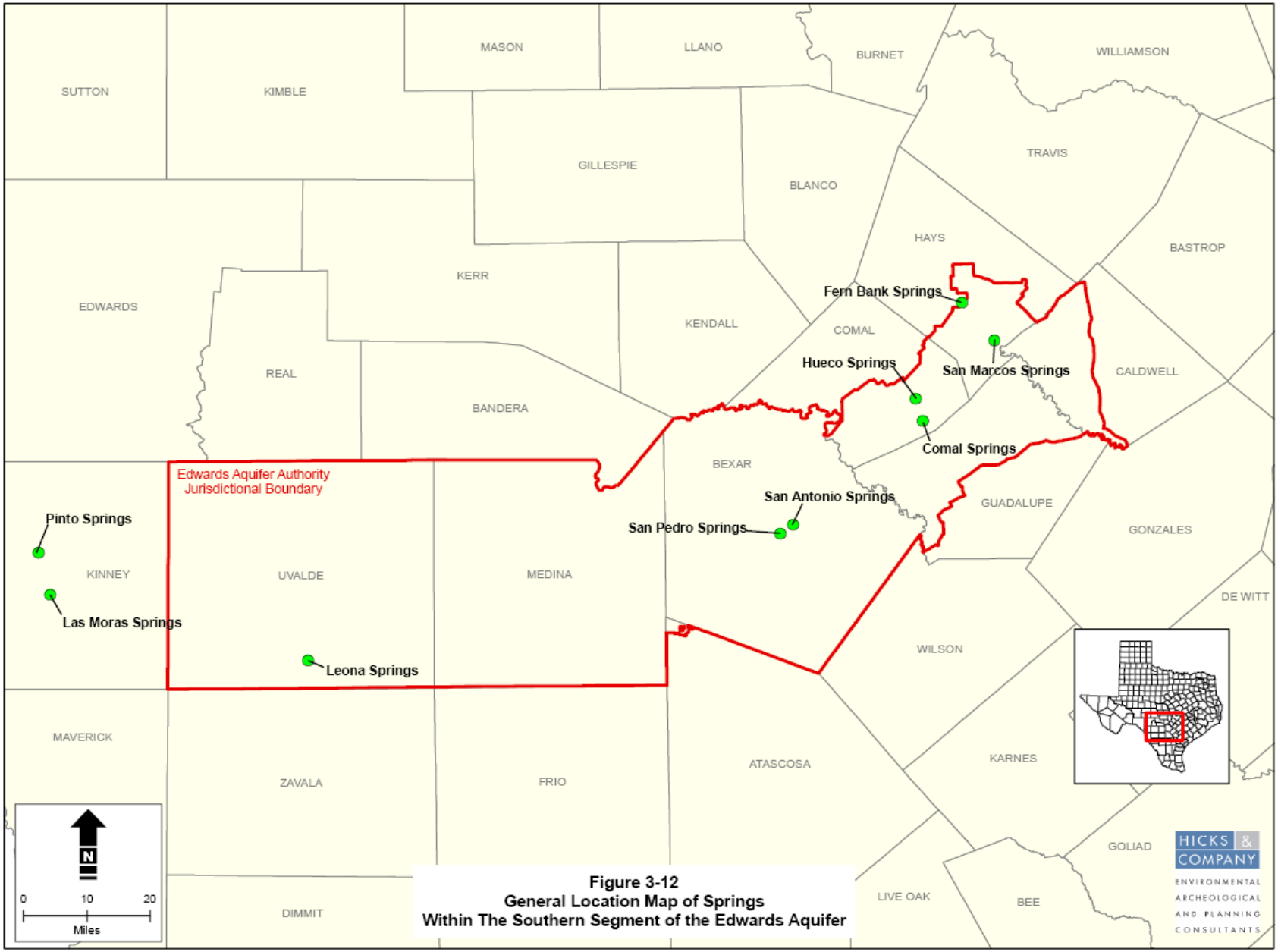


Figure 3-12
General Location Map of Springs
Within The Southern Segment of the Edwards Aquifer

TABLE 3-4
ESTIMATED SPRING DISCHARGE FROM THE EDWARDS AQUIFER, 2009
(acre-feet)

Month	Leona Springs and Leona River Underflow	San Pedro Springs	San Antonio Springs	Comal Springs	Hueco Springs	San Marcos Springs	Total Monthly Discharge from springs
January	1,970	270	322	17,910	358	6,000	26,830
February	1,406	180	16	15,570	364	5,480	23,016
March	1,487	195	0.16	16,610	505	6,140	24,937
April	1,574	110	0	15,630	405	5,680	23,399
May	764	30	0	14,210	494	5,680	21,178
June	396	10	0	11,850	338	5,340	17,934
July	366	0.65	0	10,180	194	5,420	16,161
August	415	0	0	10,290	270	5,330	16,305
September	471	3.23	0	11,610	1,880	5,550	19,514
October	549	167	7.41	16,390	5,200	9,080	31,393
November	552	277	68.3	17,590	4,130	10,670	33,287
December	584	295	91.2	19,180	2,590	11,280	34,020
TOTAL	10,534	1,538	505	177,020	16,728	81,650	287,975

Data sources: EAA 2010b; Differences in totals may occur as a result of rounding.

3.2.1 Comal Springs

Located in the City of New Braunfels in Comal County, Comal Springs is the largest natural spring system in the state and is the source of baseflow to the Comal River. At 623 feet above sea level, Comal Springs is one of the lowest elevation springs fed by the Aquifer. The springs discharge from four major orifices and numerous smaller discharge points, which flow into Landa Lake. (Abbott and Woodruff 1986; *see* Figure 3-12). Individual springs and/or spring runs have ceased flowing during recorded history, with the most recent event in 1996. The only time in recorded history that the cessation of spring discharge stopped the flow of the Comal River was during the drought of record, in 1956, for 144 days from June 13 to November 4 of that year (USFWS 1996; Longley 1995). The record high flow for Comal Springs is 1,059 ac-ft per day (534 cfs) in 1973, while the historical average flow for the period 1934 to 2010 was 291 cfs. (EAA, 2010b).

Water discharging from Comal Springs has been recharged from numerous areas upgradient in the Aquifer recharge and contributing zones. Longer, regional scale flowpaths primarily originate in Bexar and Medina counties, while short, localized groundwater contributions to springflow occur in Comal County. Different spring orifices in the Comal Spring system reflect water originating from different flowpaths. For instance, Spring Runs 1, 2, and 3 have been shown to have a larger contribution from localized, shallow flowpaths while spring orifice number 7 reflects water emerging from deeper, more regional flowpaths. This has been documented through a series of dye tracer tests at Comal Springs conducted by the EAA from the period of 2000-2011. (EAA 2010a).

3.2.2 San Marcos Springs

San Marcos Springs, located in the city of San Marcos in Hays County, and very near the base of the Balcones Escarpment, is the second largest spring system in the state and is the source of baseflow to the San Marcos River. (Figure 3-12). San Marcos Springs, at 574 feet MSL, exhibit the lowest elevation of the major springs in the San Antonio segment of the Aquifer. Much of the water flows from six major and several minor orifices at the bottom of Spring Lake. The water in San Marcos Springs averages approximately 72°F with slight seasonal variations. Because San Marcos Springs is lower in elevation than Comal Springs and is further down the pathway of the flow of water within the confined artesian Aquifer zone, discharge at Comal Springs appears to dampen effects at San Marcos Springs. Although Comal Springs went dry for approximately 144 days from June through November 1956 (South Central Texas Water Advisory Committee 2000), such an event has never occurred at San Marcos Springs. The springs did reach a recorded low discharge of 91 acre-feet per day (47 cfs) in 1956. The record high daily flow for San Marcos Springs was 627 acre-feet per day (316 cfs) in 1975 (Brune 1981), while the historical average flow from 1957 to 2009 was 175 cfs (EAA, 2010b).

Local stream recharge from the Blanco and Guadalupe rivers and Sink, Purgatory, York, Dry Comal and Alligator Creeks contributes to San Marcos Springs as they cross the Recharge Zone. (Brune 1981). San Marcos Springs are also supplied by “regional underflow past the Comal Springs area.” (Guyton *et al.* 1979).

3.2.3 Other Springs

Hueco, Fern Bank, San Antonio, San Pedro, and Leona are lesser spring outlets for the Aquifer. (*See* Figure 3-12). These springs generally have declining or erratic flow due to their high elevation, seasonal fluctuations during dry years, and increased pumping from the Aquifer and other underlying aquifers.

Hueco Springs, in Comal County, are located three miles north of New Braunfels near the junction of Elm Creek and the Guadalupe River on private property. It is the seventh-largest spring in Texas, and includes two main groups of springs, one on each side of River Road. These springs flow from the Hueco Springs fault, which is a major structural feature within the Aquifer with an offset of approximately 400 feet. (Guyton and Associates, 1979). The springs consist of two orifices at a high elevation (approximately 658 feet above sea level), and therefore have variable flow and often go dry or have long periods of low flow during drought (Abbott and Woodruff 1986). The maximum discharge for Hueco Springs was 260 ac-ft per day (131 cfs) in 1968 (Brune 1975) and has averaged about 70 acre-feet per day. Hueco Springs recharge has both local and regional components originating from the nearby Dry Comal Creek and Guadalupe River basins and from longer flowpaths from San Antonio. (Otero 2007; *see* Figure 3-13). Hueco Springs was documented with elevated nitrate levels (> 5 parts per million) during the drought of the 1950s, but values have been below 2 ppm. One measurement was just above 2 ppm in 2000 since that time (Johnson *et al*. 2009).

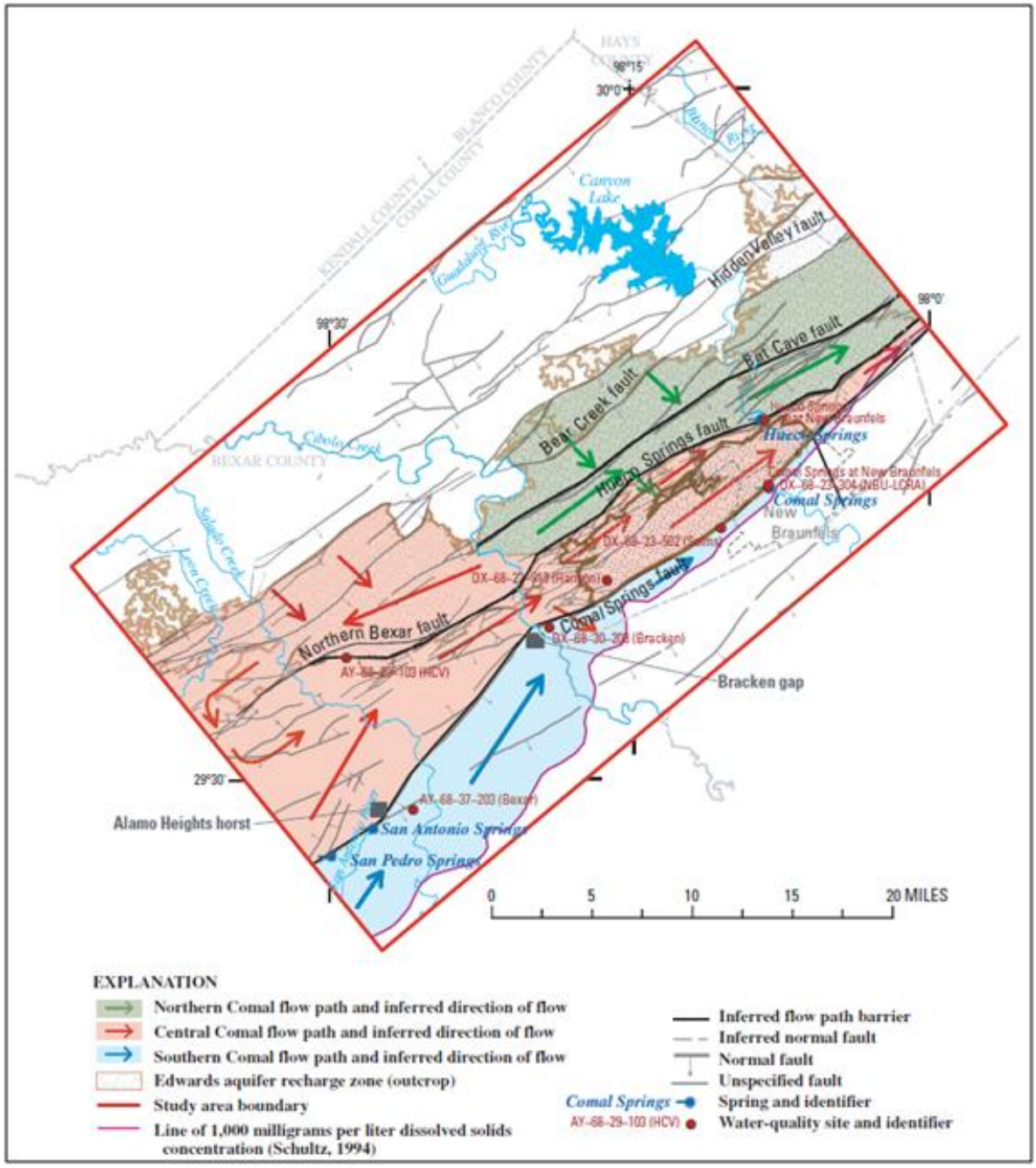


Figure 3-13. Major Faults and Interpreted Groundwater Flowpaths to Comal and Hueco Springs from Otero (2007)

Fern Bank Springs, also referred to by Brune (1981) as Little Arkansas or Krueger Springs, are about five miles east of the City of Wimberley on the south bank of the Blanco River in Hays County. The primary spring emerges from a cave that has been surveyed to a length of 130 meters and is relatively flat, with enough gradient to allow water to flow the entire length and then drain out the entrance. (*See* Figure 3-14). The spring (cave entrance) is located at the base of an approximately sixty-meter escarpment, which is the geomorphic expression of the

Hidden Valley fault. This is a major fault in the Balcones fault zone which juxtaposes the older Upper Glen Rose limestone on the northwest side (upthrown) of the fault to the lower members of the Kainer Formation on the southeast side (downthrown).

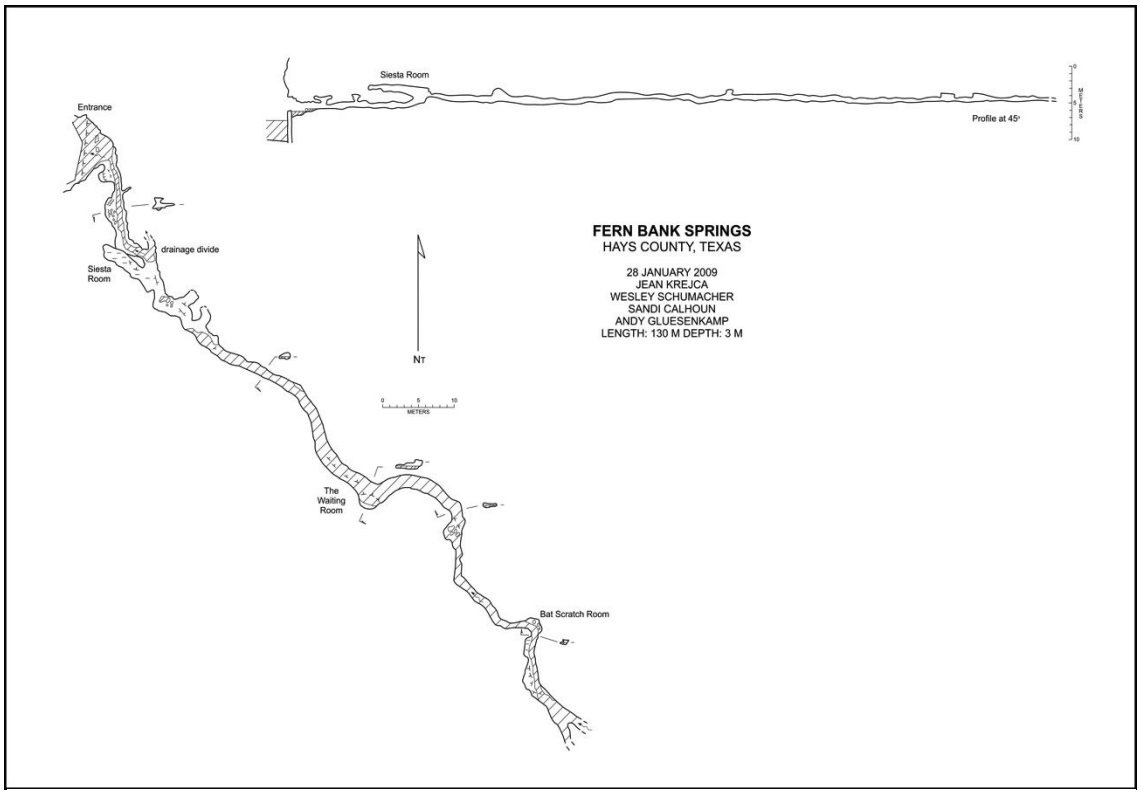
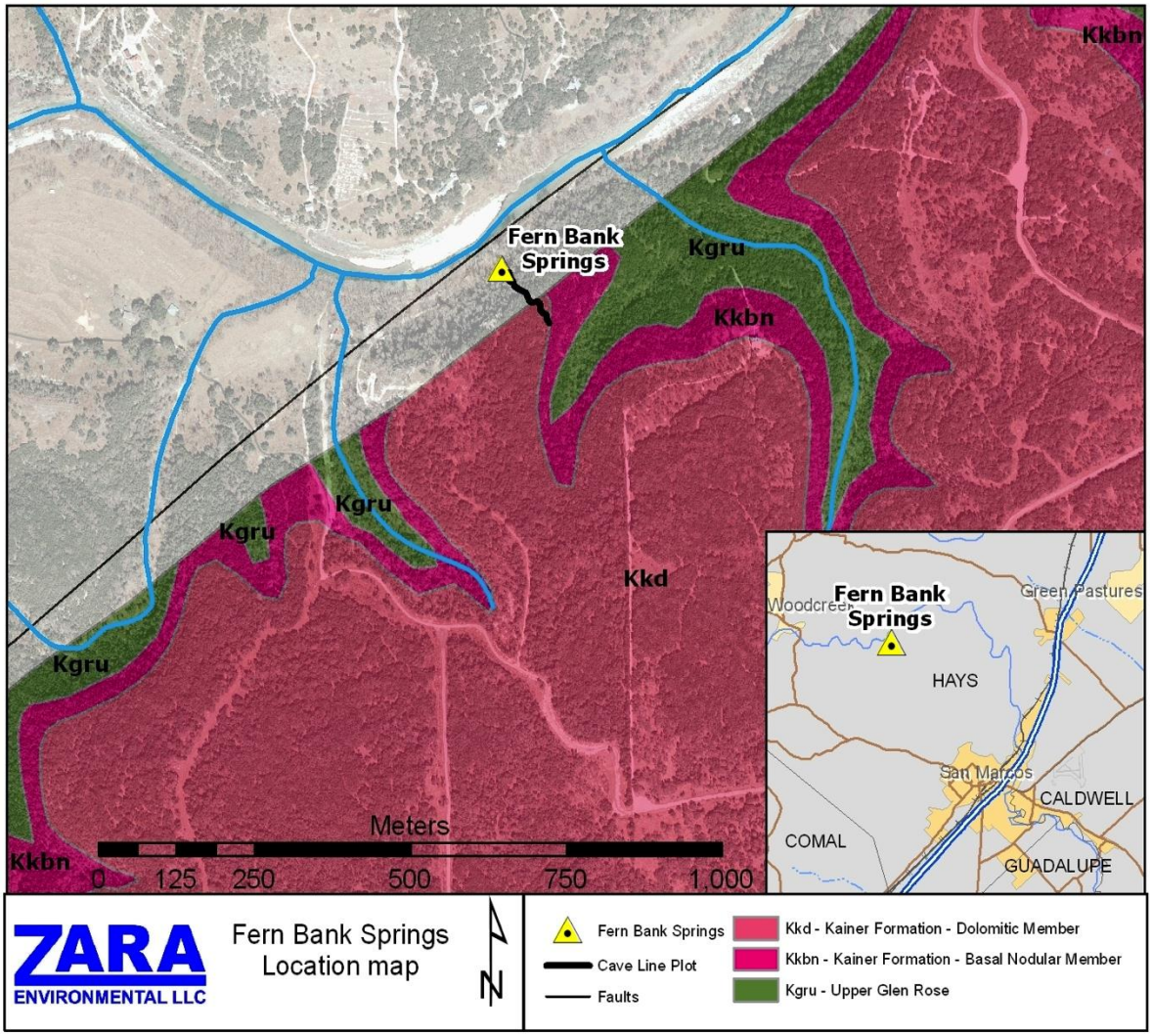


Figure 3-14. Cave Map of Fern Bank Springs

The cave passage extends southeast along a bearing that is normal (perpendicular) to that of the strike of the fault, and appears to have developed along a bedding plane near the contact of the Upper Glen Rose and Basal-Nodular member of the Kainer Formation (Edwards Group). (*See* Figure 3-15). It appears that the spring waters are sourced from the Edwards limestone located in this portion of Hays County. Here the Kainer Formation (lower formation in the Edwards Group) is relatively thin and unconfined. Recent dye traces to Fern Bank Springs confirm that groundwater recharged south of the Blanco River in the Kainer Formation feed the spring (Johnson *et al.* 2009). There is a significant topographic high between the spring (approximately 800 ft-MSL) and San Marcos Springs to the southeast (573 ft-MSL). While the source of the water for Fern Bank Springs is undetermined (USFWS 2007), it may originate from the upper member of the Glen Rose Formation, from drainage from the Aquifer recharge zone, from water lost from the Blanco River, or from some combination of those sources. (USFWS 2007). Springflow was documented to vary between five cfs in 1975 to less than one cfs in 1978. (Brune 1981). A single family owned the spring site from the late 1800's until 2009.

In 2008, the landowner claimed that the spring never ceased flowing during that time, including the drought of the 1950s.



Basemap: U.S. geological Survey (USGS) Geologic Map of the recgarge Zone (Blome et al., 2005); USGS 1:24,000 National Hydrography dataset; CAPCOG Aerial Imagery 2008

Figure 3-15. Local geologic map showing the plotted location of Fern Bank Springs cave and Edwards (Kainer Formation) limestone outcrop near the Blanco River

San Antonio Springs, originally a complex of over 100 springs (Brune 1981), are located principally on property of the University of the Incarnate Word and near Brackenridge Park within north central San Antonio. Most of the springs are at an elevation of about 672 ft-MSL. The largest spring is called Head of the River or Blue Hole, reflecting that it is the head of the San Antonio River.

San Pedro Springs, in Bexar County, are located in San Pedro Park in San Antonio at 663 ft-MSL. Both San Antonio and San Pedro springs are recharged by waters over 62 miles to the west where the Frio, Sabinal, and Medina rivers and Hondo and Leon Creeks cross the Balcones Fault Zone. Both of these springs were very important to the early development of San Antonio, providing water to ancient Payayan Indian settlements, and to Spanish missions established during the early 1700s including the San Antonio de Valero Mission (the Alamo)

founded in 1718. Water from these springs is discharged from faults in the Austin Chalk formation.

Leona Springs are found in four groupings along or beneath the surface of the Leona River in Uvalde County. Leona Springs, 860 ft-MSL, are recharged by the Nueces River and other streams to the northwest. (Brune 1981). These springs were an attractive stop on the Old Spanish Trail and were described as “the purest streams of crystal water” (Brune 1975). Water quality testing of the springs between 1976 and 1985 by USGS detected pesticide compounds, but no occurrences exceeded the maximum contaminant levels for drinking water. (USGS 1987).

3.3 Edwards (Balcones Fault Zone) Aquifer

This section provides a general description of the hydrological boundaries of the Aquifer, hydrological zones, and hydraulic properties.

The Aquifer, referred to as the Edwards Balcones Fault Zone Aquifer by the TWDB (2006a), is one of nine major aquifers in Texas and covers approximately 4,350 square miles across parts of eleven Texas counties. The Aquifer has focused recharge zones, enhanced secondary porosity, and excellent geochemical water quality conditions. These factors make the Aquifer one of the most productive groundwater reservoirs in the country (Sharp and Banner 1997). The Aquifer is the primary source of water for a large portion of central Texas, almost 2 million people. (EAA, 2010b; U.S. Census Bureau 2010). It supports cities, towns, rural communities, farms, and ranches. The water is used for a range of purposes, including municipal, industrial, or manufacturing, steam electric, irrigation, mining, livestock, and recreation. The Aquifer also supports several major springs which provide habitat for a number of endangered and threatened species.

The Aquifer extends from a groundwater divide in Kinney County through the City of San Antonio northeast to Bell County. Within this area, the Aquifer is comprised of three segments: the southern (San Antonio) segment; the Barton Springs (Austin) segment; and the northern segment. Historical hydro-geological data supports the presence of a groundwater divide running west-northwest from the City of Kyle in Hays County, that under normal conditions hydrologically separates the San Antonio and Austin (Barton Springs) segments. At this location, under most conditions, groundwater from the San Antonio and Austin segments do not mix. Generally, groundwater north of the divide flows north, while groundwater south of the divide flows south. This groundwater divide may be diminished substantially during drought conditions. A recent study (HDR 2010) suggests that as water levels in the Aquifer decline during major droughts and current levels of pumping, this groundwater divide diminishes, allowing the potential for some groundwater to bypass San Marcos Springs and flow north into the Barton Springs Segment of the Aquifer toward Barton Springs. The third segment of the Aquifer which is known as the northern segment is hydrologically separated from the Barton Springs Segment by the Colorado River. The focus of this groundwater discussion will be on the San Antonio segment of the Aquifer.

The San Antonio segment of the Edwards Aquifer is approximately 180 miles long stretching from the city of Brackettville in Kinney County to north of Kyle, in Hays County, Texas. (*See* Figure 3-16). It varies in width from 5 to 40 miles. This segment of the Aquifer extends through all or part of eleven counties: Zavata, Frio, Atasco, Guadalupe, Kinney, Uvalde, Medina, Bexar, Comal, Caldwell, and Hays. As described in Section 3.2.1 the Aquifer lies under several streams in three major river basins, the Nueces, the San Antonio, and the Guadalupe. The San Antonio segment of the Aquifer holds water that drains from approximately 8,000 square miles

in some 12 counties in the contributing and recharge zone. The water-bearing body of the Aquifer itself underlies approximately 3,600 square miles in eight counties. The total volume of circulating freshwater in the Aquifer is estimated at 173 million acre-feet (Bureau of Economic Geology 1995), making it one of the most productive aquifers in the United States, although the amount of recoverable groundwater is not known. The Aquifer, which historically has been the sole source of water for the city of San Antonio (USGS 1995; EAA, 2001), provides base flow to the three river basins mentioned above (USGS 1999). Since 1968, annual discharge from springflow and pumping has frequently exceeded average annual recharge. However, the hydrograph of the J-17 Index Well does not show a declining trend in the level of the Aquifer.

The Aquifer is considered a karst aquifer. Flow in the Aquifer is very complex (USGS 1995) and is typical of other karst aquifers, occurring over a wide range of hydraulic conductivity, from flow through the rock matrix (least conductive), flow in planar fractures and bedding planes to turbulent flow through integrated conduit systems (most conductive). In general, most storage occurs in the matrix, while most flow occurs in the fractures/faults and conduits. Matrix and conduit components may or may not mix effectively. Thus, groundwater in some components of the Aquifer may have very long residence times and be relatively resistant to surface contamination, while other components of the Aquifer may have extremely rapid travel times and be very vulnerable to contamination. The vulnerable parts of the Aquifer are also the most productive, feeding major springs and wells.

In addition to the variability of flow velocities, flow directions are also variable in karst aquifers. Flow directions are influenced by both regional and local hydraulic gradients, but they are also

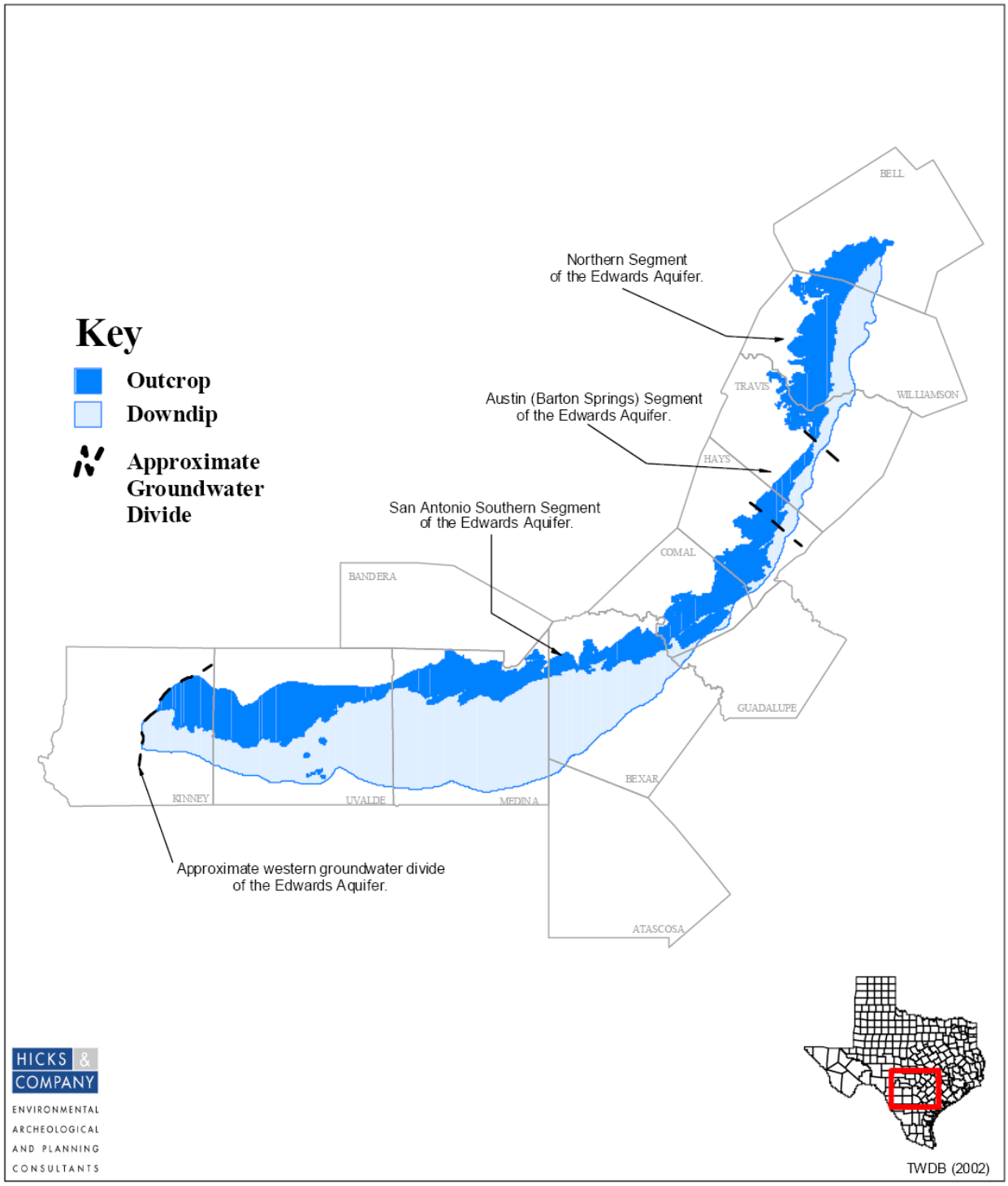


Figure 3-16
Map of the Edwards Aquifer

controlled by the location and orientation of conduit systems. Karst aquifers may be influenced by development and changes in geologic formations that occurred under previous water flow regimes, thus flow paths may not follow local topography or surface watersheds. It is common for flow in karst aquifers to cross watershed boundaries, which are typically considered as groundwater divides in other types of aquifers. Furthermore, the pattern and direction of flow in karst is often water-level dependent, as high water levels can utilize older flow paths and travel in non-linear directions using conduits formed under older groundwater regimes, which may differ from modern ones.

Generally, the water flows south-southeastward from the recharge zone along low permeabilities and steep hydraulic gradients within the unconfined portion of the Aquifer. As the water flows into the confined portion of the Aquifer, the flow direction changes toward the east and northeast within the low gradient, highly permeable artesian zone. The water is then discharged from several springs, predominantly Comal and San Marcos springs (Section 3.2.1). Although the Aquifer contains vast reserves of water, a large volume of water cannot be extracted without affecting springflow and the overall water budget. This is because the springs are higher in elevation than much of the confined artesian zone. This relationship is similar to a bucket of water with holes at the top that are analogous to the spring locations. Although water is available in the lower portions of the bucket, it cannot be extracted without affecting the flow of water through the holes (springs) at the higher levels. The water budget of the Aquifer (recharge, discharge, and springflow) is discussed in Section 3.3.3.

The San Antonio segment of the Aquifer consists of a recharge zone and artesian zone. (*See* Figure 1-1). Each of these components is described below. The Aquifer is also affected by a contributing zone. Development over the contributing and recharge zones of the Aquifer is regulated under rules established by the TCEQ Edwards Aquifer Protection Program (2010). Section 3.3.2 below provides an overview of these regulations.

Contributing Zone

The contributing zone is composed of drainage areas and catchments of surface streams upstream of the recharge zone that subsequently flow over the recharge zone. Much of the contributing zone lies over the older Glen Rose Formation, upthrust by the Balcones faulting. In the upthrown fault blocks, the Edwards Group rocks have been eroded away and are not present. Here, the Upper Glen Rose is exposed, and is classified as being the “contributing zone” to the Aquifer. The Contributing Zone of the San Antonio segment of the Aquifer is a surface component not technically part of the Aquifer that consists mainly of the drainage areas and catchments of surface streams, creeks, and rivers that subsequently flow over the Aquifer’s recharge zone in the Nueces, San Antonio, and Guadalupe River Basins. The contributing zone encompasses some 5,400 square miles in all or part of Edwards, Real, Kerr, Bandera, Kendall, Gillespie, Blanco, Bexar, Comal, Hays, Kinney, Uvalde and Medina Counties. (*See* Figure 1-1). This area is important because of its substantial contribution to Aquifer recharge. Future development in the contributing zone will affect the quality and quantity of water draining to the recharge zone of the Aquifer.

Recharge Zone

The recharge zone (also known as the unconfined zone) of the Aquifer is an approximately 1,250-square mile area where heavily faulted and fractured Edwards limestone outcrops at the land surface, allowing large quantities of water to flow into the Aquifer. The recharge zone stretches as a band from the area north and west of San Marcos and New Braunfels and extends southwesterly to the north of San Antonio, then westerly through the northern portions

of Bexar, Medina, Uvalde and Kinney Counties. Recharge occurs when streams and rivers cross the permeable formation and a portion of their flow seeps underground, or when precipitation or runoff falls directly on the outcrop. Water flows are driven by gravity to discharge at water-table springs, to enter deeper flow systems and discharge at artesian springs, or to recharge the confined zone of the Aquifer. Surface water reservoirs on the recharge zone, such as Medina Lake, also contribute large amounts of water to the Aquifer. Except for the Guadalupe River, all rivers and streams that cross the outcrop of the Aquifer lose major portions of their flows to the Aquifer through joints, faults, and sink holes and other karst features (USGS 1995). Where the Guadalupe River crosses the recharge zone it may either gain or lose water from the Aquifer, depending on Aquifer levels. This is due to water levels in the river being near the groundwater table, whereas other creeks and streams are generally at significantly higher elevations. There are three river basins that cross the Aquifer area: the Nueces, the San Antonio, and the Guadalupe River. Extending from the west, the Nueces River Basin covers over half of the Aquifer area.

Several major tributaries in the Nueces basin traverse the Aquifer Recharge Zone including the Nueces, West Nueces, Frio, Dry Frio, and Sabinal rivers, as well as Hondo Creek. The portion of the San Antonio River Basin that is located in the recharge zone extends from the Medina River to Cibolo Creek and includes the headwaters of Leon and Salado Creeks. Only a small portion of the Guadalupe River Basin intersects the eastern Aquifer area. However, two of the basin tributaries, the Comal and San Marcos rivers, are primarily fed by the Aquifer at the Comal and San Marcos springs.

Under normal conditions most of the Aquifer recharge occurs in the basins west of Bexar County (USGS 1995), where the Edwards limestone outcrop is very wide at the surface. In the recharge zone, there are no other geologic formations overlying the Edwards limestone. It is therefore exposed at the surface.

Periods of recharge are intermittent as most streams in south-central Texas are ephemeral; however, the recharge capacity of surface water into the Aquifer is extremely efficient due to the karstic nature of the system. Water passing over the contributing zone and into faults, fractures, and swallets of the recharge zone is rapidly transferred directly to the Aquifer with little or no filtration. The geologic mechanisms that form karst are complex, and many factors affect how karst is expressed in current settings. These factors control the way the groundwater system evolves, and ultimately how groundwater is recharged, transmitted, and naturally discharged through the Aquifer system.

Artesian Zone

The artesian zone (also known as the confined zone of the Aquifer) is located between two relatively impermeable formations, the Glen Rose formation below, and the Del Rio clay above (Ferrill *et al.* 2004). The weight of water entering the Aquifer from the recharge zone creates tremendous pressure on water that is already present in the formation. Flowing artesian wells and springs exist where this pressure is sufficient to force water to the surface along faults or through wells. This zone is where the highest capacity wells and largest springs exist. (Collins and Hovorka 1997). Examples of natural springs under artesian conditions are San Marcos and Comal springs in the northeast. Groundwater movement through the Aquifer is generally controlled by a number of barrier faults that disrupt the continuity of the permeable Edwards limestone. This movement tends to be from the higher elevations in the west to discharge areas in the east. The displacement of strata ranges from very large, which causes permeable and impermeable layers to be juxtaposed, to very small. Water moves more freely through the Aquifer when displacement is minimal. Additionally, groundwater divides exist in the west near

Brackettville and in the east near Kyle, so the central portion of the Aquifer is hydrogeologically separated from Edwards limestones on either side. (*See* Figure 3-16).

Transition Zone

The transition zone consists primarily of younger bedrock overlying the artesian zone of the Edwards Group that has been down thrust to the east in the Balcones Fault Zone. These younger and generally less permeable rocks of the transition zone overlie and form the upper confining units to the artesian zone of the Aquifer. While the surface bedrock in the transition zone is generally less permeable and karstified than the rocks of the Edwards Group, it was also extensively fractured and faulted by the Balcones Fault Zone, and hosts some high-permeability pathways into the artesian zone. An exception is the Austin Chalk formation, which is well karstified in some areas and hosts significant springs that discharge Aquifer water, such as San Antonio and San Pedro springs. (Veni and Heizler 2009).

Contributing Zone within Transition Zone

The area or watershed where runoff from precipitation flows down-gradient to the recharge zone of the Aquifer is considered contributing zone within transition zone. The contributing zone within the transition zone is located generally south and east of the recharge zone and includes specifically those areas where stratigraphic units not included in the Edwards Aquifer crop out at topographically higher elevations and drain to streams courses where stratigraphic units of the Edwards Aquifer crop out and are mapped as recharge zone.

Hydraulic Properties

Aquifer transmissivity (the ability of water to pass through the Aquifer, as measured by hydraulic conductivity and thickness) is high. According to Maclay and Small (1986), transmissivity of the Aquifer in the San Antonio area varies from one to two million square feet per day, allowing some wells in the city of San Antonio to discharge as much as 10,000 gpm or more (USGS 1995). One particular well was documented by the EAA to produce between 25,000 and 36,000 gpm. Highest transmissivity was determined to exceed 4,300,000 square feet per day in Comal County near Comal Springs; the smallest was 130 square feet per day in the saline water zone (Maclay and Land 1988). Linear distance at which water may move through the Aquifer appears to vary greatly, depending on location. Ogden *et al*. (1986) documented travel from up to 1,000 feet per day to only a few feet per day. Recent tracer tests conducted by the EAA revealed discrete groundwater flowpaths near Panther Springs Creek with apparent (point-to-point) groundwater velocities ranging from 43 to 17,490 feet per day from the Recharge Zone to the transition/Artesian Zone of the Aquifer. (EAA 2010a). Other evidence of high porosity of the Aquifer is the ability of Aquifer water levels to quickly respond to rainfall and recharge events and rapid decline of water levels over a large area due to increased pumpage.

The Knippa Gap near Sabinal in eastern Uvalde County (*see* Figure 1-1) is a major controller of groundwater flow within the western portion of the Aquifer. The Knippa Gap is a geological restriction within the Aquifer that allows substantial flow of groundwater from west to east but restricts flow enough to maintain higher groundwater levels in the Uvalde pool than in the San Antonio pool. (Green *et al*. 2008). Wells to the west of the Knippa Gap display much less variability in water levels than wells to the east. Water entering the recharge zone in northwestern Uvalde County appears to flow through the gap to reach the main freshwater zones of the Aquifer in Medina and Bexar Counties.

Flow models for the Aquifer show groundwater flowing from Uvalde and Medina Counties east-northeast eventually discharging at Comal, Hueco, and San Marcos springs, numerous small springs, or extracted by groundwater pumping from wells. (Kuniansky *et al*. 2001). However, recent tracer studies in northern Bexar County performed by the EAA indicate water flowing from north to south with very rapid flow velocities. (Johnson *et al*. 2009). These observations indicate that flow paths may be more complex than originally thought, and rapid groundwater transport is dominated by karstic conduit flow.

Freshwater/Saline Water Interface

The freshwater/saline water interface (also known as the “Bad Water Line” or BWL) delineates the Edwards Aquifer’s eastern and southern boundaries. It is not an actual, well-defined boundary but rather a transition zone on the southern and eastern limits of the Aquifer extending from west of Kinney County through Bexar County and northward beyond the northern extent of the San Antonio region of the Aquifer. Wells to the south and southeast of this line typically display total dissolved solids (TDS) concentrations of greater than 1,000 mg/l. Wells on the other side of this line typically have TDS concentrations of equal to or less than 1,000 mg/l. The reason the “bad-water line” exists is not clear; in some places it is coincident with geologic features such as faults, in other places there is no obvious geologic control. The presence of “bad” or more saline water appears to be more associated with relative permeabilities of the Aquifer rather than a density boundary between two different water types, which commonly exists in coastal sand aquifers. Wells in the transition zone have shown sections of brackish water that overlie freshwater, which in turn overlie brackish water, indicating that the type of rock and porosity influences the salinity of the water.

It has been hypothesized that increased pumping of freshwater from the Aquifer may lead to an expansion of the bad-water zone, which could be detrimental to existing irrigation and municipal wells. In 1985, the EAA, in cooperation with USGS, TWDB, and SAWS began testing in the fresh/saline interface area for possible saline-water encroachment into the freshwater zone. In 1997, the EAA reported that there were no significant changes in water quality in the test wells between 1985 and 1997 and that normal changes in Aquifer water levels have little effect on the quality of freshwater near the interface.

3.3.1 Inter-formational flow into the Edwards Aquifer

The Edwards Aquifer receives most of its recharge directly where the limestone of the Person and Kainer Formations outcrop. However, a significant component of groundwater flow enters the Aquifer directly as inter-formational flow from the Trinity Aquifer. The recent Groundwater Availability Model for the Hill Country Portion of the Trinity Aquifer indicates that as much as 2400 acre/feet per year for each linear mile of Edwards-Trinity boundary in Bexar and Comal Counties (Jones 2011) exits the southern boundary of the GAM, indicating possible interformational flow from the Trinity aquifer in the Aquifer. This value is lower to the west in Medina and Uvalde Counties (660 ac-ft/yr/mi), and lowest further east in Hays and Travis Counties (350 ac-ft/yr/mi). Green (2011) has also demonstrated that losing streams in the contributing zone (Upper Glen Rose outcrop) are much more connected with the Edwards Aquifer than previously thought. In the Barton Springs Segment of the Edwards Aquifer, it has been shown that the Upper Glen Rose is in close hydraulic connection with the Edwards Aquifer, as documented by monitoring sophisticated multi-port wells. (Smith and Hunt, 2011). Dye tracer studies in northern Bexar County also indicate that very prolific connection between the two aquifers exists, and have documented rapid groundwater flow across faults that juxtapose the Edwards and Trinity Aquifers.

3.3.2 Groundwater Quality of the Edwards Aquifer

Rules Governing Groundwater Quality

Regulations governing the quality of groundwater in Texas have interrelated state and federal regulatory functions. In 1974, the Federal Safe Drinking Water Act was passed to protect sources of public drinking water. This Act, amended in 1996, mandated enforceable drinking water standards established by the EPA. The TCEQ has assumed responsibility for enforcement of drinking water standards in Texas and has established standards equally strict or more strict than the EPA. The Edwards Aquifer was designated as a sole source aquifer and TCEQ promulgated rules regulating development activity over zones of the Aquifer in eight counties pursuant to 30 Texas Administrative Code, Chapter 213. The counties include: Kinney, Uvalde, Medina, Bexar, Comal, Hays, Travis, and Williamson. Subchapter A applies to all regulated activities (defined as construction-related or post-construction activity) within the recharge zone, to certain activities within the surrounding transition zone that stretches along the eastern and southern boundary of the recharge zone, and to other activities that may potentially contaminate the Aquifer and hydrologically connected surface streams. Under these rules, developers must submit an application including an Aquifer protection plan to the TCEQ prior to certain types of activity in the recharge, transition, or contributing zones of the Aquifer. For proposed development including any regulated construction-related activity over the Recharge Zone, a water pollution abatement plan (WPAP) is required. The WPAP must include a geological assessment report identifying pathways for movement of contaminants to the Aquifer, and a report on best management practices and measures to prevent pollution of the Aquifer. After the plan is approved, notice must also be filed in the county deed records that the property is subject to an approved Aquifer protection plan. Certain facilities are also prohibited from being built in the recharge or transition zones such as Type 1 municipal solid waste landfills and waste disposal wells. Subchapter B applies to regulated activities in the Aquifer's contributing zone. All activities that disturb the ground or alter a site's topographic, geologic, or existing recharge characteristics are subject to regulation, which would require either sediment and erosion controls or a contributing zone plan (CZP) to protect water quality during and after construction. Exemptions include construction of single-family residences on lots larger than five acres, where no more than one single-family residence is located on each lot; agricultural activities; oil and gas exploration, development, and production under the jurisdiction of the Texas Railroad Commission; clearing of vegetation without soil disturbance; and maintenance of existing structures not involving additional site disturbance. 30 TAC § 213.22(6).

The EAA has implemented a water quality protection program through rulemaking. Well construction rules have been adopted that regulate the construction, operation, maintenance, abandonment, and closure of wells. (*See* EAA Rules Chapter 713 (Water Quality), Subchapters B General Provisions), C (Well construction, Operation and Maintenance), and D (Well Closures). The EAA also regulates the reporting of spills (Subchapter E), storage of certain regulated substances (Subchapter F) on the recharge zone and the contributing zone of the Aquifer and the installation of tanks on the recharge zone of the Aquifer (Subchapter G)). The City of San Marcos has also enacted regulations to protect water quality over the Aquifer recharge zone.

Primary Drinking Water Standards

These standards are enforceable for public water supply systems and are often referred to as maximum contaminant levels (MCLs) or primary drinking water standards. The MCL for a contaminant is the maximum permissible level in water that is delivered to any user of a public

water system. MCLs protect drinking water quality by limiting levels of specific contaminants that can adversely affect public health and are known or anticipated to occur in public water systems. The primary standards are based on concentrations published in Title 30 of the Texas Administrative Code, Chapter 290, Subchapter, and Chapter 350. This concentration is the value estimated to be protective of human health and the environment.

Secondary Drinking Water Standards

These standards are non-enforceable and are set for contaminants that may affect aesthetic qualities of drinking water, such as odor or appearance.

Current Status

The groundwater of the Aquifer has historically been considered to be of high quality, typically fresh, but hard with an average dissolved solid concentration of less than 500 mg/l (Texas Water Commission [TWC] 1992). Cooperative efforts between the EAA, USGS, and TWDB have resulted in a systematic program of water data collection. Each year the EAA monitors the quality of water in the Aquifer by sampling approximately 80 wells, eight surface water sites, and major spring groups across the region. Sample collection sites are typically selected to provide representative samples of the recharge zone, shallow and deep artesian zone, springs, and surface streams that flow across the recharge zone as well as areas with historical detection of anthropogenic compounds.

Tests for the wells included measurements of temperature, pH, conductivity, alkalinity, major ions, minor elements (including heavy metals), total dissolved solids, nutrients, pesticides, herbicides, Volatile Organic Compounds (VOCs), and other analytes.

Results of the EAA's water quality testing program during 2009 (EAA 2010a) are summarized below:

Metals

Of 79 wells sampled for metals, laboratory analyses did not indicate the presence of any metals regulated under the primary drinking-water standards at concentrations exceeding their respective MCL. However, the metal strontium, regulated under the Texas Risk Reduction Program (TRRP), was detected above the TRRP limit, or Protective Concentration Levels (PCL) in one Medina County well near the saline water zone. The PCL for strontium is 15,000 µg/L. In addition, the metals iron and manganese were detected in several wells above their secondary drinking water standards of 300 µg/L and 50 µg/L, respectively. Iron was detected in wells in Medina and Hays Counties, while manganese was detected in Medina County near the saline water zone.

Bacteria

A total of 74 wells were sampled in 2009 for the presence of fecal *streptococcus* and fecal *coliform* bacteria presence as colony forming units (CFU) per 100 milliliters of water (CFU/100 mL). Most well bacterial results were less than two CFU/100 mL in concentration. However, the fecal *coliform* bacteria results from 12 wells were at or above two CFU/100 mL. In addition, fecal *streptococcus* bacteria were detected in three wells at two, three, and six CFU/100 mL for fecal *streptococcus.* Fecal *coliform* and fecal *streptococcus* bacteria are used to indicate the possible presence of fecal matter in ground- and surface water. There are no public water supply MCLs for fecal *streptococcus*.

Nitrates

Of 79 wells sampled for nitrates, none exceeded the MCL of ten milligrams per liter (mg/L). One well indicated a concentration above five mg/L, but less than ten mg/L, while 16 wells contained concentrations at or above 2.0 mg/L.

Volatile Organic Compounds (VOCs)

Water samples collected from 78 wells were analyzed for VOCs. Three VOC compounds were detected in well samples during the year—toluene, chloroform, and chloromethane. However, none of the detections exceeded their respective MCLs.

In 2004, contaminated ground water was discovered in Leon Valley in northwestern San Antonio during an environmental investigation conducted by the TCEQ. This area, which has been designated as the Bandera Road Ground Water Plume Superfund site, is located in a mostly commercial area near Bandera Road between Poss Road and Grissom Road. Some homes are also located nearby. Major ground water contaminants include toluene and chlorinated solvents, such as tetrachloroethene (PCE), trichloroethene (TCE), and cis-1,2-dichloroethene (DCE). (EPA 2007). In 2007, the site was placed on the final National Priorities List. The EPA has been investigating the site to monitor the pollutants and identify sources of the contamination.

Semi-volatile Organic Compounds (SVOCs)

One well was sampled for SVOCs, with none detected.

Pesticides, Herbicides, and PCBs

Well water samples collected from 59 wells were analyzed for pesticides, herbicides, and polychlorinated biphenyls (PCBs). None tested positive for these contaminants.

In summary, well sampling did not indicate widespread contamination in the Aquifer. However, elevated nitrate detections (greater than two mg/L) were present in 16 of the 79 wells sampled. Metals were detected above a regulatory limit in several of the 79 wells sampled. Detections of the metals strontium and iron are likely due to naturally occurring sources of these two metals. Strontium detections are typically highest in and close to the saline water part of the Aquifer. Iron detections are occasionally high in some parts of the Aquifer system.

Although the quality of the water in the Aquifer is generally good, man-made contaminants, such as pesticides and solvents, have been found in streams that recharge the Aquifer, and in the Aquifer itself. Most of the contaminants are found in urbanized areas, and most of them appear to be derived from non-point sources.

Examples of pesticide and solvent detections include:

- Pesticides in Lorence Creek (USGS 1999). This stream recharges the Aquifer in Bexar County.
- Atrazine in Leon Creek (Edwards Aquifer Authority 1999). This stream recharges the Aquifer in Bexar County.
- Atrazine in Aquifer recharge zone monitor wells, Bexar County (EAA 2009b; USGS 2000).

- PCE in San Antonio Water System Dreamhill well, Bexar County (SAWS 1996-2009).

In the great majority of cases, concentrations of pesticides and solvents are far below the levels that have been established to protect human health. Thus, while the presence of these contaminants is cause for concern, it is not cause for alarm.

3.3.3 The Edwards Aquifer Water Budget

Water levels of the Aquifer and associated flows of Comal and San Marcos springs are affected by the rate of water entering the Aquifer (recharge) and the rate of water exiting the Aquifer (discharge). Recharge occurs from water entering the Aquifer from streams, natural catchments, recharge structures, localized runoff from precipitation events, and from subsurface flow from adjacent aquifers. Seasonal rainfall over the region ultimately controls the rate of recharge. Discharge occurs from withdrawal of water from wells and from flow of natural springs and seeps. An unknown smaller quantity is discharged to the saline water zone (USGS 1995). Discharge is greatly affected by water demand and rate of pumping. If recharge is high, the Aquifer can sustain higher levels of pumping, while maintaining higher levels of springflows. However, if there is low seasonal recharge followed by reduced rainfall and by high rates of pumping, then Aquifer levels will decline with resulting decreased spring discharge. Historic recharge and discharge of the Aquifer and effects to springflow are discussed below.

Groundwater Recharge

Estimates of the average annual recharge of the Aquifer vary according to changes in weather cycles and resulting precipitation over the recharge and contributing zones. The USGS (1995) cites an average annual recharge of 635,000 ac-ft. However, Klemt *et al*. (1979) indicate an average annual recharge of approximately 651,000 ac-ft. Data from the EAA's 2009 Hydrogeologic Data Report (EAA, 2010b) indicate an average annual groundwater recharge of 717,500 ac-ft for the period of record 1934-2009, and an even higher annual average of 965,400 acre-feet during the last ten year period 2000-2009. Contributions of the major river basins to the average annual recharge during the period of record 1934-2009 are listed in Table 3-5.

TABLE 3-5
CONTRIBUTIONS OF MAJOR RIVER BASINS TO AVERAGE ANNUAL RECHARGE OF THE EDWARDS AQUIFER, 1934–2009

Area	Average Annual Recharge (acre-feet)
Frio River–Dry Frio River Basin	139,700
Nueces River–West Nueces River Basin	127,400
Area between Sabinal River and Medina River Basins	112,700
Cibolo Creek–Dry Comal Creek Basin	112,100
Area between Medina River and Cibolo Creek–Dry Comal Creek Basins	72,800
Medina River Basin	63,000
Blanco River Basin	46,900
Sabinal River Basin	42,900
TOTAL	717,500

SOURCE: EAA 2010b.

Recharge to the Aquifer varied greatly during the years 1934-2009 as indicated in Figure 3-17. Variability was correlated with annual precipitation and corresponding runoff into the major river and creek basins. Lowest annual recharge (44,000 ac-ft) occurred during 1956 at the peak of the drought of record. Highest recharge (2,486,000 ac-ft) occurred in 1992. Rates of infiltration of water carried by the streams across the recharge zone have been estimated by the USACE

(1965) to range from 500 to greater than 1,000 cfs. Recent modeling studies using the Hydrologic Simulation Program Fortran (HSPF) indicate that land-based recharge outside of stream channels across the nine basins varies from a low of two percent to a high of 76 percent (EAA 2010b), whereas 24 to 98 percent of recharge across the nine basins occurs in stream channels as channel loss (LBG Guyton Associates, 2005). In addition, some recharge to the Aquifer originates from inter-formational flow from adjacent aquifers such as the Trinity Aquifer. Recent studies by Green and Bertetti (2010) indicate that a substantial volume of water directly enters the Aquifer through cross-formational flow from water recharged into the Trinity Aquifer (Glen Rose Limestone). Dye tracing conducted by the EAA in northern Bexar County suggests rapid and direct groundwater flowpaths from the Trinity to the Edwards Aquifers (Johnson *et al*. 2009). Estimates of the contribution from adjacent hydraulically-connected aquifers have been estimated by the EAA (2010a) to vary from 5,000 to 60,000 ac-ft/yr.

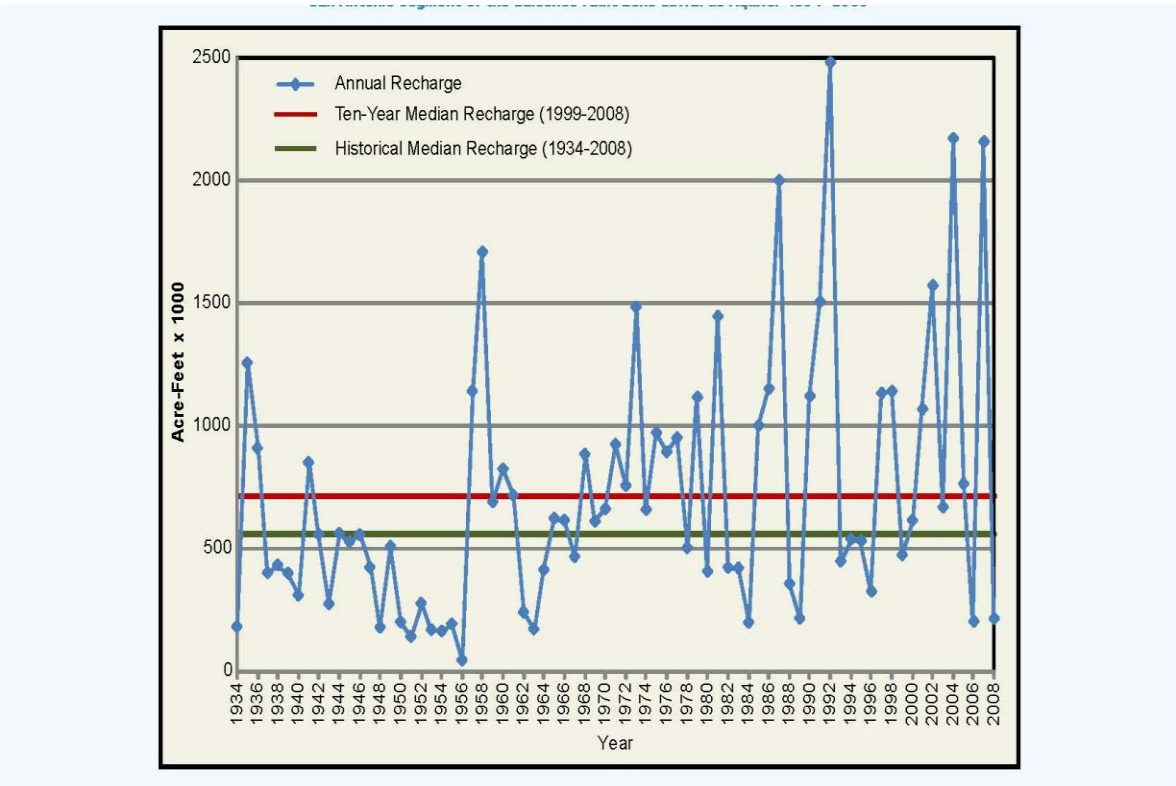


Figure 3-17. Estimated annual recharge and 10-year floating average recharge for the San Antonio Segment of the Edwards Aquifer 1934-2008 (EAA 2010a).

Groundwater Discharge

Water is diverted from the Aquifer through wells, and also exits from natural springs and seeps occurring near geological faults along the Edwards formation and Balcones Escarpment. Wells are the principal source of water for agricultural, municipal, and industrial uses in the region. Depths of wells range from less than 500 feet in the unconfined Aquifer to more than 3,000 feet in the confined Aquifer in the western region (USGS 1995). Wells in the area can be very large,

with casing diameters ranging from 10 to 30 inches and capable of pumping in excess of 35,000 gallons per minute. Average annual discharge from wells over the period of record 1934-2009 was 311,400 ac-ft (44.7 percent of all discharge), in comparison to 384,400 ac-ft (55.3 percent) from springflow. During droughts, the proportion of well discharge to spring discharge changes considerably. During 1956 at the height of the drought of record, wells contributed 82 percent of the discharge in comparison to 18 percent for springs. During the drought of 2008, wells contributed 51 percent of the total discharge, while spring discharge comprised 49 percent. Values for average and median discharge are provided in EAA (2010b).

Well discharge has generally increased over the period of record to a point beginning in 1968 and running through 1989 where annual discharge consistently exceeded the average annual recharge (USGS1995). Pumping peaked in 1989 at an estimated level of 542,000 ac-ft. Since 1980, as a result of increased pumping, there has been greater fluctuation of springflow with increased time required for recovery, even during a period that recorded the two highest levels of Aquifer recharge (1992 and 2004). Examination of Figure 3-18 indicates increases in pumping beginning in 1982, 1987, and 1996, resulting in higher fluctuation of springflow.

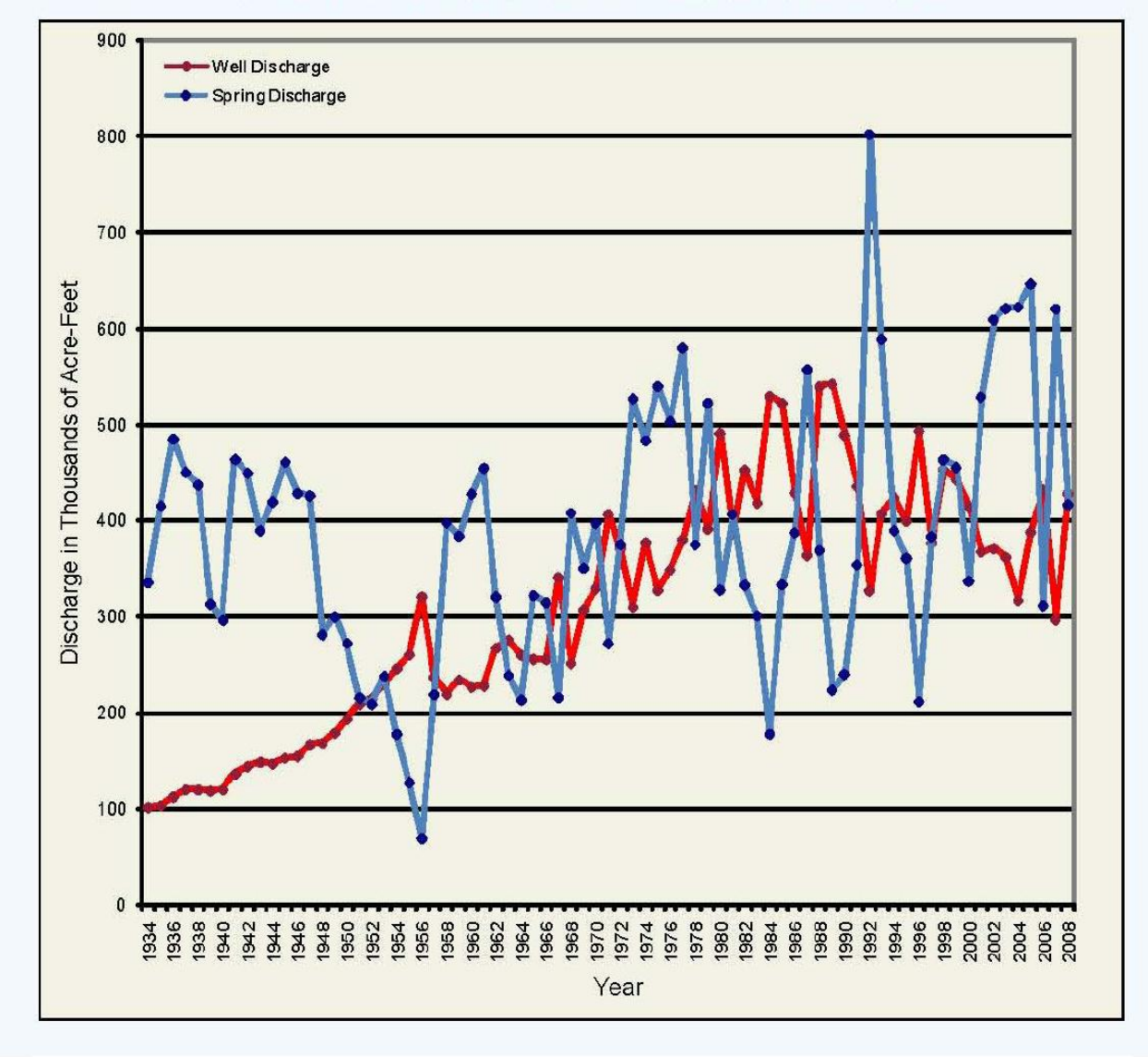


Figure 3-18. Groundwater pumping compared to springflow from the Edwards Aquifer 1934-2009 (EAA 2010a)

3.4 The Edwards Aquifer, Comal Springs, and San Marcos Springs

The Aquifer and associated springs (Comal Springs, San Marcos Springs, Hueco Springs, and Fern Bank Springs) are unique aquatic ecosystems containing some of the greatest diversity of groundwater and spring-associated species in the world. (Culver and Sket 2000, Holsinger and Longley 1980, Longley 1981; Reddell 1994).

3.4.1 Edwards Aquifer Ecosystem

The Aquifer lies within the Balcones Fault Zone along the eastern boundary of the Edwards Plateau and extends from a groundwater divide in Kinney County through San Antonio northeast to Bell County. The recharge zone occurs in the Balcones Fault Zone at the Aquifer outcrop. Groundwater levels typically have seasonal and weather-related variations, with the potential for rapid changes in water level following

heavy rainfall. While groundwater levels can change rapidly, water temperatures and quality remain constant in the absence of contamination events (McKinney and Sharp 1995). The focused recharge, enhanced cavernous porosity, and geochemical water quality conditions makes this one of the most productive groundwater reservoirs in the country (Sharp and Banner 1997), and may be one of the most biologically diverse karst aquifers in the world. Culver *et al*. (2003) showed that patterns of biodiversity were positively correlated with the number of caves and distance from the late Cretaceous Sea (among other things), which may account for the diversity of Texas caves.

The Aquifer supports a highly adaptive biological assemblage that differs considerably from spring ecosystems. However, the hydrology of the Aquifer is directly related to the surface water ecosystems as water in the springs flows from the Aquifer at the base of the Balcones Escarpment (McKinney and Sharp 1995). Therefore, the systems are intertwined by components of water quantity, quality and thermal conditions, while separate with respect to biological organisms that directly rely on sunlight and surface energy.

A high diversity of species are found only within the Aquifer and associated springs and karst formations, including blind catfish, salamanders, aquatic crustaceans, and terrestrial cave invertebrates. In a study investigating the occurrence of Aquifer biota from 33 wells and two springs in Bexar County, Karnei (1978) reported 18 aquatic species taxonomically representing three phyla, three classes, and seven orders of organisms. Several species are listed by the USFWS as endangered or threatened, or have been proposed for listing (*see* Section 3.5).

3.4.2 Comal Springs Ecosystem

The Comal Springs ecosystem (Figures 3-19a and b) is the largest spring system in Texas and in the southwestern United States, originating from the Aquifer and located mainly in Landa Park in New Braunfels, Comal County. The system is comprised of four major springs and several smaller spring runs that feed into Landa Lake. The spring runs and Landa Lake form the headwaters of the Comal River, the shortest river in Texas, which spans 3.1 miles before its confluence with the Guadalupe River. From Landa Lake, water flows into two channels, the original “old” channel and a “new” channel created in 1847 when the river was dammed and the millrace was excavated by hand to provide water for William Merriweather’s saw and grist mill. The two channels then rejoin 1.6 miles downstream. (McKinney and Sharp 1995).

The Old Channel retains many of its natural characteristics even though there are some small dams and channelization. Schlitterbahn, a water theme park, diverts some of the springflow in the Old Channel. The New Channel has a more uniform width and in some areas, a limestone bottom. Several dams have been constructed on the New Channel, to control overflow, as well as several parks and recreational tube chutes (McKinney and Sharp 1995). The city of New Braunfels withdraws some of the springflow in the New Channel for irrigation purposes. The physical, chemical, and biological characteristics of the Comal Springs and Comal River ecosystem have been recently evaluated to develop an understanding of alternative instream flow strategies for the protection of Covered Species. (Hardy *et al*. 1999; BIO-WEST 2002b; Hardy 2009).

Comal Springs has the largest mean discharge of any spring in the southwestern United States, averaging 275 cfs in 1928–1972 (George *et al*. 1952; Edwards Underground Water District 1974). From June until November of 1956, the artesian flow at the springs ceased flowing. Around this same time, all known major springs in the Balcones Fault Zone ceased flow except for San Marcos Springs (U.S. Army Corps of Engineers 1965). This system exhibits near-constant temperatures (annual mean 74.1°F or 23.4°C), excellent water quality, and low nutrient and bacteria levels (USFWS 1996a). Over the years, extensive urban development along the banks, channel modification, and the natural variability of the springs has resulted in biological community alterations (EH&A 1975). The Comal River has also been affected by recreational activities along the banks including the afore-mentioned network of parks and tube chutes. (McKinney and Sharp 1995).

Several organisms occurring in the Comal Springs ecosystem are listed by the USFWS as threatened or endangered. The listed species will be discussed in further detail in Section 3.5.

Figure 3-19a
Comal Springs
Ecosystem
Vicinity Map
Spring Run Number
Critical Habitat Zone:
- Comal Springs Dryopid Beetle (Stygoparnus comalensis)
- Comal Springs Riffle Beetle (Heterelmis comalensis)
- Peck's Cave Amphipod (Stygobromus peckii)
Plate 1
N
0 250 500 Feet
HICKS & COMPANY
ENVIRONMENTAL
ARCHEOLOGICAL
AND PLANNING
CONSULTANTS
Bliders Creek
Houston
Union
Terrey
Schlitterbahn
Old Channel
San Antonio Street
Landa Park
Elizabeth
Edgewater
Spring Island
Pecan Island
Landa Lake
Lakeview
California
Panther Canyon Well
1
2
3
4

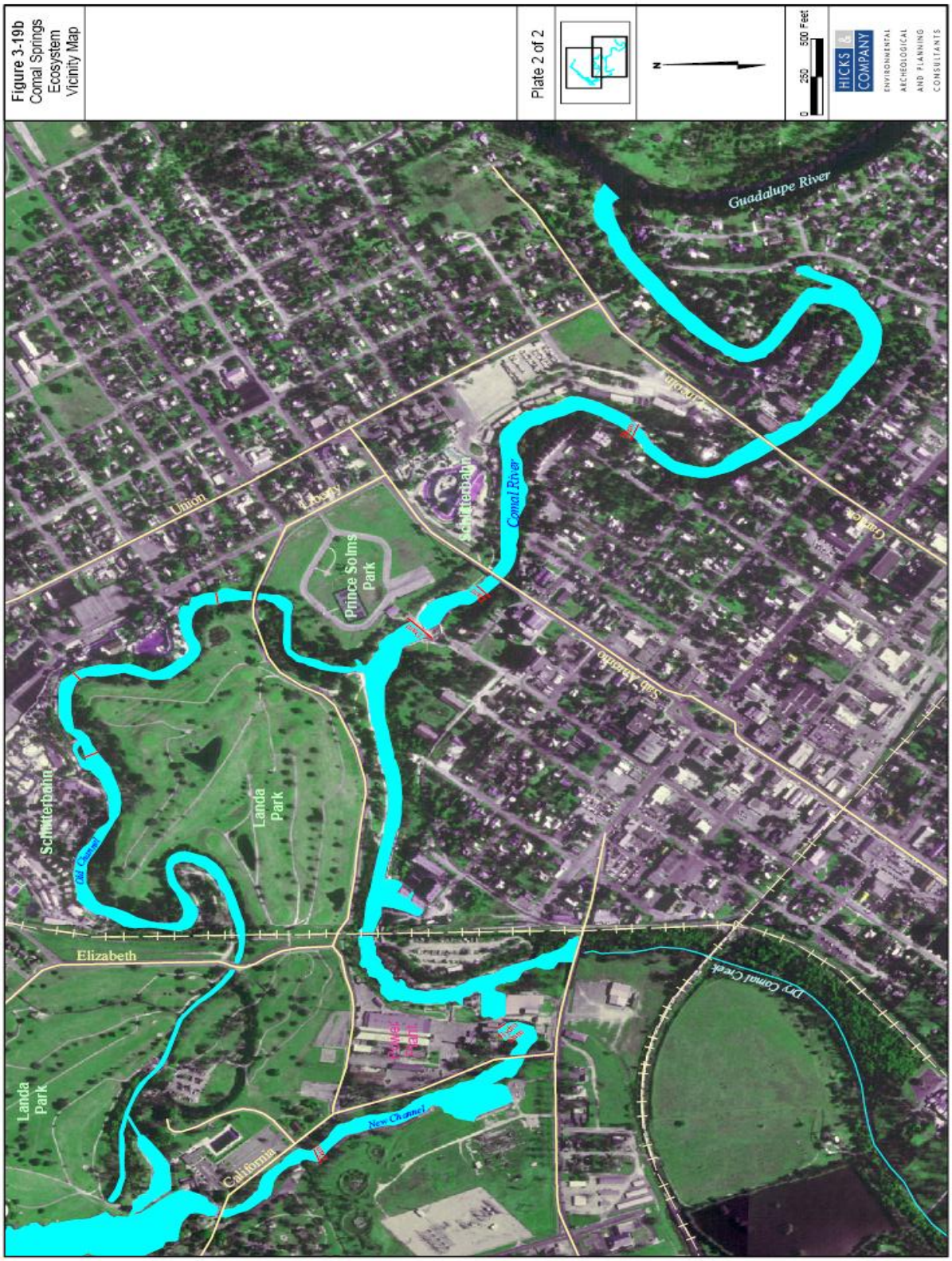


Figure 3-19b
Comal Springs Ecosystem Vicinity Map

3.4.3 San Marcos Springs Ecosystem

The San Marcos Springs ecosystem (Figures 3-20a-c) is the second-largest in Texas and has the most environmental stability and flow reliability of any spring system in the southwestern United States (USFWS 1996a). This spring system has never stopped flowing in recorded history, although it dropped to approximately 46 cfs during the drought of record occurring in the 1950s. The average discharge from the San Marcos Spring system from 1994 through 2001 was180 cfs (Edwards Aquifer Authority 2002a) and the stability of its springflow helps support the rare flora and fauna found in Spring Lake and in the San Marcos River.

Spring Lake constitutes the headwaters of the San Marcos River, which extends 68.2 miles to its confluence with the Guadalupe River. Temperatures remain nearly constant year-round at 71.1°F (21.7°C) (USFWS 1996a). The biological uniqueness and high degree of endemism found in Spring Lake and in the upper San Marcos River can be attributed to its thermal stability, reliable flow, and consistent water chemistry (USFWS 1996a). Lemke (1989) documented 31 species of aquatic macrophytes (plants large enough to be seen with the naked eye) on the upper San Marcos River. Of these, 23 were native. Increasing competition with non-native species and resulting displacement of native species was noted. A recently observed new non-native species in the San Marcos Springs ecosystem, water trumpet (*Cryptocoryne becketti*), has been observed forming colonies that extend from bank to bank excluding native plant species and threatening the habitats of Texas wild-rice and fountain darter. (Tu 2010). Construction and residential development continues to occur along the San Marcos River, although historically to a lesser degree than along the Comal River. (EH&A 1975). As with the Comal River, the San Marcos River is a haven for recreational activities.

Upstream flood control dams within the watershed of the San Marcos River have enhanced recharge to the Aquifer by allowing water behind the dams, which would have gone downstream as irretrievable rapid flow, to infiltrate and contribute to the recharge system. Hydrologically, these dams have also reduced the magnitude of scouring flood events downstream, allowing an accumulation of sediments and resultant non-native vegetation encroachment. The San Marcos River has experienced increased sedimentation, which occurs when the sediment supply exceeds the ability of flood events to remove the sediment supply. A recent study was conducted (Earl and Wood 2002) which analyzed the impacts of upstream changes in the San Marcos River. It was found that a major source of the sediment is provided by Sessoms Creek, which receives runoff from the Texas State University campus. Based upon a density of 2.0 g/cm^3, the sediment production rate from campus construction over three years of construction activities that began in 1995 would produce an annual sedimentation accumulation in the channel of the San Marcos River of 16 cm/year (6.3 inches per year). Construction on campus has continued since 1998 and it is likely that similar rates of sedimentation have occurred during this time. Projected through 2004, there would have been a total accumulation of 4.7 feet in the upper 273 yards (250 meters) of the San Marcos River channel in the nine years between 1995 and 2004. While these numbers likely have some error associated with them, it is clear that

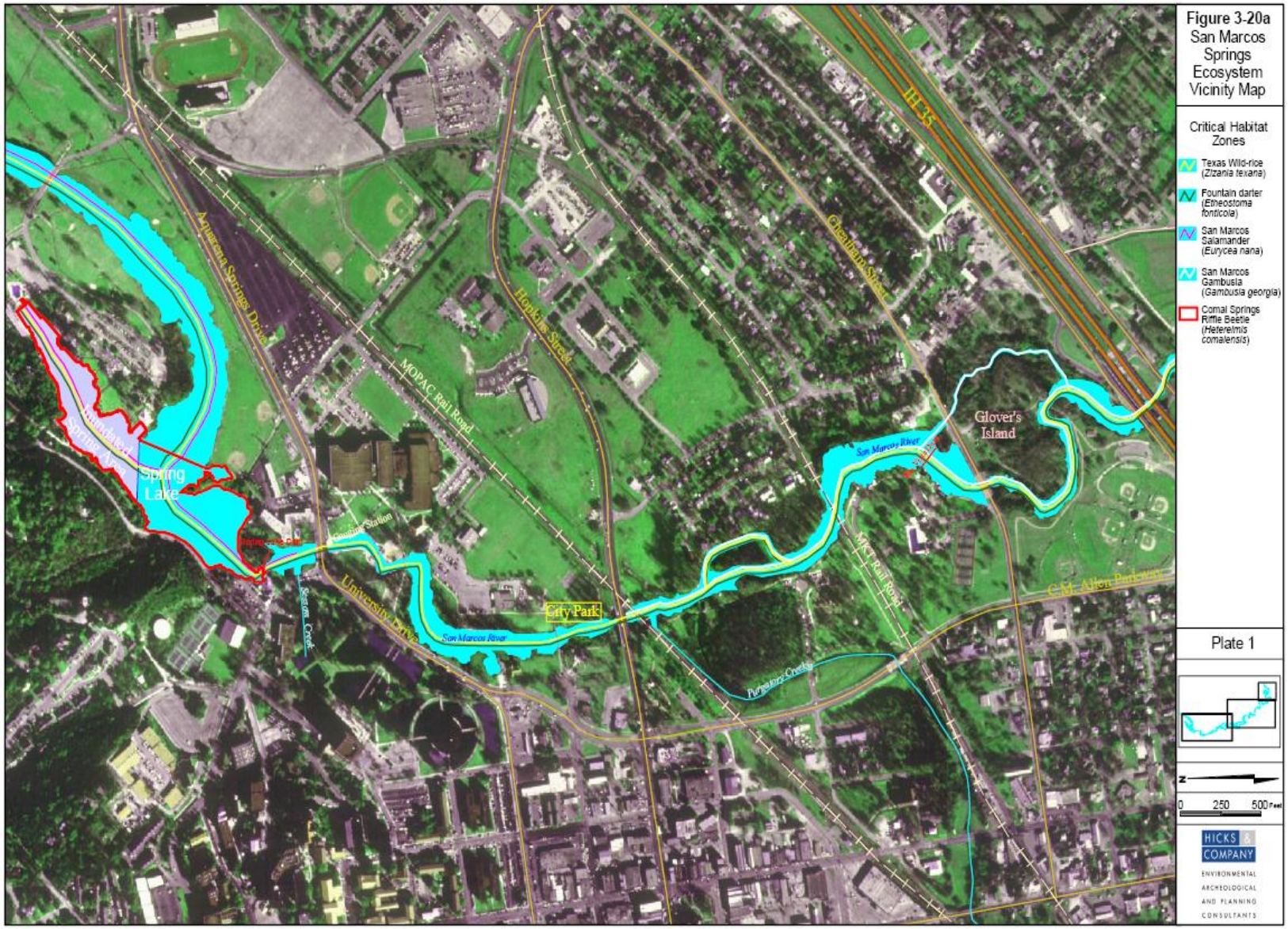


Figure 3-20a
San Marcos Springs Ecosystem Vicinity Map
Critical Habitat Zones
Texas Wild-rice (Zizania texana)
Fountain darter (Etheostoma fonticola)
San Marcos Salamander (Eurycea nana)
San Marcos Gambusia (Gambusia georgia)
Comal Springs Riffle Beetle (Heterelmis comalensis)
Plate 1
0 250 500 Feet
HICKS & COMPANY
ENVIRONMENTAL ARCHEOLOGICAL AND PLANNING CONSULTANTS
Spring Lake
Glover's Island
City Park
San Marcos River
University Drive
MOPAC Rail Road
Hopkins Street
Cheatham Street
Aquarena Springs Drive
C.M. Allen Parkway
MKT Rail Road
Purgatory Creek
Sessom Creek
Coating Station

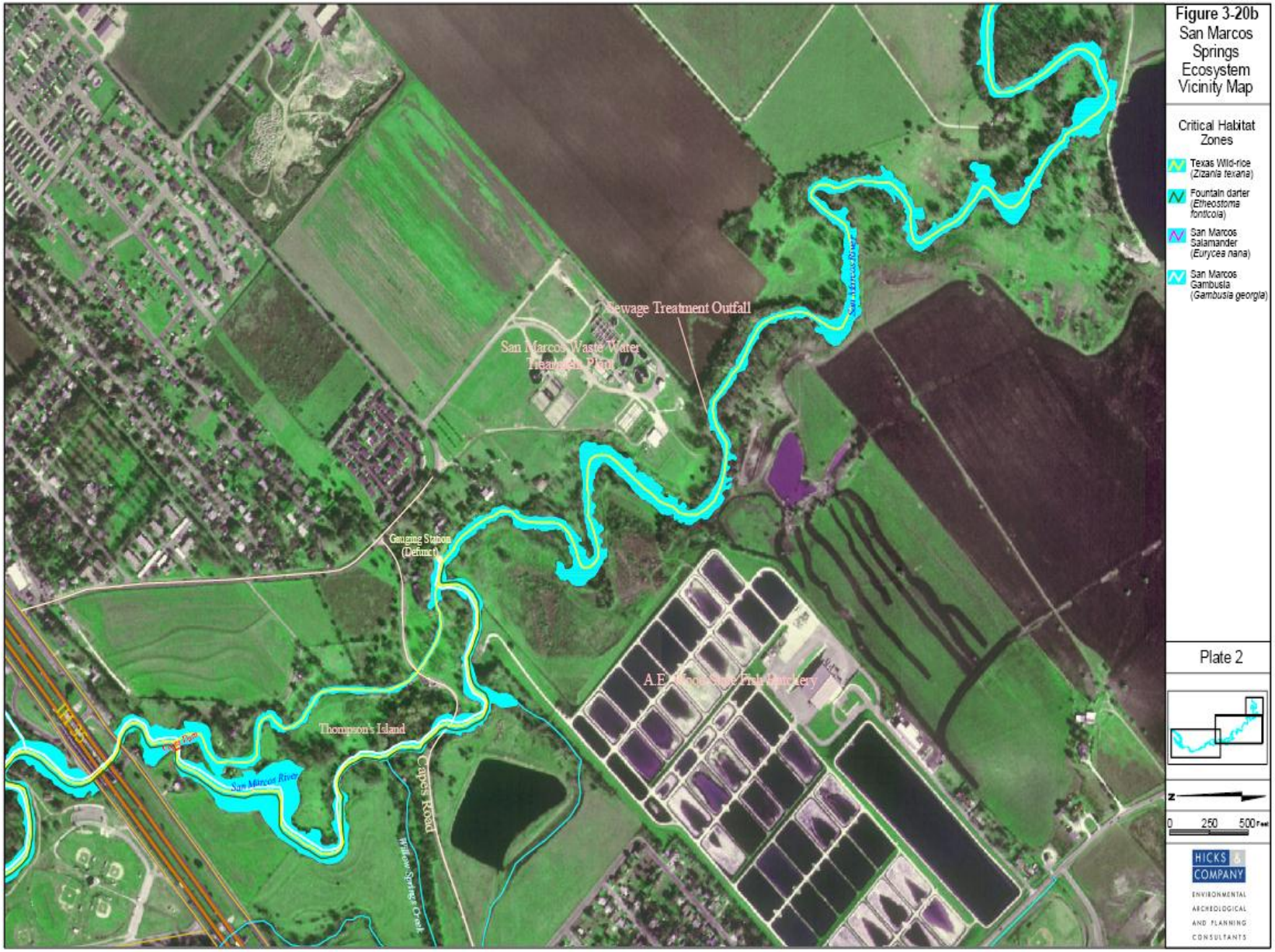


Figure 3-20b
San Marcos Springs Ecosystem Vicinity Map

Figure 3-20c San Marcos Springs Ecosystem Vicinity Map

sediments are accumulating at a high rate and that even significant floods are unable to erode and transport them.

Sediments transported downstream in Sessoms Creek alter the depth and width of the San Marcos River channel where they are deposited. They are deposited in areas that are critical to Texas wild-rice, covering the streambed's natural substrate with materials from outside of the aquatic ecosystem that are not optimum substrate for native plant species. The sediments act as fill in the natural channel, making the channel downstream more shallow than what would otherwise be natural, creating a spit that extends about half way across the San Marcos River at the confluence with Sessoms Creek, about forty yards downstream of Spring Lake Dam.

Since flood control measures on the San Marcos River have prevented large, scouring floods from occurring, the deposited sediments remain near the confluence of Sessoms Creek and the San Marcos River. The sediments impact Texas wild-rice by covering plants growing in the natural substrate and causing other plants to grow in a less than optimum substrate. The plants that do grow in the sediments are prone to being washed out or having their root masses exposed during high flow events. During low flows, the plants are unnaturally close to the surface of the stream, rather than being safely located in a deeper channel. The location in unnaturally shallow water makes Texas wild-rice more vulnerable to drought, low flow conditions, herbivores, and recreation. The end result is that more water is needed to maintain water depths necessary to minimize impacts to the threatened and endangered species and their habitat.

Even the 1998 flood event, during which the peak flow was 21,500 cfs (USGS 1999), was unable to erode and transport this sediment deposit. This analysis may provide insight on the inability of future floods to remove sedimentation deposits. The increased sedimentation could potentially be reduced through a variety of measures such as the implementation of sediment check dams, efforts to reduce erosion, increasing the amount of flow passed through the flood control dams, and the reduction of non-native vegetation. However, each of these efforts could have adverse effects on a variety of features within this aquatic ecosystem. Several organisms occurring in the San Marcos Springs ecosystem are listed by the USFWS as either threatened or endangered, candidates, or proposed for listing, and additional species, though rare, are afforded no official protection status. The threatened and endangered species will be discussed in further detail in Section 3.5. Flows of San Marcos Springs have been recently evaluated to better understand the water quantity and quality needs of the spring ecosystem. (Saunders *et al*. 2001; BIO-WEST 2003b).

Hueco Springs Ecosystem

Hueco Springs is located in Comal County approximately four miles north of New Braunfels. This spring complex consists of two main groups of springs issuing from the floodplain of the Guadalupe River. Hueco I (Hueco A) is a large, typically perennial spring on the west side of River Road in an undeveloped area and Hueco II (Hueco B) is an intermittent spring on the east side of River Road, located in a campground. Hueco Springs has a local recharge component which could be enhanced by strategically placed recharge dams (Barr 1993). Fauna recorded from this site includes the Elmid beetle *Microcylloepus* sp., and the water penny beetle, *Psephenus texanus*, surface dwelling amphipods, oligochaetes, caddisfly larvae, crayfish, clams snails, aquatic isopods, three species of copepod (*Acanthocyclops vernalis, Mesocyclops edax* and *Skstodiaptomus* sp.), hypogean amphipods (*Stygobromus russelli*) (Zara 2003), an aquifer salamander (possibly *Eurycea rathbuni*), and the federally listed Peck's Cave amphipod *Stygobromus pecki* (Barr 1993).

Fern Bank Springs Ecosystem

Fern Bank Springs is a series of small perennial springs and seeps that flow from the base of a bluff on the south bank of the Blanco River in Hays County. While the source of the water for Fern Bank Springs is undetermined, it may originate from the upper member of the Glen Rose Formation, from drainage from the Aquifer recharge zone, from water lost from the Blanco River, or from some combination of those sources (USFWS 2007). A recent dye tracer study performed by the EAA showed a connection from a sinkhole in the Edwards. (EAA 2010a). The springs themselves have been minimally altered, except for the installation of water collection containers below the spring orifices and an intake box and pipes near the uppermost orifice, where a pool inside of a small cave was previously utilized as a source of drinking water. A small orifice on the hillside to the east of the uppermost orifice is a known locality for Comal Springs dryopid beetle. Other taxa known from the site include hypogean amphipods (*Stygobromus russelli*), the spring-associated Fern Bank salamander *Eurycea pterophila,* and several aquatic epigean species. Fern Bank Springs is designated as Critical Habitat for the Comal Springs riffle beetle, Comal Springs dryopid beetle, and Peck's cave amphipod. (72 FR 39,247 (July 17, 2007)).

3.5 Listed Species Covered by the ESA Section 10(a)(1)(B) Incidental Take Permit

Eight species are currently listed as endangered or threatened by the USFWS that depend entirely on the Aquifer and associated springs. Incidental take may be allowed for seven of these species if covered by an ESA Section 10(a)(1)(B) Permit. The ESA does not prohibit take of listed plants except on federal lands [16 U.S.C. § 1532(8) and § 1532(14)]. Additionally, although the last known sighting of the San Marcos gambusia from the San Marcos River occurred in 1983 and the species is now thought to be extinct (McKinney and Sharp 1995), this species is nonetheless proposed for incidental take coverage in the HCP.

Listed species addressed in the HCP (and date of listing) include:

Endangered

- Fountain darter (Etheostoma fonticola) (35 FR16,047 (Oct. 13, 1970))
- Comal Springs riffle beetle (Heterelmis comalensis) (62 FR 66,295 (Dec. 18, 1997))
- Comal Springs dryopid beetle (Stygoparnus comalensis) (62 FR 66,295 (Dec. 18, 1997))
- Peck's Cave amphipod (Stygobromus pecki) (62 FR 66,295 (Dec. 18, 1997))
- Texas wild-rice (Zizania texana) (43 FR 17,910 (Apr. 26, 1978))
- Texas blind salamander (Eurycea [formerly Typhlomolge] rathbuni) (32 FR 4,001 (Mar. 11, 1967))
- San Marcos Gambusia ((Gambusia georgei) (35 FR 16047 (Oct. 13, 1970))

Threatened

- San Marcos salamander (Eurycea nana) (45 FR 47,355 (July 14, 1980))

A brief life history of each species covered in the HCP is provided below.

3.5.1 Fountain Darter (*Etheostoma fonticola*)

The fountain darter, a member of the family *Percidae*, is endemic to the San Marcos and Comal rivers. This species was first collected in 1884 in the San Marcos River just below its confluence with the Blanco River and in 1891 in the Comal River (Schenck and Whiteside 1976). The historic range of this species on the San Marcos River extends from Spring Lake downstream to just below its confluence with the Blanco River, and in the Comal River from the headwaters downstream to its confluence with the Guadalupe River (Schenck and Whiteside 1976). Currently the fountain darter can be found in the upper portions of the Comal River including Landa Lake and in the San Marcos River system from Spring Lake downstream to the outfall of the San Marcos City wastewater treatment plant. (McKinney and Sharp 1995; Schenck and Whiteside 1976).

Between 1954 and 1973, the original population of fountain darters was extirpated from the Comal River (Linam *et al*. 1993; Schenck and Whiteside 1976). It is believed that a combination of a rotenone treatment by the Texas Fish, Game, and Oyster Commission in 1951 [to remove non-native Rio Grande cichlids (*Cichlasoma cyanoguttatum*)], temperature variations due to the springs ceasing to flow for a six-month period in 1956, and a flood from Blieders Creek in 1971 all contributed to the die off of the fountain darter. (Linam *et al*. 1993; Schenck and Whiteside 1976). Beginning in 1975, a total of 457 fountain darters from San Marcos were re-introduced into the Comal River, from which the present Comal population is descended. (Linam *et al*. 1993; Schenck and Whiteside 1976).

Fountain darters are small (usually <1.0 inch), olive-green in color, with dark markings along the lateral line, dark spots at the base of the tail, opercule, dorsal fin, and around the eye. (Gilbert 1887; Schenck and Whiteside 1976). Competing theories have been reported in the literature regarding the wild fountain darters reproductive cycles; some researchers support continuous spawning (Strawn 1955, Hubbs 1985) while others have noted seasonal peaks in reproductive activity. (Schenck and Whiteside 1977b). Fecundity is believed to be lower in fountain darters than other species of darters and appears to be controlled by both environmental and genetic factors including the influence of repeated spawnings throughout the year. This species exhibits sexual dimorphism, with the males having four morphological forms differing in size, color, and shape. (Schenck and Whiteside 1977b). Females deposit eggs in aquatic vegetation which are then fertilized by breeding males that produce a small amount of transparent milt (sperm). (Hubbs 1958). Little or no parental care is provided to the eggs or young. (Schenck and Whiteside 1977b). Young fountain darters are restricted to the stream bottom in pools until they have grown enough to swim through currents. (Collette 1965; Strawn 1955).

Fountain darter habitat requirements include clear, clean, flowing, and thermally constant waters, adequate food supply, undisturbed sand and gravel substrates, rock outcrops, and areas of submergent vegetation (algae, moss, vascular plants) for cover. (McKinney and Sharp 1995; Schenck and Whiteside 1977a; USFWS 1996b). BIO-WEST studies utilizing drop-net techniques have documented the highest densities of fountain darters in filamentous green algae (*Rhizoclonium* sp.) and the moss *Riccia* (BIO-WEST 2003a, 2003b) and rarely in areas devoid of vegetation (Schenck and Whiteside 1976; USFWS 1996b). Young fountain darters are found in heavily vegetated areas with low flows, while adults can be found in all suitable habitats (Schenck and Whiteside 1976). This strong preference for aquatic vegetation highlights the concern posed by the grazing activities of the afore-mentioned giant rams-horn snail.

Critical habitat for the fountain darter has been designated at Spring Lake and its outflow, and the San Marcos River downstream to 0.5 mile below the IH-35 bridge. (45 FR 47355, 47364 (July 14, 1980)). Fountain darters appear to have adapted to a relative narrow temperature

range at the downstream edges of their available habitat. Water temperature is a concern and laboratory studies have shown a significant decrease in reproductive capacity above 26°C (Brandt *et al*. 1993, Bonner *et al*. 1998, McDonald *et al*. 2007) and a critical thermal maximum of 34.8°C (Brandt *et al*. 1993). A more recent study conducted by BIO-WEST (2002c) and Dr. T.H. Bonner has discounted the hypothesis that the 2°C diel fluctuations that occur in the wild have a significant impact on earlier findings. Regardless, these ranges in temperature tolerance observed in the laboratory are similar to other species with "wider geographic and thermal distributions." (Bonner *et al*. 1998).

Food sources for fountain darters consist of copepods, aquatic insect larvae, and amphipods. (McKinney and Sharp 1995; Schenck and Whiteside 1977a). Generally small aquatic invertebrates are the preferred food item; however, type and amount of food consumed changes with growth of the fish. (Schenck and Whiteside 1977a). The food sources of fountain darters are different in Spring Lake and the San Marcos River since the invertebrate communities are different and darters eat what is present and suitable in their environment. Fountain darters feed based on visual cues, primarily during the day, and are stationary feeders; waiting for their prey to come to them. (USFWS 1996b; Schenck and Whiteside 1976).

Population estimates of the fountain darter are difficult to make because of its small body size, the range of sampling methods used in the past and the difficulty in accounting for all of the habitat dynamics in calculations. Prior to 1974, no collections gave any indication of the population abundance. When the rotenone treatment occurred in Landa Lake in 1951, an unknown number of fountain darters, along with other native fishes were seined, held in a protected area until the rotenone dissipated, and subsequently reintroduced (Ball *et al*. 1952). The stress imposed by this event likely reduced the fountain darter population in the Comal River. The collection by Hubbs and Strawn (1957) that occurred between the rotenone poisoning and the zero springflow conditions in 1956 only indicated that the species was still present, not how many were there. Since that time, despite the difficulties, a few attempts have been made to estimate the population abundance in the San Marcos and Comal rivers. Schenck and Whiteside (1976) estimated the total population in the San Marcos River at 103,000 but did not provide a confidence range and the authors cautioned that the estimate was not the primary focus of their study. They also estimated 339 fountain darters within a small portion of Spring Lake. As part of that study, Schenck and Whiteside (1976) spent 300 person-hours between March 1973 and February 1975 sampling the Comal River but did not collect any fountain darters there. After the fountain darters were reintroduced into the Comal River in 1975 using individuals from the San Marcos River, the population became re-established in the former. In 1990, Linam *et al*. (1993) estimated the total abundance of fountain darters in the San Marcos River (excluding Spring Lake) to be 45,900 individuals with a 90 percent confidence interval of 15,900 to 107,700. Recent observations in Spring Lake (BIO-WEST 2003a, 2003b) suggest that fountain darter densities are much higher there than in downstream areas and a population estimate that included the lake would be significantly higher. The Linam estimate was calculated using different methods of capture than those used by Schenck and Whiteside (1976) which limits comparisons; however, the earlier estimate falls within the range described by Linam *et al*. The Linam *et al*. study also estimated the mean population for the Comal River upstream of Torrey Mill Dam at 168,078 with 95 percent confidence limits of 114,178 and 254,110.

The wide confidence intervals for these population estimates indicate the difficulty in developing them with any real confidence. There are a large number of factors that influence the population that are difficult to account for in a single sample effort. In addition, the fountain darter is short-lived and highly fecund which allows it to respond quickly to changes in habitat availability. Therefore, estimates of population abundance may have changed by the time the

estimates are published. Population estimates have not been generated from sampling associated with the Variable Flow Study but the study has documented high densities of fountain darters in the Comal and San Marcos springs/river ecosystems recently. (BIO-WEST 2003a, 2003b). That study has shown that there is a wide range of habitat suitability among species of aquatic vegetation. Using vegetation composition (high, moderate, and low habitat suitability) may be a more accurate means of estimating the current status of the fountain darter population than developing population estimates.

Recently, there has been an increase of parasitism in the fountain darter, especially in the Comal River. The most serious threat comes from the trematode hosted by the red-rimmed melania, which attacks the gills of the fountain darter causing reddening, swelling, and bleeding. The immune system of the fountain darter is sufficient to rid its body of the trematode, but not until the damage has already been done. (BMWD 1998; Fuller and Brandt 1997). Some of the concerns of the impact of this parasite are increased stress, reduced ability to avoid predators, and reduced reproductive capabilities. Recent laboratory studies suggest; however, that the trematodes do not impact reproduction, at least in early stages of infestation and under moderate parasite loads. (BIO-WEST 2002c).

3.5.2 Comal Springs Riffle Beetle (*Heterelmis comalensis*)

The Comal Springs riffle beetle (family *Elmidae*) is known primarily from Comal Springs, and was first collected there in 1976 and described in 1988 by Bosse *et al*. (1988). Barr (1993) collected a single specimen in the headwaters of the San Marcos River, but specimens have been regularly found in that location more recently. (Gibson *et al*. 2008; Gonzales 2008). Although some riffle beetles are capable of flight, the Comal Springs riffle beetle is a flightless, surface aquatic beetle about one-eighth of an inch long (62 FR 66,295 (Dec. 18, 1997). Both larvae and adult riffle beetles are entirely aquatic with the adults feeding mainly on algae and detritus scraped from submerged weeds and rocks (Brown 1987). Comal Springs riffle beetles are found in the flowing, uncontaminated waters of the spring runs, but also occupy areas along the Landa Lake shoreline where springflow is present or in areas of upwelling springflow (including the deepest portions of the Landa Lake (BIO-WEST 2002a). Water flow appears to be important to respiration and survival of this species; therefore, a reduction of water flow or drying of the spring runs could be a limiting factor to their survival. (62 FR 66,295 (Dec. 18, 1997)). Previously, it was unclear how the species might respond to reduced springflow. Recent laboratory studies suggest that individuals tend to orient downward in the substrate, and toward flow BIO-WEST 2002b), a behavioral response that may permit individuals to move to suitable habitat when springflow is reduced at the surface. However, because this species was not identified until 1976, well after the documented drought of record and cessation of springflow at Comal Springs, the question of survivability of the species during no-flow periods remains unanswered. In addition to behavioral responses, the presence of individuals in deeper areas of Landa Lake, somewhat removed from the spring runs, may have facilitated survival despite loss of habitat and provided a source for recolonization.

In 2007, the USFWS designated 19.8 acres of the Comal Springs complex and 10.5 acres of the San Marcos Springs complex as critical habitat for this species. (72 FR 39,247 (July 17, 2007)).

3.5.3 Comal Springs Dryopid Beetle (*Stygoparnus comalensis*)

First collected in 1987, the Comal Springs dryopid beetle is the only known subterranean aquatic (stygobiotic) species from the family Dryopidae. This species is translucent, is slightly pigmented, has vestigial (non-functioning) eyes, and is about one-eighth of an inch long. Specimens have predominantly been collected from Comal Springs spring run #2; however, they have also been collected from spring runs 3 and 4 on the Comal River and Fern Bank Springs in Hays County (Barr and Spangler 1992). This species is assumed to be restricted to headwaters of springs and spring runs due to its inability to swim. They are able to maintain a mass of small hydrophobic (unwettable) hairs on their underside where they retain a thin air bubble through which gas exchange occurs during respiration (BMWD 1998; Chapman 1982). As water flow decreases, subsequently decreasing dissolved oxygen levels, this method of respiration loses its effectiveness. Thus, FWS found that dryopid beetle requires flowing uncontaminated waters for survival. (62 FR 66,295 (Dec. 18, 1997)).

In 2007, the USFWS designated 31.8 acres of critical habitat for this species at the Comal Springs complex and 1.4 acres of critical habitat at the Fern Bank Springs complex. (72 FR 39,247 (July 17, 2007)).

3.5.4 Peck's Cave Amphipod (*Stygobromus pecki*)

Peck's Cave amphipod, is a subterranean aquatic species in the family Crangonyctidae. This species is eyeless and un-pigmented, which indicate that its primary habitat lies within the Aquifer in permanent darkness. If individuals venture outside the spring orifice, they become easy prey from predators. Therefore, individuals are typically found in the crevices of rocks and gravel near spring orifaces. This species was first collected at Comal Springs in 1964 and again in 1965. (62 FR 66,295 (Dec. 18, 1997)). Most of the specimens collected (over 300) were netted from gravel substrates near Spring Runs 1, 2, and 3 in the Comal Springs system. (Arsuffi 1993; Barr 1993). In 2002, five individuals were collected from Panther Canyon Well, known to be hydrologically connected to Spring Run 3 through dye tracer tests. (USFWS 2003a). Several specimens have also been collected from Hueco Springs. Extensive collection efforts have been unable to locate the species in other localities. (Barr 1993; Gibson *et al*. 2008; 62 FR 66,295 (Dec. 18, 1997)). Very little is currently known about the life history requirements of this species.

Two critical habitat units have been designated for Peck's Cave Amphipod: Comal Springs and associated portions of Landa Lake, and the Heuco Spring complex (encompasses Hueco Springs and associated satellite springs).

Primary constituent elements of the critical habitat for all three federally listed aquatic invertebrate species include: unpolluted, high quality water, Aquifer water temperatures between 68°–75°F, adequate dissolved oxygen levels and food supply, and substrates between 0.3–5.0 inches in diameter.

3.5.5 San Marcos Salamander (*Eurycea nana*)

The San Marcos salamander is a member of the lungless salamanders belonging to the family Plethodontidae. *Eurycea* are known as the brook salamanders, and include three species on the Edwards Plateau: the Texas blind salamander; the San Marcos salamander in the San Marcos River; and the Texas salamander (*Eurycea neotenes*), in the Comal River (USFWS 1996a). It

was once thought that the latter two species were the same; however, investigations by Chippendale et al. (1992, 1994, and 1998) have suggested that these two populations may be genetically different. The San Marcos salamander is currently listed as a threatened species by the TPWD and as a threatened species by the USFWS. (USFWS 1996a).

San Marcos salamanders were first collected from the San Marcos Springs and described in 1938. (Bishop, 1943). They are small, reaching a maximum length of 2.3 inches (58.4 mm), slender, and light brown in color. Prominent features include large eyes with a dark ring around the lens, well-developed and highly pigmented external gills, moderately short and slender limbs, four toes on the forefeet and five on the hind feet, and a well-developed dorsal fin. (USFWS 1996a). Water issuing from the springs has a low oxygen content (30-40 percent saturated), causing the external gills of the San Marcos salamander to have a bright red coloration due to increased blood flow through the gills. (Tupa and Davis 1976). San Marcos salamanders are distinct when compared to other neotenic *Eurycea* from Texas, in that they are smaller, more slender, have different coloration, greater number of costal grooves (vertical wrinkles in the skin between front and hind legs), larger eyes relative to their head, and fewer teeth. (Tupa and Davis 1976; USFWS 1996a).

San Marcos salamanders are found in Spring Lake in rocky areas around spring openings and downstream of the dam at Spring Lake. (Tupa and Davis 1976; Nelson 1993). They require clean, clear waters associated with springs in areas of sand, gravel, large rock, and vegetative cover at depth of 3.3 to 6.6 feet (Nelson 1993; USFWS 1996a). Populations have been found in front of the Aquarena Springs Hotel on concrete banks and in boulders which are covered with an aquatic moss (*Leptodictyium riparium*). (USFWS 1996a). Individuals can also be found in *Lyngbya* sp., a filamentous blue-green algae, which covers shallow sandy substrates and provides a good hiding place by means of camouflage for the salamanders (BMWD 1998; USFWS 1996a). Numerous rooted aquatic macrophytes occur on the boundary of the salamander habitat in suitable depths including arrowhead, water primrose, and eelgrass). Numerous individuals are found within these mats of vegetation at the shallow headwater areas. The vegetation houses the food source for the salamander in addition to protective cover for avoidance of predators (larger fish, crayfish, turtles, and aquatic birds) (Tupa and Davis 1976; USFWS 1996a).

Flowing waters are one of the main requirements for the survival of the San Marcos salamander. They prefer waters that are slightly alkaline (pH 7.2), thermally constant 69.8° to 71.6°F (21-22°C), an oxygen saturation of 40-50 percent, and little variation in bicarbonate alkalinity (220-232 mg/l). (Tupa and Davis 1976).

Critical habitat has been designated for the San Marcos salamander as Spring Lake and its outflow and the San Marcos River downstream to 164 feet below Spring Lake Dam. (USFWS 1996a).

The main food source of the San Marcos salamander is amphipods. Stomach content analyses have shown that San Marcos salamanders also feed on tendipedid (midge fly) larvae and pupae, other small insect pupae and naiads, and small aquatic snails. San Marcos salamanders and the fountain darter often occupy the same habitat and pursue their prey in much the same way. These salamanders wait for the prey to come near their head, then snap forward with an open mouth and engulf their prey, indicating a behavior response to sensory cues from living prey. (Tupa and Davis 1976).

Male San Marcos salamanders reach sexual maturity when they reach a snout-vent length of 0.74 inch or total length of 1.37 inches. (Tupa and Davis 1976). MacKay (1952) found sperm in

all mature males from October to May and postulated that they have a breeding season in June and another in the fall. There are four classes of ova in female San Marcos salamanders: very small clear ova, small opaque-white ova, small yellow ova, and large yellow ova. Those that carried large yellow ova were considered ready for oviposition and were found in almost every month of the year. Large yellow ova were present in females with a snout-vent length greater than 0.78 inch or 1.37 inches. (*Id.*).

Courtship and egg deposition have not been observed and no eggs have been collected from the San Marcos salamander's natural habitat. However, in the closely related Comal Springs blind salamander (*Eurycea tridentifera*), courtship, oviposition, and hatching have been observed. Typically *Eurycea* breed in the running water of streams, springs, or caves and their adherent eggs are singly deposited on the bottom and sides of vegetation or rocks (USFWS 1996a). Tupa and Davis (1976) and Bogart (1967) performed studies on the San Marcos salamander that suggests they breed most of the year with a peak in late spring (May and June).

Attempts to estimate population size have also been made. The San Marcos salamander population found in the shallow area of Spring Lake along the northern bank in front of the Aquarena Springs Hotel was estimated by Tupa and Davis (1976) to be 20,880. In 1991, the population was estimated at 23,200 in the same area, at 25,238 for rocky substrates around spring openings, and at 5,213 for rocky substrates 492 feet (150 m) downstream of the Spring Lake Dam, for a total population estimate of 53,651. (Nelson 1993).

3.5.6 Texas Blind Salamander (*Eurycea rathbuni*)

The Texas blind salamander was first collected in 1895 from the NFHTC in San Marcos, Texas, when they were expelled from an artesian well drilled to supply the hatchery with water (Longley 1978). Earlier taxonomists supported the recognition of genus *Typhlomolge* (Wake 1966, Potter and Sweet 1981); however, Mitchell and Reddell (1965) disagreed, stating that *E. rathbuni* represents *Eurycea* that has an extreme cave-associated morphology. Based on biochemical, morphometric, and molecular techniques, Chippindale *et al.* (1994) concluded that the Texas blind salamander is phylogenetically within the Texas *Eurycea* group. This conclusion has been more recently supported by allozyme and mitochondrial genetic (DNA) sequence studies by Chippendale *et al*. (2000). The USFWS reassigned this species as *Eurycea.* It was listed on the March 1999 *"Texas Threatened and Endangered Species"* list. (TPWD 1999).

The Texas blind salamander is a smooth, unpigmented troglobitic (cave-adapted) species, and has a maximum length of 4.7 inches. It has a large and broad head, reduced eyes (two small dark spots beneath the skin), long and slender limbs, four toes on the forelegs and five on the hind legs. There are no definite external characteristics that can be used to determine sex. Due to the presence of juveniles year round, the Texas blind salamander appears to be sexually active throughout the year due to the thermally constant waters of the Aquifer. Observations of this species in captivity have shown three spawning events in one year and indicated a clutch size from 8 to 21 eggs per spawning (Longley 1978). Unpigmented eggs were attached to gravel either singly or in groups of 2 to 3 eggs. Constant water temperature within the Aquifer is essential for normal egg development (Longley 1978). Eggs hatch within 12 to 16 days after laying and feeding of the larvae begins within 1 month after hatching. Young salamanders feed on copepods while larger salamanders eat amphipods, blind shrimp (*Palaemonetes antrorum*) in captivity, daphnia, small snails, and other invertebrates. Cannibalism has also been documented with the Texas blind salamander. (USFWS 1996a).

Texas blind salamanders have been well documented from the subterranean waters of the San Marcos area of the Aquifer in Hays County. They live in water-filled cavernous areas and are neotenic (reproduce in the larval form) and aquatic throughout their life. Texas blind salamanders have been observed, in caves with access to the water table, traveling along submerged ledges within the Aquifer and swimming small distances before spreading their legs and settling to the bottom. It is likely that they are sensitive to changes in water temperatures, preferring the thermally constant temperatures of the Aquifer, although more research is needed to determine critical thermal minima and maxima for their various life stages. (Longley 1978; Berkhouse and Fries 1995).

All collections of Texas blind salamanders documented in the literature have occurred in Hays County and since its initial collection from the San Marcos NFHTC, the salamander has been found at Ezell's Cave, San Marcos Springs, Rattlesnake Cave, Primer's Fissure, Texas State University's artesian well, and Frank Johnson's well (Russell 1976; Longley 1978). Previously it had been found in Wonder Cave; however, searches in 1977 did not discover any individuals (Longley 1978). The distribution of this species may be the Aquifer beneath and near San Marcos in an area as small as 25.9 square miles. (USFWS 1996a). Recent collections and genetic work support a more widespread distribution of this species, including four additional sites (Hueco Springs, Comal Springs, Panther Canyon Well, and Mission Bowling Well in Comal County). (Gluesenkamp, 2011).

3.5.7 Texas Wild-Rice (*Zizania texana*)

Texas wild-rice, an aquatic perennial grass from the family Poaceae, was originally collected in 1892 and identified as southern wild-rice (*Z. aquatica*). It was later labeled *Z. texana* in 1921, although not recognized as a distinct species. In 1932 amateur botanist W.A. Silveus of San Antonio, Texas collected and recognized Texas wild-rice as a distinct species (Terrell *et al*. 1978; Poole and Bowles 1999; Silveus 1933). Texas wild-rice is endemic to the San Marcos River and is thought to have evolved in geographic isolation from other species of *Zizania*. The nearest present-day population is a coastal plain population of *Z. aquatica* in southern Louisiana, 400 miles (640 km) away, and is morphologically different from *Z. texana*. (Terrell *et al*. 1978).

Texas wild-rice is primarily an aquatic, monoecious, perennial macrophyte, 3.3 to 6.6 feet long. It is found growing and submerged at a depth of ≤3.3 feet in swift moving, shallow areas of the San Marcos River. During times of low flow, the upper portions of the culms (stems) and leaves become emergent (Terrell *et al*. 1978; USFWS 1996a). Texas wild-rice is securely attached to the substrate by short spongy roots which are tightly intertwined and develop into a plant colony in 1.0 to 6.0 feet of water. (Beaty 1975). The leaves are linear, up to 3.3 feet long, and 0.5 inch wide. (Terrell *et al.* 1978). Flowering typically occurs in the spring and fall but may be seen throughout the year due to the constant water temperatures. There is some debate about the ability of Texas wild-rice to reproduce via seeds; it has done so under laboratory conditions. However, many researchers believe this occurs infrequently, if at all, in the wild (Beaty 1975; Emery 1967). Texas wild-rice does reproduce vegetatively, by stolons, and appears to reestablish readily when uprooted and relocated during flood events. (BIO-WEST 2003a, 2003b).

Texas wild-rice forms large clumps rooted in sand and gravel sediments which is overlain by Crawford black silt and clay (Vaughan 1986). They grow primarily in the middle of the river in areas with swift moving, shallow water of 3.3 feet or less, (Poole and Bowles 1999). Wild-rice require thermally constant temperatures, clear water, undisturbed stream bottom habitat,

protection from floods, and protection allowing inflorescence (flower production) during reproduction. (McKinney and Sharp 1995).

Associated plant species that occur in the upper 0.25-mile area of the San Marcos River, which is inhabited by Texas wild-rice, include eelgrass, arrowhead, pondweed, hydrilla, hornwort (*Ceratophyllum demersum*), elodea (*Elodea densa*), and water primrose. In the lower sections of the river, Texas wild-rice is found in isolated clumps and competition from other species is minimal (Terrell *et al*. 1978; Vaughan 1986). In many places on the river, the non-native elephant ear has invaded the edges of the river, narrowing the river and crowding other aquatic species. Other species such as sycamore (*Platanus occidentalis*), pecan (*Carya illinoensis*), bald cypress (*Taxodium distichum*), live oak (*Quercus fusiformis*), and American elm (*Ulmus americana*) have shaded the river, although it is not known if wild-rice is influenced by the amount of shading by the tree canopy. (Vaughan 1986).

When Texas wild-rice was first described in 1933, it was found in abundance in the San Marcos River, as well as in Spring Lake, and in contiguous irrigation ditches, requiring considerable effort by an irrigation company to control its growth (Terrell *et al*. 1978; Silveus 1933). Thirty-four years after its discovery, its abundance had been significantly reduced. In 1967, Emery found only one plant in Spring Lake, and none in the uppermost 0.5 mile of the San Marcos River. Only scattered plants were found in the next 1.5 miles, and none were found below this point. (Emery 1967). Emery rechecked the abundance of Texas wild-rice in the upper portions of the San Marcos River in 1976, and found no plants in Spring Lake. During that investigation, the greatest concentrations of plants were found at the extreme upper and lower segments of the 1.5-mile reach of the river (Emery 1977). He also estimated that Texas wild-rice plants covered 12,169.6 square feet of river habitat. Texas wild-rice was listed as an endangered species in 1978. After the listing, a continued decline occurred in the areal coverage of Texas wild-rice until it had declined to just 4,881 square feet (Vaughn 1986), which is less than half of Emery's 1976 estimate. Recent years have seen a significant increase in areal coverage of Texas wild-rice to 20,404 square feet in 2001. The species is abundant throughout the upper portion of its range, but rare downstream of the IH-35 bridge, despite the historic suitability of habitat below this point.

Since June 1989, the TPWD has monitored areal coverage of Texas wild-rice which has averaged 14,794 square feet between 1989 and 1994. The current distribution of Texas wild-rice extends from the upper reaches of the San Marcos River, including several plants in Spring Lake just upstream of the dam and numerous stands just below the dam (Emery and Vaughan did not report wild-rice from this area), throughout the river habitat to an area just below the wastewater treatment plant. Until recently, it had not occurred between the Rio Vista railroad bridge and the Cheatham Street dam (USFWS 1996a), however a single plant is now present in this reach (E. Oborny, BIO-WEST, personal communication). Increased sedimentation, water depth and turbidity, and a decrease in current velocities have contributed to a loss of habitat for Texas wild-rice growth throughout the lower portions of its historic range (Poole and Bowles 1999). While water depth and current velocity are a direct result of the influence of springflow into the San Marcos River, the impacts of increased sedimentation and turbidity on Texas wild-rice are largely a result of urbanization within the contributing watershed.

The species' critical habitat has been designated as Spring Lake and its outflow, and the San Marcos River downstream to its confluence with the Blanco River (USFWS 1996a).

The invasion of a new non-native plant, water trumpet (*Cryptocoryne beckettii*), has created a new, very serious threat to Texas wild-rice. The plant, a native of southeast Asia, was introduced into the San Marcos River in 1993. (USFWS 2003b). The plant probably escaped

into the river from a dumped aquarium as the plant is very popular in the aquarium trade. (Tu 2010). The plant has habitat preferences that are nearly identical to Texas wild-rice and has quickly established in the section of the San Marcos River from the A.E. Wood State Fish Hatchery to the confluence of the San Marcos and Blanco rivers. (USFWS 2003b).

Since August of 2002, through a cooperative effort led by the USFWS NFHTC, over 400 square meters of the noxious plant have been removed from the San Marcos River. Unfortunately, the plant's growth continues to outpace the removal effort and it is now feared that unless more ambitious control measures are implemented, full removal may not be assured. (USFWS 2003b).

The cultivation of Texas wild-rice in a controlled environment has been attempted with varying success. Replanting attempts have been made with cultured plants into Spring Lake with disappointing results. Emery was successful under controlled conditions in a spring-fed raceway at Texas State University at San Marcos, with seed storage and germination, seedling survival, pollination, and development of survival clones to the next generation. (Terrell *et al*. 1978).

Efforts to grow Texas wild-rice outside the San Marcos River have been unsuccessful. (USFWS 1996b).

The recovery plan lists disturbances to the environment and diminished springflow as the main threats to Texas wild-rice. (USFWS 1996a). In addition, impacts from recreationists (*e.g.*, tubing), floating debris (aquatic vegetation cut at Spring Lake and by landowners), shade which reduces photosynthesis, or interference with pollination and seed maturation can damage the plants (Beaty 1975; Poole 1992). Herbivory by nutria (*Myocastor coypus*), the introduced giant rams-horn snail (*Marisa cornuarietis*), and waterfowl, as well as competition from aquatic plants are believed to be significant factors in reducing the size and vigor of stands of wild-rice (McKinney and Sharp 1995). Other threats include water quality degradation, waterborne contaminants, genetic erosion of the population, chemical spills, and siltation (Poole 1992; BMWD 1998).

3.5.8 San Marcos Gambusia (*Gambusia georgei*)

The San Marcos gambusia (*Gambusia georgei*), a member of the family Poeciliidae, was first described by Hubbs and Peden in 1969. It is just one of three species of *Gambusia* native to the San Marcos River, the others being largespring gambusia (*G. geiseri*) and western mosquitofish (*G. affinis*) which have continually been found in greater numbers than the San Marcos gambusia (Hubbs and Peden 1969). This genus originated in Central America and contains more than 30 species of the live-bearing freshwater fishes. (USFWS 1996a). *Gambusia* is a well-defined genus and mature males have a thickened upper pectoral fin ray that distinguishes it from related genera (Rosen and Bailey 1963). In the United States, only a limited number of *Gambusia* are native, and of these, the San Marcos gambusia has one of the most restricted ranges. (USFWS 1996). As specimens were caught in the late 1800s and again in 1925, it is likely that the San Marcos gambusia have inhabited the area for some time (Hubbs and Peden 1969).

San Marcos gambusia range in size from 1.0 to 1.5 inches, adult females being larger than males (Whiteside 1976). Their scales tend to be strongly crosshatched which is contrary to the less distinct scale markings of the western mosquitofish (USFWS 1996). San Marcos gambusia are usually plainly marked; however, behaviorally aggressive fish may develop a dark stripe on their dorsal fin, a black bar on their cheek, and a dark patch above their pectoral fin (Whiteside

1976). Under normal conditions, their coloring appears to be lemon yellow, bright yellowish orange, or bluish. (USFWS 1996a).

The exact locations of early collections of San Marcos gambusia were only recorded as "San Marcos Springs" although they were probably collected near the headwaters of the springs. (USFWS 1996a). Over time, the distribution of the San Marcos gambusia appears to have been significantly altered. Only a few records show the fish occurring downstream of the headwaters of the San Marcos River although collections in this area were few prior to 1950. A single individual was taken during a 1953 collection effort below the dam at Rio Vista Park, and since that time, almost all specimens of the San Marcos gambusia have been taken in the vicinity of the IH-35 bridge downstream to Thompson's Island. The only exception to this was in 1974 when one individual was collected below the outfall of the San Marcos wastewater treatment plant (USFWS 1996a; Longley 1975). Historically, populations of San Marcos gambusia have been low, and were rare during collection efforts in 1978 and 1979 which yielded only 18 San Marcos gambusia from a total of 20,199 (0.09 percent). (Edwards *et al*. 1980). Populations decreased during a 1981 and 1982 collection effort (0.06 percent of all *Gambusia* collected) and sampling efforts between 1982 and 1995 have not yielded a single individual. (USFWS 1996a). Intensive collection efforts were conducted in 1990 with no San Marcos gambusia being collected (USFWS 1996a).

San Marcos gambusia prefer quiet, shallow, thermally constant, open waters adjacent to areas of moving water. Historically, they have been found mostly in the upper portions of the San Marcos River on muddy substrates without silting and in areas of shade from overhanging vegetation or bridge structures (Edwards *et al*. 1980; Hubbs and Peden 1969). At some localities, the introduced aquatic vegetation elephant ear has been found in abundance. Researchers suggest that this nonnative plant may have modified essential aspects of the San Marcos gambusia habitat. (USFWS 1996a). Critical habitat has been designated by the USFWS as the San Marcos River from the Highway 12 bridge downstream to just below the IH-35 bridge (*Id.*).

Very little is known about the food preferences of the San Marcos gambusia. It is thought that insect larvae and other invertebrates make up the majority of their diet, as in other poecillids (USFWS 1996a). The reproductive capabilities of this species are not known, although two individuals kept in laboratory aquaria produced clutches of 12, 30, and 60 young, with the largest having been aborted prior to full development. (Edwards *et al*. 1980).

Hybridization of the San Marcos gambusia and the western mosquitofish has been going on since 1925 and was first recognized by Hubbs and Peden (1969). This went on for many years without the introduction of genetic material into either of the parental species; however, a series of collections from 1981 to 1983 indicated that hybrid individuals were becoming more abundant than the pure San Marcos gambusia. (USFWS 1996a). This may indicate that hybrid individuals are competing with the San Marcos gambusia and putting stress on native populations. Despite efforts to locate pure San Marcos gambusia, the last known sighting from the San Marcos River occurred in 1983 and the species is now thought to be extinct. (McKinney and Sharp 1995).

3.6 Species Warranted for Listing Covered by the Section 10(a)(1)(B) Permit, If Listed in the Future

There are many species within the Plan Area that are proposed for listing as threatened or endangered. The Covered Species Work Group recommended coverage by this HCP for three species: Aquifer diving beetle (*Haideoporus texanus*), Texas troglobitic water slater (*Lirceolus*

smithii), and Comal Springs salamander (*Eurycea* sp. 8), which have similar ranges, habitats, and threats as the listed species described above in Section 3.5. The following sections provides a brief summary of the locations, habitat requirements, and morphological descriptions of these species, for which a USFWS 90-day finding indicates that listing as threatened or endangered may be warranted. (74 FR 66,866 (Dec. 16, 2009)).

3.6.1 Edwards Aquifer Diving Beetle (*Haideoporus texanus*)

The Edwards Aquifer diving beetle, also known as Texas cave diving beetle, is a small (less than one half inch), elongate, oval-shaped and somewhat flattened member of the family Dytiscidae. This species is restricted to the subterranean waters of the Aquifer in Hays and Comal counties, where it has been collected from the Artesian Well and from Comal Springs (Bowles and Stanford 1997, Gibson *et al*. 2008). The Texas cave diving beetle was the first blind, unpigmented, aquifer-adapted water beetle known from North America. They have reduced nonfunctional eyes and a greater development of sensory setae (hairs) on their wings, legs, and mouth area. (Young and Longley 1975).

The USFWS (2009) has declared that substantial information was presented in the petition to indicate that the listing of this species may be warranted due to the present or threatened destruction, modification, or curtailment of its habitat or range resulting from water drawdown and loss of water quality due to development.

3.6.2 Texas Troglobitic Water Slater (*Lirceolus smithii*)

Texas troglobitic water slater is one of six described species in the *Lirceolus* genus in Texas. (Lewis and Bowman 1996, Lewis 2001). Phylogeographic work on *Lirceolus* showed patterns of relatedness that follow surface river drainage basins (Krejca 2005). There are collections of unidentified material from across the state, and at least one locality, Barton Springs in Travis County, has sympatric species. Members of this genus are not commonly collected. They are extremely small compared to the widespread Texas asellid (*Caecidotea reddelli)*. While no *Lirceolus* have formal protection, several of the species are endemic to small areas and a regional Habitat Conservation Plan in Hays County recognizes *Lirceolus smithii* as one that could become listed as threatened or endangered in the future (Loomis Partners, Inc. *et al*. 2009). This species is known from two localities in Hays County, San Marcos Springs (Diversion Springs) and the Artesian Well that is located very close to San Marcos Springs.

The USFWS (2009) has declared that substantial information was presented in the petition to indicate that the listing of this species may be warranted due to the present or threatened destruction, modification, or curtailment of its habitat or range resulting from aquifer drawdowns and decreasing water quality.

3.6.3 Comal Springs Salamander (*Eurycea* sp.)

A population of salamanders occurs at Comal Springs, and for the purposes of this HCP we use the common name ‘Comal Springs Salamander’ that refers only to this population, in accordance with the federal listing petition for the species *Eurycea* sp. (USFWS 2009). This population was initially identified as *E. nana* (Sweet 1978), however Chippindale *et al*. (2000) confirmed these individuals were not *E. nana* but in fact a unique species. The morphology and genetics of this species is very similar to that of *E. neotenes*, and Bendik (2006) suggests that this "species" be synonomized with *E. neotenes* and the Comal collections be treated as a range extension. The USFWS (2009) has declared that substantial information was presented in

the petition to indicate that the listing of this species may be warranted due to habitat loss or degradation resulting from numerous human factors including groundwater withdrawal and contamination. It is worthwhile to note that a second species of aquifer salamander also occurs at Comal Springs. Recent data suggest the characteristics of this aquifer salamander are consistent with it being *Eurycea rathbuni*. (Gluesenkamp 2011).

Chapter 4 Covered Species Analysis

4.0 Introduction

Issuance criteria under section 10(a) of the ESA require, among other things, that the incidental take resulting from the Covered Activities will "not appreciably reduce the likelihood of the survival and recovery of the species in the wild." (16 U.S.C. § 1539(1)(a)(1)(B)(iv)). Furthermore, because the ITP is an action authorized by a Federal agency, section 7(a)(2) of the ESA requires that the issuance of the permit is not likely to "jeopardize the continued existence of" any federally-listed species or to result in the "destruction or adverse modification of" designated critical habitat. (*Id.* at 1536(a)(2)).[1] FWS must make these determinations "using the best scientific and commercial data available."

Further, under USFWS's 5-Point policy, an applicant must "clearly and consistently define the expected outcome (*i.e.*, biological goal(s))" of the HCP. (65 FR at 35,250). These goals are intended to create "parameters and benchmarks for developing conservation measures" and "determine the focus of the adaptive management strategy." (*Id.* at 32,250-51).

The purpose of this chapter is to: (1) establish the biological goals and objectives for the HCP; (2) estimate the amount of incidental take that may result from the Covered Activities; and (3) evaluate the impact of that take on the likelihood of the survival and recovery of the Covered Species.

4.1 Long-Term Biological Goals and Objectives

4.1.1 Biological Goals and Objectives

The identification of biological goals and objectives is one of five components outlined in the HCP Handbook Addendum (USFWS and NMFS 2000), referred to as the "5-Point Policy." (*See* Section 1.6.4). Long-term biological goals are the rationale behind the minimization and mitigation strategies and, conversely, minimization and mitigation measures are the means for achieving the long-term biological goals and objectives. The purpose of Section 4.1 is to establish the biological goals and objectives for the HCP based on the best scientific and commercial data available.

All long-term biological goals, accompanying management objectives, and flow-related objectives are subject to change under limited circumstances set out in the Funding and Management Agreement (FMA). Any such change will be based solely on the best scientific and commercial data available.

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[1] The term "jeopardize the continued existence of" means "to engage in an action that reasonably would be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival and recovery of the species in the wild by reducing the reproduction numbers, or distribution of that species." (50 C.F.R. § 402.02). This standard is obviously very similar to the "appreciable reduction" issuance criterion. The jeopardy and critical habitat analysis will be done by USFWS as part of its Section 7(a)(2) Biological Opinion. Accordingly, the jeopardy and critical habitat analysis will not be specifically addressed in this chapter.

4.1.1.1 Comal Springs/River Ecosystem

Fountain Darter

Long-term Biological Goals

The long-term biological goals for the fountain darter at Comal Springs are quantified as areal coverage of aquatic vegetation (habitat) within four representative reaches of the Comal system (Upper Spring run [upstream most portion of the system to Spring Island], Landa Lake [Spring Island to the outflow to Old and New channels], Old Channel, and New Channel) and fountain darter density (population measurement) per aquatic vegetation type. (Figure 4-1). The habitat-based and population measurement goals are presented in Table 4-1 and include proposed aquatic vegetation restoration efforts. The population measurement goal is to maintain the median densities of fountain darters observed per aquatic vegetation type per system at a level greater than or equal to that observed over the past 10 years in the EAA Variable Flow Study monitoring.

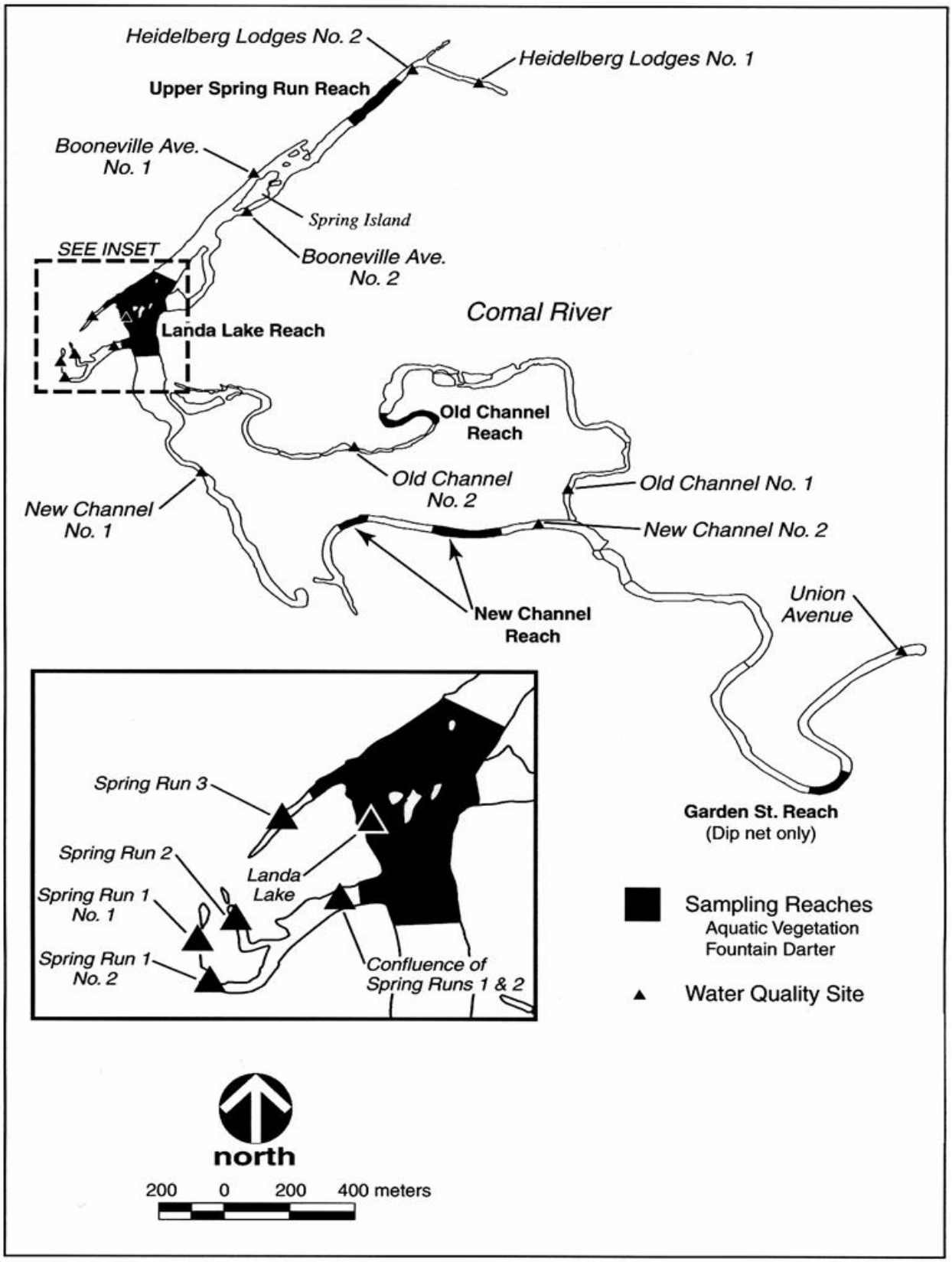

Figure 4-1. Representative Sample Reaches – Comal Springs

TABLE 4-1
FOUNTAIN DARTER HABITAT (AQUATIC VEGETATION) IN METERS SQUARED (M^2) AND FOUNTAIN DARTER MEDIAN DENSITY (NUMBER/M^2) PER HABITAT TYPE

Fountain darter habitat (aquatic vegetation) goal in meters squared (m^2)							
Study Reach	Bryophytes	*Hygrophila*	*Ludwigia*	*Cabomba*	Fil. Algae	*Sagittaria*	*Vallisneria*
Upper Spring Run Reach	1,850	650	150			600	
Landa Lake	4,000	250	900	500		1,250	13,500
Old Channel	150	200	1500		300		
New Channel	150	1,350		350			
TOTAL	6,150	2,450	2,550	850	300	1,850	13,500
Fountain darter median density goal (number/m^2)							
	Bryophytes	*Hygrophila*	*Ludwigia*	*Cabomba*	Fil. Algae	*Sagittaria*	*Vallisneria*
	20	4	7	7	14	1	1

Key Management Objectives

The long-term biological goals are accompanied by two key management objectives needed to achieve the long-term biological goals. The management objectives for the fountain darter in the Comal Springs/River Ecosystem are (in no particular order):

- Active native vegetation restoration and protection will be implemented in Landa Lake and the Old Channel. Restoration activities will extend beyond the study reaches in equal proportion to effort expended per study area in relation to the total area of Landa Lake and Old Channel. For example, if 50 percent of the Old Channel study reach was restored, 50 percent of the entire Old Channel would be subsequently restored.

- Surface water quality within the Comal River should not exceed a 10 percent deviation (daily average) from historically recorded water quality conditions (long-term average) as measured at the fifteen EAA Variable Flow Study water quality monitoring locations (Figure 4-1). This includes water quality constituents currently measured in the EAA Variable Flow Study except water temperature and dissolved oxygen. This objective assumes that a 10 percent deviation in average conditions would be acceptable; however, more extensive work to evaluate and assess water quality tolerances of the fountain darter will be addressed as part of the AMP. Water temperature and dissolved oxygen will be monitored and evaluated on an instantaneous basis within the four representative study reaches with established thresholds. Water temperatures <25°C will be maintained throughout the Comal system as to not inhibit fountain darter reproduction and recruitment over time. Dissolved oxygen concentrations > 4.0 mg/L will be maintained throughout fountain darter habitat.

Flow-related Objectives

The current level of uncertainty associated with the habitat-based long-term biological goals and the associated restoration and water quality management objectives necessitate the flow-related objectives in Table 4-2.

TABLE 4-2
LONG-TERM AVERAGE AND MINIMUM TOTAL COMAL DISCHARGE MANAGEMENT OBJECTIVES

Description	Total Comal Discharge (cfs)[a]	Time-step
Long-term average	225	Daily average
Minimum	30 [b]	Daily average

[a]Assumes a minimum of a 50-year modeling period that includes the drought of record
[b]Not to exceed six months in duration followed by 80 cfs (daily average) flows for 3 months.

To track progress towards the long-term goals and learn more about the cause-and-effect relationships responsible for the variability in the habitat and population measures, the Applicants will monitor key components (*i.e.,* aquatic vegetation, the species themselves, water quality, non-native species, gill parasites, etc.) and conduct applied research and ecological modeling as part of the AMP. (*See* Section 6.3). The monitoring, applied research, and ecological modeling will be clearly described and defined as the AMP is further developed and

implemented as any changes to the long-term biological goals will be based on the best available science.

Historical and Present Day Perspective

Aquatic vegetation and fountain darters have been routinely monitored within these four representative study reaches since fall 2000. The aquatic vegetation and subsequent fountain darter densities have varied over that period (BIO-WEST 2002a-2011a). An example of bryophytes areal coverage in the Upper Spring Run Reach and Landa Lake, and *Hygrophila* areal coverage in the Old and New channels over time is presented below in Table 4-3.

TABLE 4-3
EXAMPLE OF BRYOPHYTES AREAL COVERAGE IN THE UPPER SPRING RUN REACH AND LANDA LAKE, AND *HYGROPHILA* AREAL COVERAGE IN THE OLD AND NEW CHANNELS OVER TIME

	Bryophytes (m^2)		*Hygrophila* (m^2)	
Sampling Period	Upper Spring Run Reach	Landa Lake	Old Channel	New Channel
Spring 2002	457	3,985	3	3,158
Fall 2002	1,156	3,964	2	2,310
Spring 2003	2,476	4,190	21	3,011
Fall 2003	2,021	3,305	133	3,291
Spring 2004	1,859	1,971	493	3,300
Fall 2004	712	735	648	620
Spring 2005	1,386	2,801	953	18
Fall 2005	1,915	1,055	1,326	220
Spring 2006	1,850	2,114	1,444	310
Fall 2006	1,251	929	1,292	715
Spring 2007	2,358	2,779	1,373	1,108
Fall 2007	2,407	2,601	1,519	1,300
Spring 2008	2,760	3,364	1,349	1,340
Fall 2008	1,057	176	1,350	2,131
Spring 2009	1,068	2,789	1,526	1,991
Fall 2009	853	386	1,569	100
Spring 2010	1,872	2,587	1,587	113

Fall 2010	16	412	1,338	181
Long-term Average	1,526	2,230	996	1,401

Table 4-4 breaks out the "current" (spring and fall 2010) areal coverage of aquatic vegetation within each of the four reaches. (BIO-WEST 2011a).

From review of these tables, it is evident that the aquatic vegetation in the Comal system can vary considerably (most notable in Upper Spring Run Reach and New Channel) within any given year. For example, in 2010, the considerable reduction in aquatic vegetation in the Upper Spring Run Reach and New Channel, as well as for bryophytes in Landa Lake was due to the intense flooding event experienced in June. For a more comprehensive description of aquatic vegetation in the Comal study reaches over the past decade *see* EARIP (2009) or BIO-WEST (2002a-2011a)).

Methods and Discussion

Data collected over the past 10 years for the EAA Variable Flow Study was used for this analysis. For this approach, the maximum amount of each aquatic vegetation type per study reach was selected independent of year and vegetation type. For instance, 2003 had the highest areal coverage of bryophytes in Landa Lake, but 2009 had the highest amount of *Sagittaria*. As a starting point, both maximums were used even though they did not occur concurrently. Table 4-5 shows the maximum areal coverage per vegetation type within each study reach over the ten-year study period.

TABLE 4-4
FOUNTAIN DARTER HABITAT IN COMAL SPRINGS ECOSYSTEMS (AQUATIC VEGETATION) (m^2)

Study Reach	*Bryophytes*	*Hygrophila*	*Ludwigia*	*Cabomba*	*Fil. Algae*	*Sagittaria*	*Vallisneria*
SPRING 2010							
Upper Spring Run Reach	1,872	297	8			740	
Landa Lake	2,587	512	29	229		1,458	13,671
Old Channel	18	1,587	9		1		
New Channel	96	113	8	109			
TOTAL	4,573	2,509	54	338	1	2,198	13,671
FALL 2010							
Upper Spring Run Reach	16	14				518	
Landa Lake	412	412	28	239		1,484	12,923
Old Channel	0	1,338	22		7		
New Channel	0	181		52			
TOTAL	427	1,945	50	290	7	2,001	12,923

Two assessments were made to transform the data in Table 4-5. First, the total area of each of these study reaches was evaluated and a determination made as to whether or not these maximum (but not concurrent) values could be supported within a given reach (or if there simply was not enough wetted area). For example, when you add up all the maximum vegetation coverage for the Upper Spring Run reach in Table 4-5, you get 4,542 m^2. However, only 4,312 m^2 of vegetative cover is physically possible in that reach. As the Upper Spring Run reach is subject to frequent disturbance, a 75 percent (3,234 m^2) goal of that total amount was set for this reach. The 3,234 m^2 was rounded to 3,250 m^2 and carried forward in the analysis. Based on the quality of habitat present and the risk of disturbance, Landa Lake was given a 95 percent goal, Old Channel a 90 percent goal, and the New Channel a 45 percent goal.

Second, it is not appropriate to base long-term biological goals in key areas (Landa Lake and Old Channel) on non-native vegetation maximums. Accordingly, the effectiveness of restoration efforts to replace the majority of *Hygrophila* with *Ludwigia* were considered for Landa Lake and the Old Channel. (*See* Section 5.2.2) Approximately 35 percent of the total non-native *Hygrophila* was left as, realistically, it is likely not possible to remove all of it and it does provide a measure of habitat. To a much lesser degree, expansion of *Cabomba* in Landa Lake was incorporated beyond the maximum as was some restoration of *Ludwigia* at the Upper Spring Run Reach. The latter *Ludwigia* restoration needs to be done carefully (*i.e.*, planting in areas protected by *Sagittaria*) or otherwise the routine flushing of this area will limit the effectiveness of that activity.

A review of the Hardy (2010) fountain darter modeling shows that there would be sufficient quality and quantity of habitat in all four reaches at long-term average flows (*i.e.*, 225 cfs) to support the long-term biological goals for the fountain darter in the Comal system.

Both assessments resulted in adjustments to the areal coverage habitat goals. (Table 4-6). As part of the HCP long-term monitoring program, these reaches will continue to be monitored semi-annually over time. Additionally, to ensure the representative nature of each study reach to the Comal system, aquatic vegetation mapping of the entire system as well as stratified random fountain darter sampling within designated aquatic vegetation types throughout the entire system will be conducted every two years during Phase I.

Comal Springs Riffle Beetle

Long-term Biological Goals

The long-term biological goals for the Comal Springs riffle beetle involve a qualitative habitat component and quantitative population measurement. As with the fountain darter, a representative reach approach was employed. From a habitat perspective, the goal is to maintain silt-free habitat conditions via continued springflow, riparian zone protection, and recreation control throughout each of the three sample reaches (Spring Run 3, Western shoreline, and Spring Island area). (Figure 4-2). Additionally, the population measurement goal is to maintain greater than or equal to the median densities observed over the past six years of EAA Variable Flow Study monitoring.

TABLE 4-5
MAXIMUM—FOUNTAIN DARTER HABITAT (AQUATIC VEGETATION) (m^2)

Study Reach	*Bryophytes*	*Hygrophila*	*Ludwigia*	*Cabomba*	*Fil. Algae*	*Sagittaria*	*Vallisneria*
Upper Spring Run Reach	2,760	992	42			748	
Landa Lake	4,190	904	259	349		1,552	13,931
Old Channel	99	1,587	209		274		
New Channel	353	3,300	23	751			
TOTAL	7,402	6,784	533	1,100	274	2,300	13,931

TABLE 4-6
GOALS—FOUNTAIN DARTER HABITAT (AQUATIC VEGETATION) (m^2)

Study Reach	*Bryophytes*	*Hygrophila*	*Ludwigia*	*Cabomba*	*Fil. Algae*	*Sagittaria*	*Vallisneria*
Upper Spring Run Reach	1,850	650	***150***			600	
Landa Lake	4,000	***250***	***900***	***500***		1,250	13,500
Old Channel	150	***200***	***1,500***		300		
New Channel	150	1,350		350			
TOTAL	6,150	2,450	2,550	850	300	1,850	13,500

Bold/italics indicate a restoration activity that deviates from the Maximum observed.

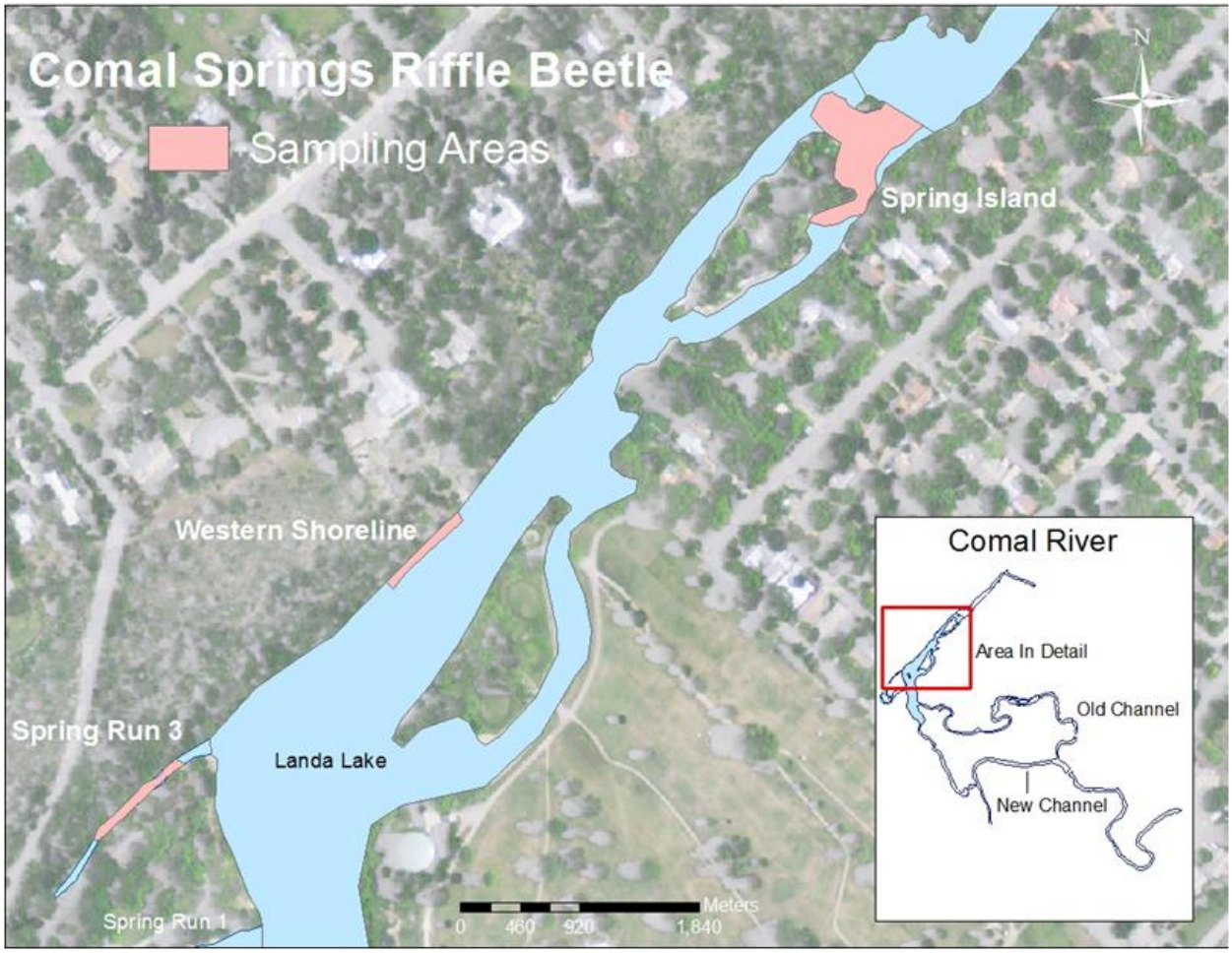

Figure 4-2. Comal Springs riffle beetle sample areas.

Table 4-7 summarizes the two components of the long-term biological goal.

TABLE 4-7
COMAL SPRINGS RIFFLE BEETLE LONG-TERM BIOLOGICAL GOALS

	Spring Run 3	Western Shoreline	Spring Island Area
Habitat	Silt-free gravel and cobble substrate ≥ 90% of each study area		
Density (# of CSRB/ Lure)	≥20	≥15	≥15

Key Management Objectives

The long-term biological goals are accompanied by two key management objectives needed to achieve the long-term biological goals. The management objectives for the Comal Springs riffle beetle in the Comal Springs/River Ecosystem are (in no particular order).

- Aquifer water quality should not exceed a 10 percent deviation (daily average) from historically recorded water quality conditions (long-term average) within the Edwards Aquifer as measured issuing from the spring openings at Comal Springs. This includes water quality constituents currently measured in the EAA Variable Flow Study. (*See* 5.7.2). This objective assumes that a 10 percent deviation would be acceptable. More extensive work to evaluate and assess water quality tolerances of the Comal Springs riffle beetle will be addressed as part of the AMP.
- Active restoration of riparian habitat adjacent to spring openings (Spring Run 3 and Western Shoreline) will be implemented to limit the sedimentation that is experienced following rainfall events.

Flow-related Objectives

The current level of uncertainty associated with the habitat-based long-term biological goals and the associated restoration and water quality management objectives necessitate the incorporation of flow-related objectives presented above in Table 4-2.

Historical and Present Day Perspective

As part of the EAA Variable Flow Study, the Comal Springs riffle beetle population is monitored at three spring upwelling reaches in and around Landa Lake. Riffle beetle monitoring occurs in spring seeps within Spring Run 3, in several springs along the western shoreline of Landa Lake, and near springs upstream of Spring Island. Table 4-8 below shows the total number of Comal Springs riffle beetles captured during each sampling event from 2004 through 2010 (BIO-WEST 2005a–2011a). Similar to fountain darter abundance data, this data is variable across sampling events. However, the riffle beetle data also suggests a relatively stable long-term trend in abundance. (BIO-WEST 2011a).

TABLE 4-8
NUMBER OF COMAL SPRINGS RIFFLE BEETLES CAPTURED DURING EACH SAMPLING EVENT VIA COTTON LURE METHODOLOGY FROM 2004 THROUGH 2010

Sample Period	Spring Run 3	Western Shore	Spring Island	TOTAL
May–June 2004	88	83	122	293
August 2004	169	143	90	402
Nov–Dec 2004	170	175	146	491
April 2005	119	121	121	361
Nov–Dec 2005	262	201	185	648
May–June 2006	256	195	160	611
Nov–Dec 2006	185	92	125	402
May–June 2007	59	161	119	339
Nov–Dec 2007	204	83	132	419
May–June 2008	155	139	156	450
Nov–Dec 2008	144	133	227	504
May–June 2009	136	226	74	436
Nov–Dec 2009	72	56	198	326
May–June 2010	53	110	20	183
Nov–Dec 2010	298	264	104	666
TOTAL	2,370	2,182	1,979	6,531
Average	158.0	145.5	131.9	458.3

Methods and Discussion

Unlike for the fountain darter habitat, it is more complex to quantify the amount (or areal coverage) of high quality habitat for the riffle beetle. A major unknown is the beetle's use of subsurface habitat. As such, the habitat-based component of this goal involves maintaining silt-free substrates (gravels and cobbles) throughout the representative sample reaches.

For the population measurement component, data collected over the past six years for the EAA Variable Flow Study was used for this analysis. The approach involved calculating the minimum, 25th, median, 75th, and maximum densities of Comal Springs riffle beetles collected per lure within the three representative sample reaches. The results are shown in Table 4-9.

TABLE 4-9
COMAL SPRINGS RIFFLE BEETLE DENSITY (#/LURE)

	Spring Run 3	Western Shoreline	Spring Island Area
Minimum	7	9	7
25th	12	13	11
Median	17	14	13
75th	21	20	16
Maximum	32	26	23

As the recent six-year trend suggests a stable population of Comal Spring riffle beetles within the sample reaches, it was decided that the median density over the past six years would serve as starting point for a long-term biological goal.

As with the other species, continued semi-annual monitoring will be conducted at each of the three representative study reaches as part of the AMP. (*See* Section 6.3.2).

Comal Springs Dryopid Beetle and Peck's Cave Amphipod

Long-term Biological Goal

The Comal Springs dryopid beetle and Peck's Cave amphipod are subterranean species inhabiting the Comal system. The subterranean nature and restricted range of the Comal Springs dryopid beetle (to the headwaters of the springs and spring upwelling areas) suggests that it does not require substantial surface discharge from springs to survive and presumes that springflow (of sufficient water quality) that continually covers the spring orifice should prevent long-term detriment to the population. EARIP (2009). Similarly, the Peck's Cave amphipod requirements include sufficient springflow covering the spring orifices and adequate water quality to prevent long-term adverse impacts to the species. (*Id.*).

As such, the long-term biological goal for these subterranean species focuses on Aquifer water quality as well as a springflow component. The water quality goal is:

- to not exceed a 10 percent deviation (daily average) from historically recorded water quality conditions (long-term average) within the Edwards Aquifer as measured issuing from the spring openings at Comal Springs.

This includes all water quality constituents currently measured in the EAA Variable Flow Study. This goal assumes that a 10 percent deviation would be acceptable; however, more extensive work to evaluate and assess water quality tolerances of these species will be addressed as part of the AMP.

Flow-related Objectives

The current level of uncertainty associated with the water quality long-term biological goal necessitates the incorporation of the flow-related objectives presented above in Table 4-2.

Quantitative population measurements were considered for each species, but not established at this time for the following reasons. The Comal Springs dryopid beetle is infrequently captured and, thus, a population metric is not practicable with available data. Peck's Cave amphipods are collected in number, but a trend of increasing numbers of individuals with increased springflow is observed. The hypothesis is that as water movement through the Aquifer increases, more individuals are expelled through the spring openings and carried away from their livable habitat. A reduction in individuals expelling from the spring openings does not necessarily suggest a reduction in the quality of Aquifer habitat for this species. As such, semi-annual drift net sampling for both species will be continued in the context of the AMP during Phase I, and this additional data will be evaluated with the intent of establishing population metrics for these species for Phase II of the HCP.

Coupled with the water quality long-term biological goal, these flow conditions should provide habitat conditions and food supplies supportive of these Aquifer species.

4.1.1.2 San Marcos Springs

Texas Wild-Rice

Long-term Biological Goal

The long-term biological goal for Texas wild-rice has been determined by an evaluation of: (1) the maximum occupied area of Texas wild-rice that has been present in the San Marcos system over time; (2) TPWD analysis of the Hardy (2010) physical habitat modeling; and (3) the 1996 USFWS recovery plan goals.

The long-term biological goal for Texas wild-rice is presented in Table 4-10 and subsequent discussion.

TABLE 4-10
LONG-TERM BIOLOGICAL GOAL FOR TEXAS WILD-RICE

River Segment	Areal Coverage (m^2)	Reach Percentage of Total Areal Coverage
Spring Lake	1,000 – 1,500	n/a
Spring Lake Dam to Rio Vista Dam	5,810 – 9,245	83 – 66
Rio Vista Dam to IH-35	910 – 1,650	13 – 12
Downstream of IH-35	280 – 3,055	4 – 22
TOTAL	8000 – 15,450	100

Key Management Objectives

The long-term biological goal is accompanied by three key management objectives needed to achieve the long-term biological goal. The management objectives for Texas wild-rice in the San Marcos Springs/River Ecosystem are (in no particular order):

- Minimum Texas wild-rice areal coverage per segment during drought of record-like conditions (Table 4-11).

- Recreation awareness throughout the whole river at all flows with designated control in the following high quality habitat areas below 100 cfs total San Marcos discharge (Table 4-12).

- Active restoration and Texas wild-rice expansion efforts and long-term monitoring focused on high-quality habitat areas.

TABLE 4-11
MINIMUM TEXAS WILD-RICE AREAL COVERAGE PER SEGMENT DURING DROUGHT OF RECORD-LIKE CONDITIONS

River Segment	Areal coverage (m^2)	Reach percentage of total areal coverage
Spring Lake	500	n/a
Spring Lake Dam to Rio Vista Dam	2,490	83
Rio Vista Dam to IH-35	390	13
Downstream of IH-35	120	4
TOTAL	3,550	100

TABLE 4-12
RECREATION AWARENESS THROUGHOUT THE WHOLE RIVER AT ALL FLOWS WITH DESIGNATED CONTROL IN THE FOLLOWING HIGH QUALITY HABITAT AREAS WHEN FLOW IS BELOW 100 CFS TOTAL SAN MARCOS DISCHARGE

Combined River Segment	TPWD Individual Segments
Spring Lake Dam to Rio Vista Dam	B, C
Rio Vista Dam to IH-35	F
Downstream of IH-35	K

Flow-related Objectives

The long-term biological goals for Texas wild-rice are defined as areal coverage over a spatial extent of the San Marcos River (*see* Table 4-10). However, because of the uncertainty associated with the long-term biological goals, the associated management objectives necessitate the flow-related objectives presented above in Table 4-13.

TABLE 4-13
LONG-TERM AVERAGE AND MINIMUM TOTAL SAN MARCOS DISCHARGE OBJECTIVES

Description	Total San Marcos Discharge (cfs)[a]	Time-step
Long-term average	140	Daily average
Minimum	45[b]	Daily average

[a] Assumes a minimum of a 50-year modeling period that includes the drought of record

[b] Not to exceed six months in duration followed by 80 cfs (daily average) flows for 3 months.

Historical and Present Day Perspective

Whole system monitoring for Texas wild-rice in the San Marcos River was initiated in 1976 and TPWD has conducted annual monitoring since 1989. (EARIP 2009). The TPWD 1976 to 2009 data set (EARIP 2009) was used for this analysis. During this time period the largest amount of Texas wild-rice in the San Marcos River was 4,277.5 m^2 measured in 2007. The areal coverage and percentage breakdown per combined river segment for the 2009 TPWD data is presented in Table 4-14.

TABLE 4-14
TEXAS WILD RICE AREAL COVERAGE AND PERCENTAGE OF BREAKDOWN PER COMBINED RIVER SEGMENT FOR THE 2009 TPWD DATA

River Segment	2009 Areal coverage (m^2)	Reach % of total areal coverage
Spring Lake Dam to Rio Vista Dam	3,345	87
Rio Vista Dam to IH-35	402	11
Downstream of IH-35	81	2
TOTAL	3,828	100

For a complete description of Texas wild-rice historical and present day conditions, see EARIP (2009) or BIO-WEST (2011b).

Methods and Discussion

The 1976 to 2009 data set (EARIP 2009) was used for this analysis. TPWD has divided the San Marcos River into 14 segments for their annual monitoring. To evaluate the potential for Texas wild-rice over time in each of these segments, the data set was used to select the largest total of Texas wild-rice in any segment regardless of year. Those totals and associated dates are presented in Table 4-15 below.

TABLE 4-15
FULL TPWD DATA SET: 1976–2009

TPWD River Segment	Areal Coverage (m^2)	Year Experienced	Combined River Segment	Reach % of total areal coverage
A	410.47	2006	Spring Lake Dam to Rio Vista Dam (A-D) – 3,785.62 m^2	76.95
B	2529.3	2007		
C	830.9	2005		
D	14.95	2008		
E	109.81	1991	Rio Vista Dam to IH-35 (E-G) – 728.8 m^2	14.81
F	550.99	2006		
G	68	1976		
H	28.67	2009	Downstream of IH-35 (H-M) – 405.23 m^2	8.24
I	12.86	1989		
X	1.04	1989		
J	120.46	1990		
K	234.94	1998		
L	6.74	2006		
M	0.52	1989		

Using this approach, the hypothetical total Texas wild-rice areal coverage for the river would have been 4,919.65 m^2. A level of conservatism (buffer) was added to this hypothetical total. The level of conservatism selected was to multiply 4,919.65 by 1.5 for a new total of 7,379.48 m^2. The multiplier of 1.5 is considered a reasonable buffer in that it provides for nearly twice the areal coverage of Texas wild-rice that has actually been recorded since measurements were started nearly three decades ago. This total was then rounded up to 7,500 m^2 and divided by the combined river segment percentages (Table 4-15 above) to come up with the goals set out in Table 4-16.

TABLE 4-16
"RECOVERY" 1.5 MULTIPLIER GOALS

River Segment	Areal coverage (m^2)	Reach percentage of total areal coverage
Spring Lake Dam to Rio Vista Dam	5,771	76.95
Rio Vista Dam to IH-35	1,111	14.81
Downstream of IH-35	618	8.24
TOTAL	7,500	100

Upon initial evaluation of these goals, it was apparent that the 618 m^2 goal for the lower segment probably was unrealistic considering the affect that the 1998 flood has had on Texas wild-rice's potential for establishment in the lower segment. The greatest amount of Texas wild-rice in this segment (combined) using all data (regardless of year) was 405.23 m^2. The greatest amount observed since the 1998 flood is 170.59 m^2. Since that 1998 flood event, this lower section has had 12 plus years to establish Texas wild-rice including several transplant efforts (under a variety of high, average, and low flow conditions) and yet it has not been able to sustain 200 m^2, and in 2009 only sustained 81.47 m^2. Therefore, it was felt that a goal of 618 m^2 for this lower segment would likely not be obtainable without significant channel modification, which likely still left the reach exposed to future flooding impacts.

As such, a subsequent analysis was conducted using the same methodology but only considering the post-1998 data which resulted in the data presented in Table 4-17:

TABLE 4-17
POST – 1998 FLOOD DATA*

TPWD River Segment	Areal Coverage (m^2)	Year Experienced	Combined River Segment	Reach % of total areal coverage
A	410.47	2006	Spring Lake Dam to Rio Vista Dam (A-D) – 3,785.62 m^2	***82.83***
B	2529.3	2007		
C	830.9	2005		
D	14.95	2008		
E	***38.67***	***1999***	Rio Vista Dam to I35 (E-G) – ***613.96*** m^2	***13.43***
F	550.99	2006		
G	***24.3***	***2008***		

H	28.67	2009	Downstream of I35 (H-M) – ***170.59*** m^2	***3.73***
I	***0***	***Post-1998***		
X	***0***	***Post-1998***		
J	***7.33***	1999		
K	***127.85***	***2004***		
L	6.74	2006		
M	***0***	***Post-1998***		

***Bold/italics** indicates a change from the full data set to the post-1998 data set.

Using the Post-1998 TPWD data and the same approach, the hypothetical total Texas wild-rice areal coverage for the river would have been 4,570.17 m^2. Taking that number times 1.5 results in 6855.26 m^2. That number was then rounded to 7,000 m^2 and used with the percentages to calculate the goals at the beginning of this section. The following table (Table 4-18) shows the comparison in total areal coverage per combined segment for the two respective data sets.

TABLE 4-18
"RECOVERY" 1.5 MULTIPLIER GOALS – POST 1998 DATA

River Segment	Post -1998 flood Areal Coverage (m^2)	Full Data Set Areal Coverage (m^2)	Difference (m^2)
Spring Lake Dam to Rio Vista Dam	5,810	5,771	+39
Rio Vista Dam to IH-35	910	1,111	-201
Downstream of IH-35	280	618	-338
Total	7,000	7,500	-500

Because of the inability of Texas wild-rice to re-establish in the lower reaches to the amounts recorded prior to that event under a full range of flow conditions, the Post-1998 data set was selected for use as the lower end of the long-term biological goal range (see Table 4-10). Even such, the 280 m^2 may be difficult to establish in the lower reach during Phase I as it is a 345 percent increase from 2009 conditions.

Second, a review of the Hardy (2010) Texas wild-rice modeling shows that there is enough quality (>0.75 suitable) Texas wild-rice potential habitat in each combined river segment to meet the long-term biological lower end goal (*see* Table 4-10) by the maximum amount plus multiplier

methodology discussed above at the flow ranges considered (45 cfs and above). It needs to be emphasized that this is modeled suitable habitat and not occupied Texas wild-rice area. The current amounts of occupied Texas wild-rice areas within this modeled quality (>0.75 suitable) habitat is lower than the long-term biological goals at all flow ranges discussed (45 cfs and above). This again emphasizes the importance of Texas wild-rice restoration activities to meet the long-term biological goals.

Subsequent to the Texas wild-rice analysis described above, TPWD reviewed an analysis conducted by the River Systems Institute based on the Hardy (2010) physical habitat model for Texas wild-rice. Its objective was to alleviate the concern regarding modeled versus occupied habitat and establish an upper end for the long-term biological goal range based on Texas wild-rice habitat potential. For this analysis, TPWD evaluated the areal coverage (m^2) of non-native species occupying Texas wild-rice habitat in the San Marcos River downstream of Spring Lake Dam at >0.75 suitability in the Hardy (2010) model. The model predicts that approximately 17,140 m^2 of non-native plants occupy potential Texas wild-rice habitat (>0.75 suitability). Realizing that even with outstanding restoration results, establishing Texas wild-rice in all 17,140 m^2 is unlikely, it made the assumption that half of that area or 8,570 m^2 would be available for Texas wild-rice. To establish the upper end of the long-term biological goal range, TPWD then took this number (8,570 m^2) added it to their 2010 mapped areal coverage (5,382 m^2) for a total of 13,951 m^2. Based on professional judgment on the potential for Spring Lake, an additional 500 m^2 of potential habitat was added bringing the total to 14,451 m^2. This value was then broken down into combined river segments, rounded and entered as the upper end of the long-term biological goal presented in Table 4-10 above. Areal coverage of three times the 2010 coverage (highest amount in recorded history) will not likely be possible within Phase I of the program. However, since Phase I measures will be implemented for the entire HCP period, setting an upper end goal provides the incentive to continue to restore and enhance Texas wild-rice within the San Marcos system during Phase II with the ultimate goal of recovery of the species.

Finally, the USFWS Recovery Plan areal coverage for Texas wild-rice recommended a range of areal coverage for the species. (USFWS 1996a). Table 4-19 shows the comparison of Post-1998 data (maximum amount of Texas wild-rice areal coverage observed in each segment) and the USFWS (1996a) recommendations.

TABLE 4-19
USFWS TEXAS WILD RICE RECOVERY PLAN RECOMMENDATIONS

TPWD River Segment	Post-1998 Maximum Observed Areal Coverage (m^2)	1996 Recovery Plan Recommended Areal Coverage (m^2)*	Percent Difference
Spring Lake	Not measured	1,500	N/A
A	410.47	1,400	341
B	2,529.3	5,000	198
C	830.9	1,000	120

D	14.95	100	669
E	38.67	500	1,293
F	550.99	900	163
G	24.3	100	412
H	28.67	50	174
I	0	30	N/A
X	0	50	N/A
J	7.33	400	5,457
K	127.85	700	548
L	6.74	100	1,484
M	0	100	N/A

*"Wild-rice plants should be present with at least the following areal coverage and distribution." (USFWS 1996)

The areal coverage per segment was "calculated to achieve an average cover of 75 percent of the potential wild-rice habitat believed to be present in each segment. This percent cover is typical of that found in healthy, vigorous stands of rice monitored over the last several years." USFWS (1996a)

Table 4-20 compares the areal coverage summed over the three described river segments using the maximum amount methodology with and the USFWS recommendations (1996a). It is evident that the 1996 recovery goals are bracketed for each reach by the long-term biological goal recommendation (*see* Table 4-10) for Texas wild-rice.

Although no minimum goal is specified in the USFWS (1996) recovery plan, a minimum goal is included in the HCP.

Fountain Darter

Long-term Biological Goals

The long-term biological goals for the fountain darter are quantified as areal coverage of habitat within three representative river reaches of the San Marcos system (Figure 4-3) and fountain darter density (population measurement) per aquatic vegetation type. These habitat-based and population measurement goals are presented in Table 4-21. The population measurement goal is to maintain greater than or equal to the median densities observed per aquatic vegetation type per system over the past 10 years of EAA Variable Flow Study monitoring.

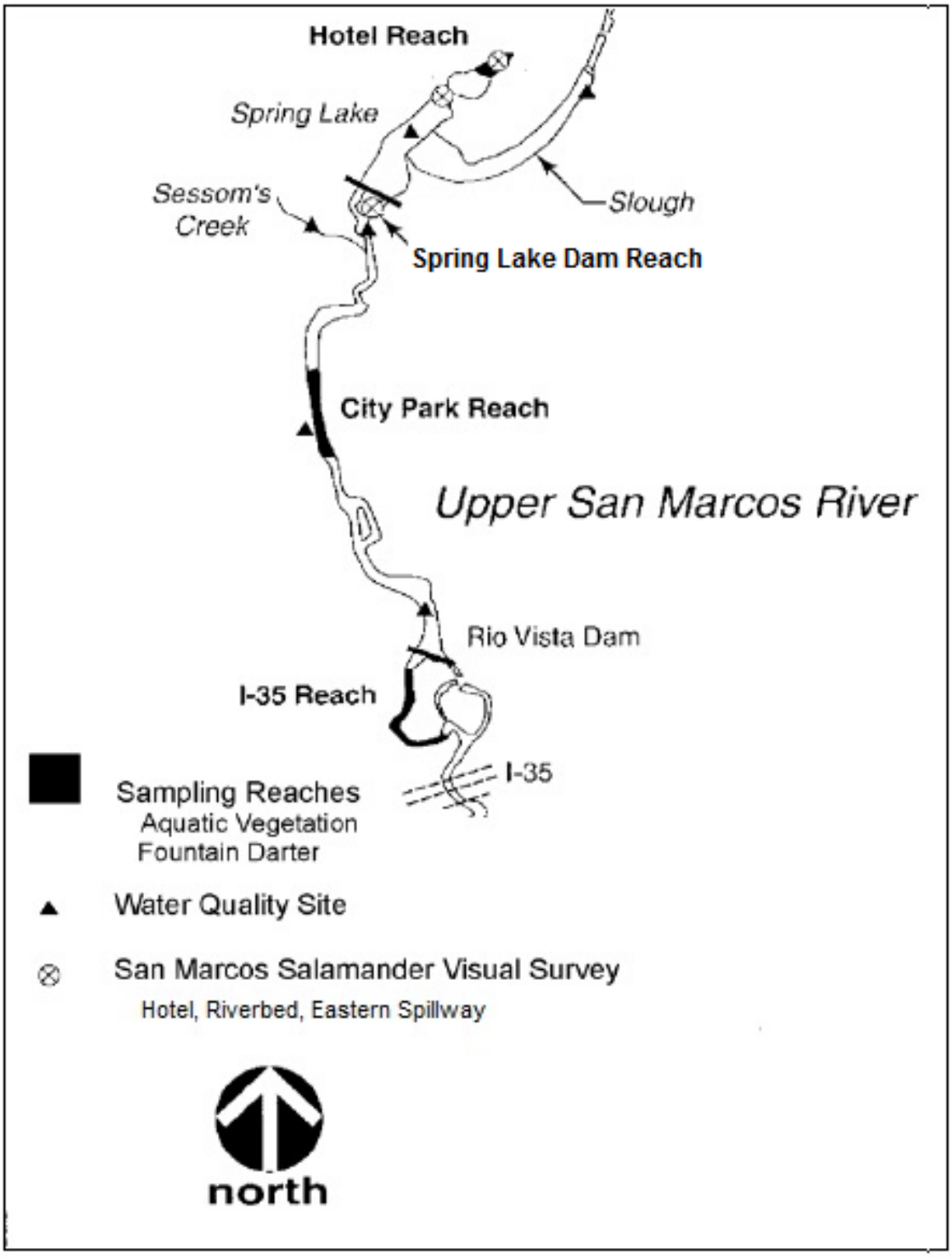

Figure 4-3. Representative Sample Reaches – San Marcos Springs

TABLE 4-20
COMPARISON OF BIOLOGICAL GOALS USING DIFFERENT METHODOLOGIES

	Proposed Goals (Maximum Area Approach)				USFWS (1996) Recommended Areal Coverage (no minimum goal specified)	
	Long-term Goal		Minimum Goal		Long-term Goal*	
River Segment*	Areal coverage (m^2)	Reach % of Total areal coverage	Areal Coverage (m^2)	Reach % of total areal coverage	Areal coverage (m^2)	Reach % of total areal coverage
Spring Lake Dam to Rio Vista Dam	5,810	83	2,490	83%	7,500	72
Rio Vista Dam to IH-35	910	13	390	13%	1,500	14
Downstream of IH-35	280	4	120	4%	1,430	14
Total	7,000	100	3,000	100%	10,430*	100

*USFWS (1996) also recommended 1,500 m^2 for Spring Lake bringing the overall total to 11,930 m^2.

TABLE 4-21
FOUNTAIN DARTER HABITAT (AQUATIC VEGETATION) IN METERS SQUARED (m^2) AND FOUNTAIN DARTER MEDIAN DENSITY (NUMBER/M^2) PER HABITAT TYPE

Fountain darter habitat (aquatic vegetation) in meters squared (m^2)							
Study Reach	*Hygrophila*	*Ludwigia*	*Cabomba*	*Hydrilla*	*Potamogeton*	*Sagittaria*	*Vallisneria*
Spring Lake Dam	50	200	25	100	1,000	100	125
City Park	200	1,000	50	500	2,000	300	50
IH-35	50	200	300	100	300	100	25
TOTAL	300	1,400	375	700	3,300	500	200
Fountain darter median density (number/m^2)							
	Hygrophila	*Ludwigia*	*Cabomba*	*Hydrilla*	*Potamogeton*	*Sagittaria*	*Vallisneria*
	4	7	7	5	5	1	1

Key Management Objectives

The long-term biological goals are accompanied by two key management objectives needed to achieve the long-term biological goals. The management objectives for the fountain darter in the San Marcos Springs/River Ecosystem are (in no particular order):

- Active native vegetation restoration and protection will be implemented in all three representative study reaches. Restoration activities will extend beyond the study reaches in equal proportion to effort expended per study reach in relation to the total river segment. For example, if 50 percent of the IH-35 study reach was restored, 50 percent of the area from Rio Vista Dam to IH-35 would be subsequently restored.
- Surface water quality within the San Marcos River should not exceed a 10 percent deviation (daily average) from historically recorded water quality conditions (long-term average) as measured at the water quality monitoring stations for the EAA Variable Flow Study (Figure 4-3). This includes water quality constituents currently measured in the EAA Variable Flow Study to be monitored per Section 5.7.2, excluding water temperature and dissolved oxygen. This objective assumes that a 10 percent deviation in average conditions would be acceptable, however, more extensive work to evaluate the validity of that assumption and to assess water quality tolerances of the fountain darter will be addressed as part of the AMP. Water temperature and dissolved oxygen will be monitored within the representative study reaches and evaluated on an instantaneous basis with established thresholds. Water temperatures <25°C will be maintained throughout the San Marcos system as to not inhibit fountain darter reproduction and recruitment over time. Dissolved oxygen concentrations >4.0 mg/L will be maintained throughout fountain darter habitat.

Flow-related Objectives

The current level of uncertainty associated with the habitat-based long-term biological goals and the associated restoration and water quality management objectives necessitate the incorporation of flow-related objectives in Table 4-13 above.

Historical and Present Day Perspective

Aquatic vegetation and fountain darters have been routinely monitored within the representative study reaches (Figure 4-3) since fall 2000. The aquatic vegetation and subsequent fountain darter densities have varied over that period (BIO-WEST 2002b-2011b). Table 4-22 breaks out the most current (spring and fall 2010) areal coverage of aquatic vegetation within each reach. (BIO-WEST 2011b).

TABLE 4-22
AREAL COVERAGE OF AQUATIC VEGETATION BY REACH—FOUNTAIN DARTER HABITAT (AQUATIC VEGETATION) (m^2)

Study Reach	*Hygrophila*	*Ludwigia*	*Cabomba*	*Hydrilla*	*Potamogeton*	*Sagittaria*	*Vallisneria*
SPRING 2010							
Spring Lake Dam	1	0	0	344	400	12	50
City Park	1,099	0	0	2,558	503	106	2
IH-35	115	8	148	169	0	37	0
TOTAL	1,214	8	148	3,071	903	155	52
FALL 2010							
Spring Lake Dam	65	4	5	201	272	6	32
City Park	1,095	0	0	1,758	562	114	
IH-35	126	14	142	185	0	19	0
TOTAL	1,286	18	147	2,145	834	138	32

From review of BIO-WEST (2002b-2011b), it is evident that the aquatic vegetation in the San Marcos system can vary considerably within any given year. As such there are inherent complexities with using habitat measures as long-term goals and thus, they cannot be used independent of long-term monitoring to evaluate these cause-and-effect relationships. For a more comprehensive description of aquatic vegetation in the San Marcos study reaches over the past decade, *see* EARIP (2009) or BIO-WEST (2002b-2011b).

Methods and Discussion

Data collected over the past 10 years for the EAA Variable Flow Study was used for this analysis. (BIO-WEST 2002b-2011b). Similar to the Texas wild-rice approach, the maximum amount of each aquatic vegetation type per study reach was selected independent of sample event and vegetation type. For instance, the highest areal coverage of *Cabomba* in the IH-35 reach was fall 2006, while Spring 2007 had the highest amount of *Sagittaria* in that same reach. As a starting point, both maximums were used even though they did not occur concurrently. Table 4-23 shows the maximum areal coverage per vegetation type within each study reach over the 10-year study period.

An exercise was then conducted to evaluate the total area of each of these study reaches and whether or not these maximum (but not concurrent) values could be supported within a given reach (or if there simply was not enough wetted area). Additionally, the long-term biological goals (areal coverage) for Texas wild-rice were incorporated into this evaluation and subtracted from the total available wetted area. This resulted in adjustments to the fountain darter biological goals for aquatic vegetation. Additionally, aquatic native vegetation restoration efforts were considered for each of the three reaches. For a recovery program, it did not seem appropriate to base long-term biological goals on non-native vegetation maximums. Approximately 20 percent of the non-native *Hygrophila* and *Hydrilla* was left in each area as, realistically, it probably is not possible to remove all of it and it does provide a measure of fountain darter habitat.

In summary, the Maximum table (immediately above) was transformed into the goals (below in Table 4-24) based on these additional assessments.

Finally, a review of the Hardy (2010) fountain darter modeling shows that there would be sufficient quality and quantity of habitat in these reaches at long-term average flows (140 cfs, in this example) to support the biological goals for the fountain darter in the San Marcos system.

As part of the HCP long-term monitoring program, these reaches would continue to be monitored semi-annually over time with additional monitoring triggered by either high-flow or low-flow events as described in the EAA Variable Flow Study. Additionally, to ensure the representative nature of each study reach to the San Marcos system, aquatic vegetation mapping of the entire system as well as stratified random fountain darter sampling within designated aquatic vegetation types throughout the entire system will be conducted every two years during Phase I.

TABLE 4-23
MAXIMUM (m^2)—FOUNTAIN DARTER HABITAT IN SAN MARCOS SPRINGS ECOSYSTEM (AQUATIC VEGETATION)

Study Reach	*Hygrophila*	*Ludwigia*	*Cabomba*	*Hydrilla*	*Potamogeton*	*Sagittaria*	*Vallisneria*
Spring Lake Dam	154	35	7	547	782	77	107
City Park	1,235	0	35	3,021	1,691	253	14
IH-35	162	22	253	382	0	72	0
TOTAL	1,552	57	295	3,950	2,473	401	121

TABLE 4-24
PROPOSED GOALS (m^2) FOR FOUNTAIN DARTER HABITAT IN SAN MARCOS SPRINGS ECOSYSTEM (AQUATIC VEGETATION)

Study Reach	*Hygrophila*	*Ludwigia*	*Cabomba*	*Hydrilla*	*Potamogeton*	*Sagittaria*	*Vallisneria*
Spring Lake Dam	50	***200***	***25***	100	1,000	100	125
City Park	200	***1,000***	***50***	500	2000	300	***50***
IH-35	50	***200***	300	100	***300***	100	***25***
TOTAL	300	1,400	375	700	3,300	500	200

***Bold/italics** indicates a restoration activity that deviates from the maximum observed.

San Marcos Salamander

Long-term Biological Goals

The long-term biological goals for the San Marcos salamander include a qualitative habitat component and a quantitative population measurement. As with the fountain darter and riffle beetle, a representative reach approach was employed. From a habitat perspective, the goal is to maintain silt-free habitat conditions via continued springflow, riparian zone protection, and recreation control throughout each of the three representative reaches (Hotel area, Riverbed area, and eastern spillway below Spring Lake Dam) (Figures 4-3, 4-4). Additionally, the population measurement goal is to maintain greater than or equal to the median densities observed over the past 10 years of monitoring. Table 4-25 summarizes long-term biological goals.

TABLE 4-25
SAN MARCOS SALAMANDER LONG-TERM BIOLOGICAL GOALS

	Hotel Area (Spring Lake)	Riverbed Area (Spring Lake)	Eastern Spillway below Spring Lake Dam
Habitat	Silt-free gravel and cobble substrate ≥ 90% of each study area		
Density (# of salamanders/m^2)	≥15	≥10	≥5

Key Management Objectives

The long-term biological goals are accompanied by two key management objectives needed to achieve the long-term biological goals. The management objectives for the San Marcos salamander in the San Marcos Springs/River Ecosystem are (in no particular order):

- Aquatic gardening at similar capacity to what has occurred over the last 10 years in Spring Lake will be continued for the Riverbed Area. This is currently being coordinated and performed by Aquarena Springs personnel. (*See* Section 5.4.3.1)
- Recreation control will be implemented in the eastern spillway below Spring Lake Dam, particularly at total San Marcos discharge of < 100cfs. (*See* Section 5.6.1).

Flow-related Objectives

The current level of uncertainty associated with the habitat-based long-term biological goals and the associated vegetation and recreation management objectives necessitate the incorporation of the flow-related objectives presented above in Table 4-13.

Historical and Present Day Perspective

As part of the EAA Variable Flow Study, San Marcos salamander is monitored at two locations within Spring Lake and just below Spring Lake dam. The monitoring occurs near the Hotel, within the Riverbed, and in the eastern spillway below Spring Lake Dam.

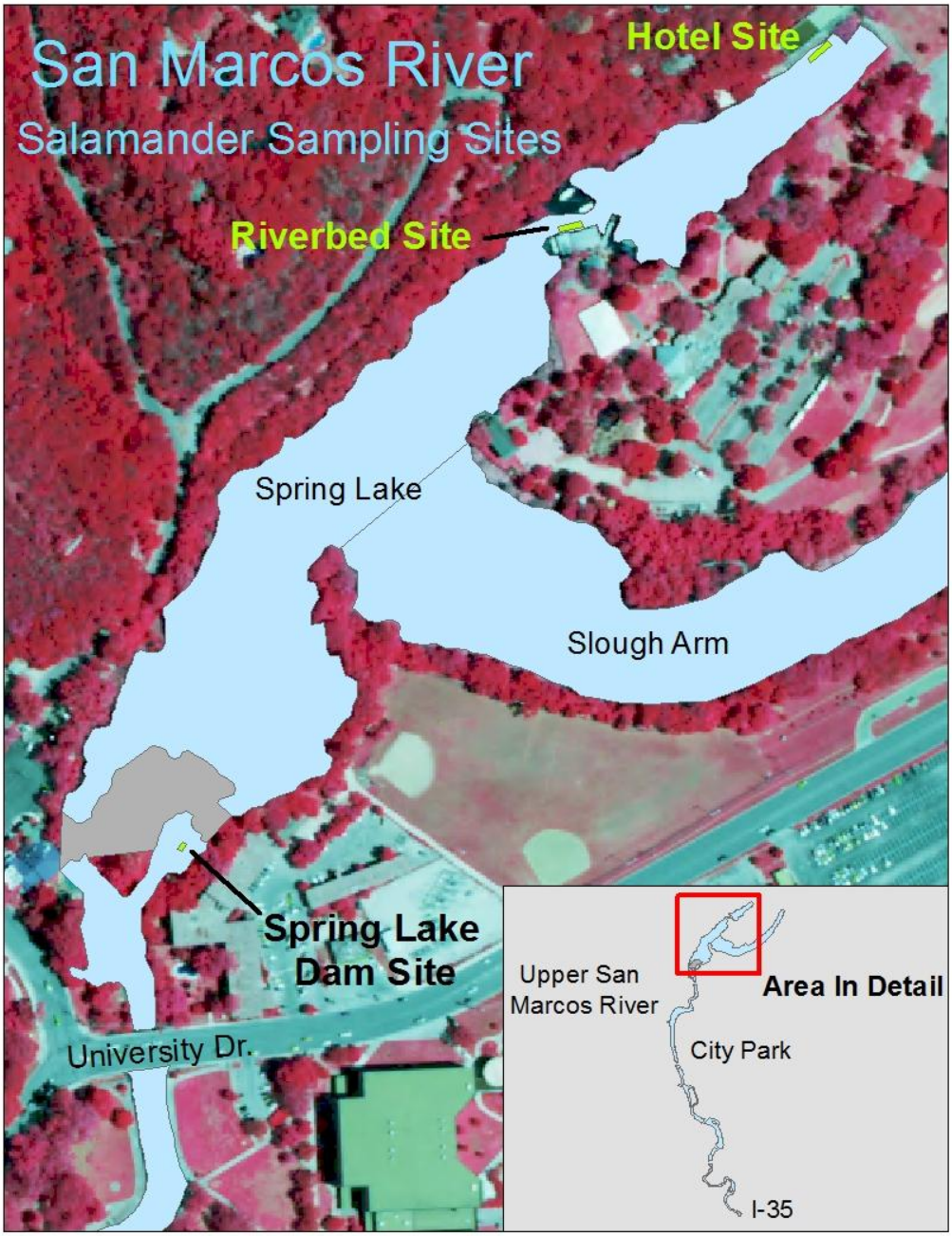

Figure 4-4. San Marcos salamander sample areas.

Table 4-26 shows the total number of San Marcos salamanders observed at each representative study reach from 2000-2010 (Spring and Fall comprehensive sampling). Similar to other species discussed, this data is quite variable across sampling events.

TABLE 4-26
SAN MARCOS SALAMANDER DENSITY (#/M^2) 2000–2010

Sampling Period	Hotel Area	Riverbed	Eastern Spillway
Fall 2000	19.4	3.4	5.2
Spring 2001	9.4	13.9	0.4
Fall 2001	10.0	6.7	3.2
Spring 2002	20.2	8.5	0.6
Fall 2002	16.8	8.7	3.0
Spring 2003	7.9	11.9	1.0
Fall 2003	11.3	9.5	2.7
Spring 2004	14.6	9.9	7.1
Fall 2004	11.7	13.7	4.5
Spring 2005	18.2	7.8	3.5
Fall 2005	11.6	12.6	12.1
Spring 2006	15.5	7.7	7.1
Spring 2007	9.0	13.7	2.8
Fall 2007	9.2	8.1	9.1
Spring 2008	16.8	12.3	6.0
Fall 2008	15.1	11.7	8.6
Spring 2009	13.7	12.1	7.4
Fall 2009	15.3	15.9	4.8
Spring 2010	17.6	23.5	5.8
Fall 2010	8.7	14.1	2.4
Average	13.6	11.3	4.9

Methods and Discussion

Unlike for the fountain darter with aquatic vegetation, it is more complex to quantify the amount (or areal coverage) of high quality habitat for the San Marcos salamander. High quality habitat consists of a synergy of clean substrates, rock sizes, aquatic vegetation, filamentous algae, with the additional complexity of the salamander's use of subsurface habitat. Because of the almost

endless combinations of those parameters and embedded complexity, we have simplified the habitat-based goals to the predominant factors of silt-free substrates, with large gravel and cobble substrates present. The habitat-based component of this goal involves maintaining silt-free substrates (gravels and cobbles) over greater than or equal to 90 percent of the fixed sampling reaches. The salamander sample reaches have predominantly fixed areas as follows:

- Hotel Area 31 m^2
- Riverbed Area 62 m^2
- Eastern Spillway 20 m^2

This fixed sample area with a known size allows one to assess the amount of total area that is sustaining high quality habitat conditions as specified in the goal.

For the population measurement, data collected over the past decade for the EAA Variable Flow study was used for this analysis. (BIO-WEST 2002a-2011a). The approach involved calculating the minimum, 25th, median, 75th, and maximum densities of San Marcos salamanders within the three study sites. The results are shown in Table 4-27.

TABLE 4-27
SAN MARCOS SALAMANDER DENSITIES (#/M^2)
2000–2010 (all sampling events included)

	Hotel Area	Riverbed	Eastern Spillway
Minimum	6.1	3.4	0.4
25th	9.9	8.3	2.8
Median	14.9	9.9	4.7
75th	17.5	13.2	7.2
Maximum	25.2	23.5	12.1

Professional judgment was employed to determine that the median density would serve as starting point for a long-term biological goal. The habitat and population goals must be met concurrently to be deemed successful. For instance, should habitat quality degrade surrounding the study area, it is possible that clumping of salamanders into the study reach would occur inflating the densities. However, if habitat was degrading outside of the study area, and the reaches are representative, soon thereafter it would also start to degrade within the representative study area. In this example, for some period of time the density goal could be met while habitat-based requirement of silt-free substrate would have failed. Another example in the other direction is the habitat goal could be met with silt-free substrates, but because of recreational influences (dam and structure building using rocks suitable for salamander habitat), the densities of salamanders might not be attainable.

As with the other species, these biological goals require a flexible long-term monitoring and adaptive management process. As such, continued semi-annual monitoring will be implemented at each of the three study areas as part of the HCP.

Texas Blind Salamander

Long-term Biological Goal

Similar to the Comal Springs dryopid beetle and Peck's Cave amphipod, the Texas blind salamander is a subterranean species. An assumption of the HCP is that as subterranean species, mechanisms exist for these species to retreat into the Aquifer should springflows cease at the spring outlets at San Marcos Springs. As such, the long-term biological goal for this subterranean species relates to Aquifer water quality. The water quality goal for the Texas blind salamander is:

- Not to exceed a 10 percent deviation (daily average) from historically recorded water quality conditions (long-term average) within the Aquifer as measured issuing from the spring openings in Spring Lake.

This includes water quality constituents currently measured in the EAA Variable Flow Study. (*See* Section 5.7.2). To be conservative, the long-term goal assumes that a 10 percent deviation would be acceptable; however, more extensive work to evaluate and assess the validity of that assumption and the water quality tolerances of the Texas blind salamander will be considered in the AMP.

Flow-related Objectives

The current level of uncertainty associated with the long-term biological goal necessitates the incorporation of the flow-related objectives presented above in Table 4-13. Coupled with the water quality goal, these flow conditions should provide habitat conditions and food supplies supportive of this Aquifer species.

Comal Springs Riffle Beetle

Due to the paucity of data for this species in the San Marcos system, it is not possible to establish specific long-term habitat-based biological goals. As such, the HCP assumes that the flow-related goals presented in Table 4-13 would be protective of this species, until such time as additional information is available. This is a reasonable assumption in that the Comal Springs riffle beetle inhabits similar areas to the San Marcos salamander with similar habitat requirements, and as such, protection of the salamander and its habitat coupled with water quality protection of the aquifer should similarly protect this species. As part of the HCP long-term monitoring program, Comal Springs riffle beetles at San Marcos Springs will be monitored semi-annually over time with additional monitoring triggered by either high-flow or low-flow events as described in the EAA Variable Flow Study.

4.2 Potential Impacts to and Incidental Take of Covered Species

The HCP must provide information as to the impacts likely to result from the incidental take of Covered Species for which ITP coverage is requested. (16 U.S.C. § 1539(a)(2)(A)(i)). As part of the review of the ITP application, the USFWS must find that "the [incidental] taking will not appreciably reduce the likelihood of survival and recovery of the species in the wild." (16 U.S.C. § 1539(a)(2)(B)(iv)). In addition, the USFWS in its biological opinion issued to address the

incidental take must make the finding that the ITP is not likely to jeopardize listed species or result in destruction or adverse modification of their critical habitat. (16 U.S.C. § 1536(a)(2)).

Section 9 of the ESA prohibits the "take" of threatened and endangered species, including the attempt or action to "harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect" such species. (16 U.S.C. § 1532). Habitat modification can result in take if either it actually kills or injures wildlife by significantly impairing essential behavioral patterns, including breeding, feeding or sheltering (*See* 50 C.F.R. § 17.3 (definitions of the term "harm").

As part of a February 1, 1993, Judgment (as amended on May 26, 1993) in the case of *Sierra Club v. Babbitt* (No. MO-91-CA-069, U.S. Dist. Ct., W.D. Texas), the Court ordered the USFWS to make, within 45-days, determinations relative to: (1) the springflow levels at which take of fountain darters and Texas blind salamanders begins at Comal and San Marcos springs, (2) springflows necessary to avoid appreciable diminution of the value of critical habitat of any listed species; (3) the springflow at which Texas wild-rice begins to be damaged or destroyed; (4) the minimum springflow to avoid jeopardy for the fountain darter, San Marcos gambusia, San Marcos salamander and Texas blind salamander; and (5) the springflow levels at which take of San Marcos gambusia and the San Marcos salamander begins at San Marcos Springs. Table 4-28 summarizes the USFWS determinations.

TABLE 4-28
USFWS 1993 DETERMINATION OF MINIMUM SPRINGFLOWS NEEDED TO PREVENT TAKE, JEOPARDY, OR ADVERSE MODIFICATION OF CRITICAL HABITAT

Species	*Take*	*Jeopardy*	*Adv. Mod.*
Fountain darter in Comal	200	100	100
Fountain darter in San Marcos	60	50*	150
San Marcos gambusia	100	100	60
San Marcos salamander	50*	N/A	100
Texas blind salamander	100	60	N/A
Damage and Destruction			
Texas wild-rice	100	100	100

NOTE: All flow rates are given in cfs.
* Refers to San Marcos springflow

USFWS explained that, because its "take" evaluation was conducted with much less data than are normally available, it was forced to base its determination on its "best professional judgment" and that its determinations were conservative. (*Sierra Club v. Babbitt*, "Springflow Determinations Regarding 'Take' of Endangered and Threatened Species," April 15, 1993) at 2). It further explained that as more information becomes available, the numbers [it was providing] "may change to more accurately reflect that best available scientific and commercial information". (*Id.*)

With respect to jeopardy, USFWS reiterated its concern regarding the "significant gaps in knowledge." (*Sierra Club v. Babbitt*, "Springflow Determinations Regarding Survival and Recovery and Critical Habitat of Endangered and Threatened Species," June 15, 1993) at 1). It explained that these gaps resulted in a "conservative approach" regarding the flow estimates. (*Id.) USFWS* found that flow levels at Comal Springs could be reduced to 60 cfs for short time periods during certain times of the year without jeopardizing the continued existence of the fountain darter if a "very effective" program to control the giant rams-horn snail was in place and if there was the ability to control the timing and duration of low springflows.

The Service also found that short-term reductions in flow levels below 100 cfs might avoid jeopardy for Texas wild-rice, if: (1) exotic species (*e.g.*, nutria) could be effectively controlled, (2) an aquifer management plan is implemented to control timing and duration of lower flows, and (3) the distribution of the species is improved throughout its historic range. The USFWS, however, did not specify what flow levels might be acceptable if those conditions were satisfied. As discussed throughout the HCP and emphasized in EARIP (2008 and 2009), since the USFWS response to the Court's order in 1993, a wealth of information regarding the Covered Species has been collected and analyzed. The purpose of Section 4.3 is to use the best available scientific information to: (1) estimate the amount of incidental take that may result from the Covered Activities; (2) evaluate the impact of that take on the survival and recovery of the Covered Species; and (3) evaluate the impacts of the Covered Activities, with the proposed minimization and mitigation measures, on the Covered Species.[2]

4.2.1 Environmental Baseline and Incidental Take Analysis Framework

To evaluate whether the incidental take resulting from Covered Activities will appreciably reduce the likelihood of the survival and recovery of the Covered Species, an "environmental baseline" must be established. The environmental baseline includes "the past and present impacts of all Federal, State, or private actions and other human activities in the action area, the anticipated impacts of all proposed Federal projects in the action area that have already undergone formal or early section 7 consultation, and the impact of State or private actions which are contemporaneous with the consultation in process."[3] (50 C.F.R. § 402.02). To determine whether the effects of the incidental take will appreciably reduce the likelihood of the survival and recovery of the Covered Species, the effects of the action and the cumulative effects[4] must be aggregated with the environmental baseline to see if together likelihood of survival and recovery is "appreciably reduced." (*Id*. at 4-35).

4.2.1.1 Elements of the Environmental Baseline for the HCP

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[2] The analysis of the impacts of take was conducted for each of the fish and wildlife Covered Species at Comal and San Marcos springs. As previously discussed in Section 1.5.3.1, Texas wild-rice does not require a take assessment under federal law as it is a plant species, but the impacts of the Covered Activities, with the minimization and mitigation measures that will be implemented, will be analyzed with respect to whether they are likely to jeopardize the continued existence of Texas wild-rice. Accordingly, information related to this analysis is presented in Section 4.2.2.10 below.

[3] "The environmental baseline is a "snapshot" of a species' health at a specified point in time." (USFWS and NMFS, 1998). It includes the "effects of past and ongoing human and natural factors leading to the current status of the species." (*Id.*).

[4] The term "cumulative effects" means "those effects of future State or private activities, not involving Federal activities, that are reasonably certain to occur within the action area … ." (50 C.F.R. § 402.02).

In 2010, the EARIP held workshops involving a multi-disciplinary team of biologists to develop influence diagrams regarding the impacts on fountain darters, Texas wild-rice, and the Comal Springs riffle beetle. (*See* Hardy 2010). These species were believed to be good indicator species for the impacts on other Covered Species. The meeting was facilitated by Ms. Jean Cochrane of the United States Geophysical Survey using Strategic Decision-Making principles. The influence diagrams were developed by consideration of both intrinsic and extrinsic factors affecting these species.

Figures 4-5 a, b, and c are examples of the influence diagrams developed in the workshops on the factors related to direct mortality of the species. A full set of the diagrams can be found in Hardy 2010.

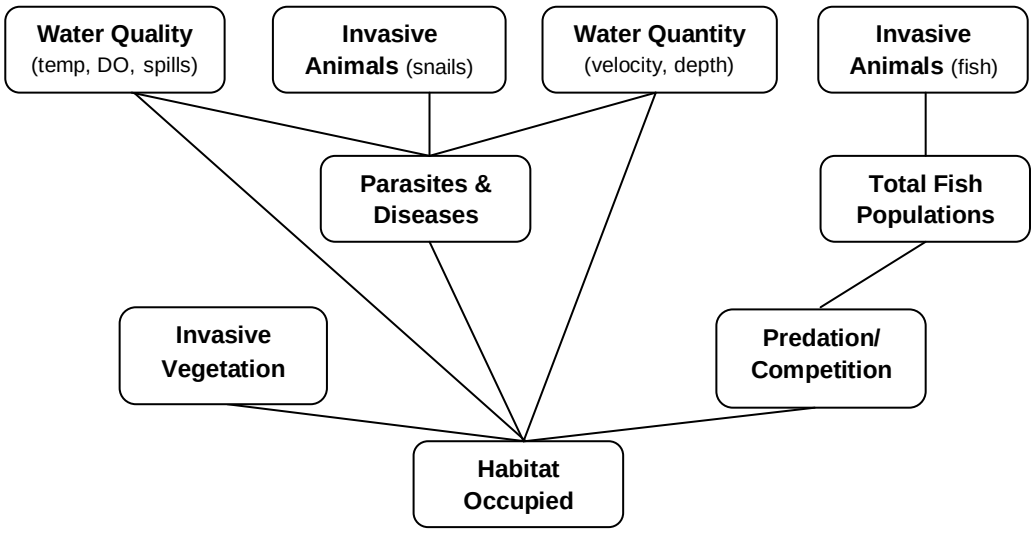

Figure 4-5a: Direct mortality factors affecting the fountain darter and its habitat.

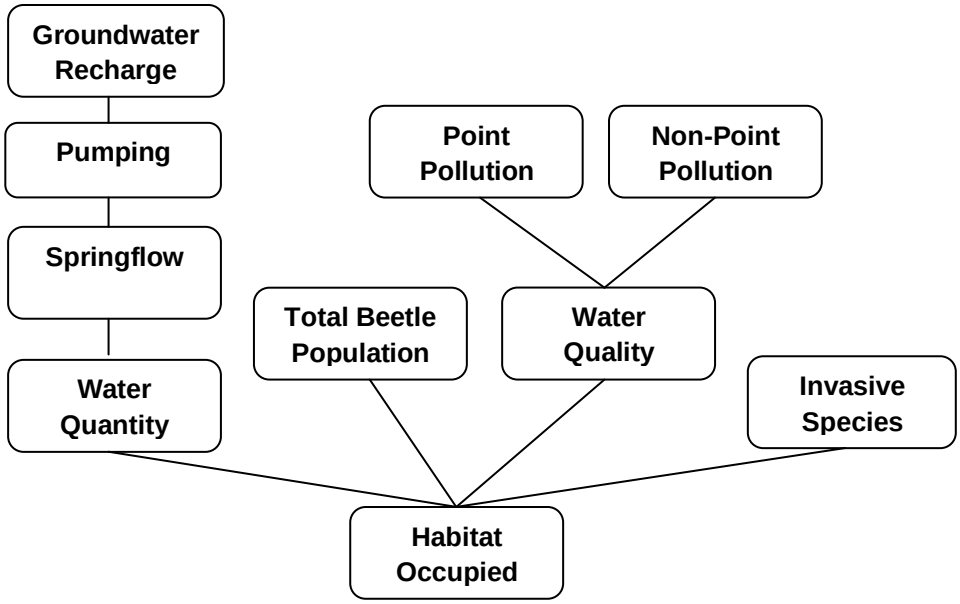

Figure 4-5b: Direct mortality factors affecting the Comal Springs riffle beetle and its habitat

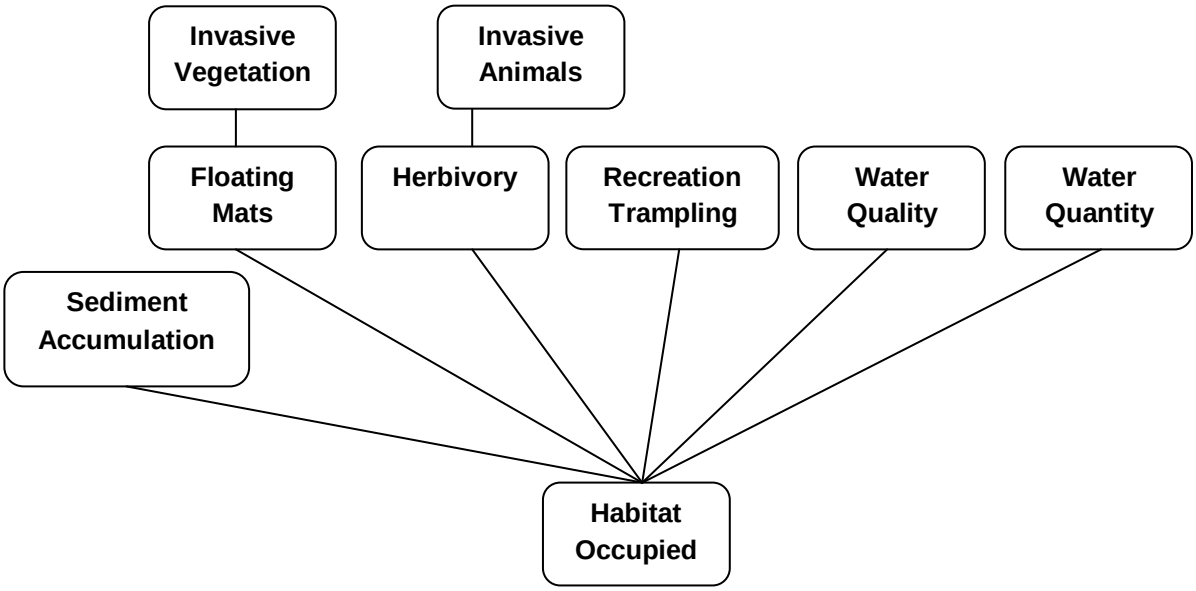

Figure 4-5c: Direct mortality factors affecting Texas wild-rice.

From the influence diagrams and other studies, it appears that the principal impacts for purposes of the baseline are: water quantity, water quality, invasive animal and plant species, sediment accumulation, and recreational impacts.

Water Quantity

Recharge and pumping from the Aquifer are factors affecting water quantity (springflow). SB 3 allows up to 572,000 ac-ft of annual permitted withdrawals from the aquifer. These withdrawals are subject to Critical Period Management reductions. (*See* 2.2.2.3). SB 3 was not effective until September 1, 2007. From 2008 through 2010, Initial Regular Permit withdrawals were 408,178 ac-ft, 377,255, ac-ft and 354,081 ac-ft. (EAA 2010b;, EAA (2011). Over the last 11 years (2000-2010) total pumping has averaged 381,218 ac-ft, with a maximum total pumping of 456,500 ac-ft in 2006 and a minimum total pumping of 317,400 ac-ft in 2004. (EAA 2010; *see* Section 3.2.2.8).

The factors affecting water quantity also include Department of Defense (DoD) pumping and exempt withdrawals for domestic and livestock use. From 2000 through 2009, the domestic and livestock withdrawals averaged 13,600 ac-ft. (EAA 2010b). In 2009, unpermitted federal wells accounted for 6,907 ac-ft in withdrawals EAA 2009) and 5,128 ac-ft in 2010 (personal communication, Rick Illgner, EAA). These withdrawals are not subject to the EAA Critical Period Management reductions.

Data for 2009 from EAA's Hydrogeologic Data Report (2010) indicate an average annual groundwater recharge of 717,500 ac-ft for the period of record 1934-2009, and an even higher

annual average of 965,400 ac-ft during the last ten year period 2000-2009. (*See* Section 3.2.2.8).

Water Quality

Water quality at San Marcos and Comal springs is influenced by both groundwater and surface water. Principal threats include stormwater runoff and releases of contaminants. Land use changes over the recharge area and/or watersheds adjacent to the springs can degrade the quality of stormwater runoff. The release of contaminants (point source and non-point source) in the recharge areas that potentially can be discharged or released to the springs, directly or indirectly, is another major threat.

The groundwater of the Aquifer has historically been considered to be of high quality. (*See* Section 3.3.2). Each year the EAA monitors the quality of water in the Aquifer by sampling approximately 80 wells, eight surface water sites, and major spring groups across the region. Tests for the wells included measurements of temperature, pH, conductivity, alkalinity, major ions, minor elements (including heavy metals), total dissolved solids, nutrients, pesticides, herbicides, VOCs, and other analytes. This well sampling does not indicate contamination in the Aquifer. However, elevated nitrate detections (greater than two mg/L) were present in 16 of the 79 wells sampled. Metals were detected above a regulatory limit in several of the 79 wells sampled.

Although the quality of the water in the Aquifer is generally good, man-made contaminants, such as pesticides and solvents, have been found in streams that recharge the Aquifer, and in the Aquifer itself. Most of the contaminants are found in urbanized areas, and most of them appear to be derived from non-point sources.

Invasives

Gill parasites, non-native plants, and invasive animal species also impact the Covered Species. A major concern in the Comal Springs ecosystem is the presence of an Asian trematode, *Centrocestus formosanus*. The parasite attaches to the fish's gill filaments causing extensive gill tissue proliferation and damage (Mitchell *et al.* 2000) with mortality in the wild being reported following the discovery in 1996 (Tom Brandt, personal communication). This trematode, which affects the gills of numerous fish species, including fountain darters, has been found at higher levels in fish from the Comal River than from the San Marcos River (Fuller and Brandt 1997). The parasite is present in the San Marcos River at low levels and is not currently considered as a threat to the fountain darter.

The giant rams-horn snail, an aquarium species that was first discovered in the San Marcos River in 1983 and in Landa Lake in 1984 poses a potential threat to Covered Species in both the Comal and San Marcos rivers ecosystems. (McKinney and Sharp 1995). This snail grazes on aquatic plants and in the 1990s played a major role in reducing plant growth. (Horne *et al*. 1992). The snails thrive in low flow conditions, and could add significantly more stress on spring associated ecosystems in time of drought. The population of rams-horn snails in these systems has diminished since the mid-1990s, however the potential for a population resurgence and alteration of the plant communities in these two systems remains, and could affect the habitat of the Covered Species. (McKinney and Sharp 1995).

Studies have shown that many fishes (especially small fish) have very similar food habitats (Hubbs *et al*. 1978). If non-native species are added to the aquatic ecosystems, greater competition or overlap among species is possible as these non-native species may be able to acquire resources with greater efficiency than native species (USFWS 1984). Aquarium

"dumps" and the use of non-native live bait have added species such as tilapia and the suckermouth catfish to both the Comal and San Marcos systems.

Scouring due to floods and sustained high flows have allowed non-native plants to occupy habitat in both the San Marcos and Comal systems. Three non-native plant species, hydrilla (*Hydrilla verticillata*), West Indian hygrophila (H*ygrophila polysperma*), and elephant ear (*Colocasia esculenta*) have significantly altered both ecosystems.

Vegetation mats interfere with Texas wild-rice by impeding flowering and reproduction, blocking sunlight, interfering with photosynthesis, and slowing current velocity. (Power 1996).

Sediment Accumulation

Sediment has accumulated in the two spring systems due to the installation of flood control dams, urbanization and natural processes. These accumulations have altered the river's morphology and natural flow patterns. In addition, deposition of sediments on or around Texas wild-rice stands causes direct mortality by smothering or burying stands.

Recreational Impacts

Recreation is a factor affecting Texas wild-rice due to trampling and physical removal ofthe plants. (Bradsby 1994; Breslin 1997). Fountain darters can be impacted by increasing turbidity and the physical destruction of their habitat. (EARIP 2009). Recreational activities such as tubing, boating, allowing pets in the water, diving and snorkeling can result in these impacts. The effect of these factors is greater at lower flows. (*Id*.). Recreation can also impact other Covered Species, such as the San Marcos salamander by physically disturbing their habitat. (*Id.*).

The minimization and mitigation measures are expected to effectively reduce most of the impacts on habitat. The specific measures addressing each impact are illustrated in Figures 4-6 a-c below along with a citation to the relevant section of the HCP where the measures are described.

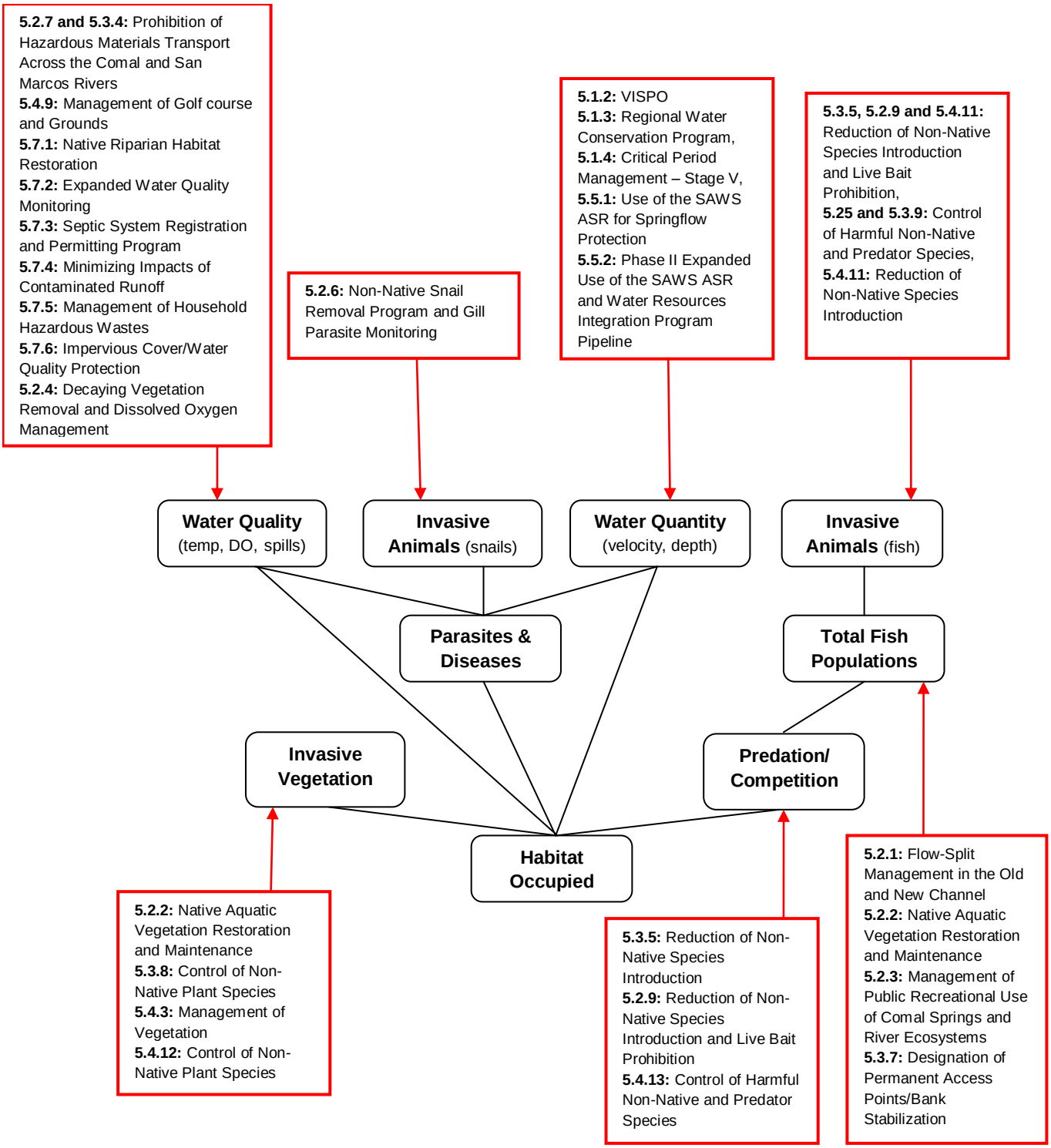

Figure 4-6a: Minimization and Mitigation Measures for fountain darter impacts.

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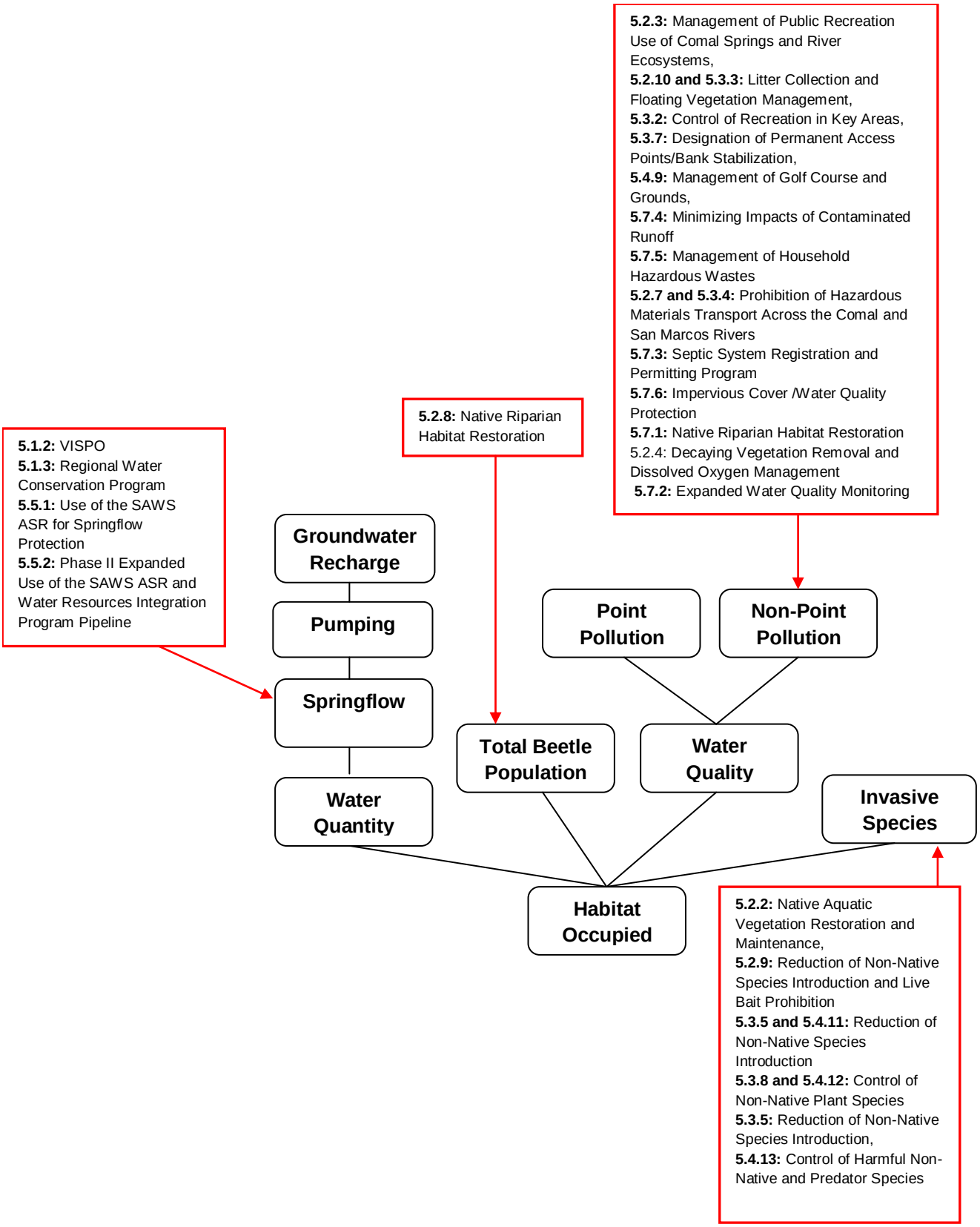

Figure 4-6b: Minimization and Mitigation Measures For the Comal Springs riffle beetle impacts

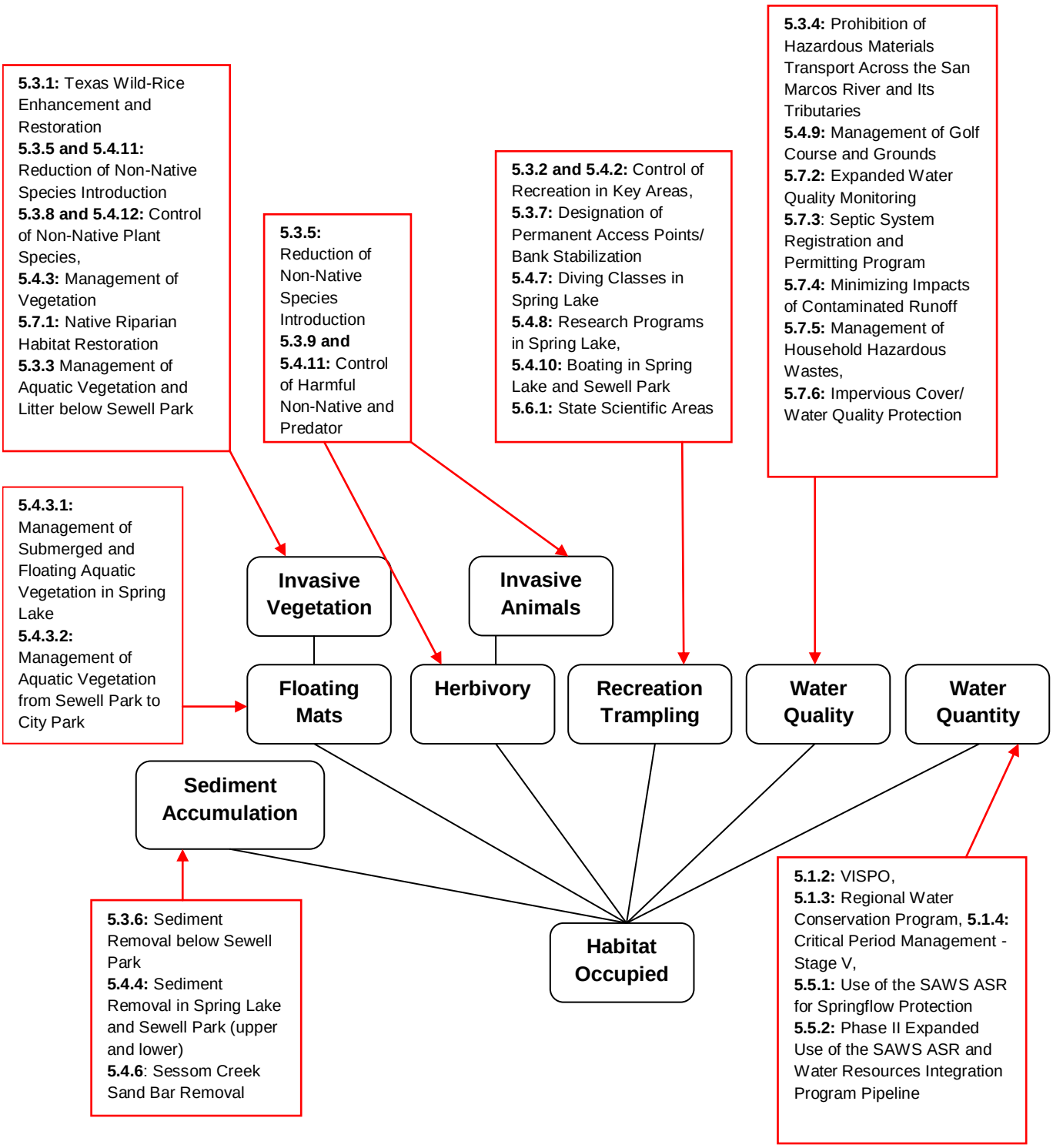

Figure 4-6c: Minimization and Mitigation Measures for Texas wild-rice.

Because the minimization and mitigation Measures are new, additional measures designed to reduce existing adverse impacts on water quality, invasive animal and plant species, recreation, and sedimentation, the aspects of the baseline conditions addressed by those measures can reasonably be expected to improve relative to the existing conditions.

4.2.1.2 Role of the Environmental Baseline in the "Appreciable Reduction" Analysis

Figure 4-7 is a depiction of a generic approach for the analytic process for the "appreciable reduction in the likelihood of survival and recovery" issuance criterion. To determine whether the effects of the incidental take will appreciably reduce the likelihood of the survival and recovery of the Covered Species, the effects of the Covered Activities and minimization and mitigation measures and the cumulative effects are aggregated with the environmental baseline.

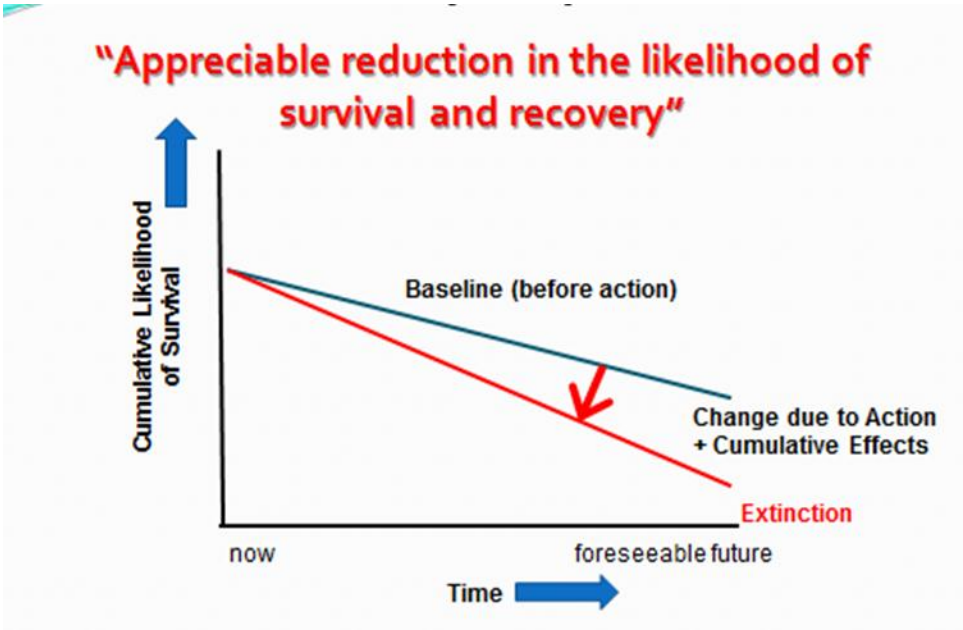

Figure 4-7. http://earip.org/MeetingArchive.aspx?MeetingType=EARIPMeetings (Adapted from presentation of Adam Zerrener, May 18, 2010).

As discussed below, as a general matter, the characterization of a reasonable baseline is a key factor in such an analysis. The generic approach to this analysis works very well where a new proposed action is being added to the baseline. It is more difficult here where the current status of the Covered Species can fluctuate dramatically depending on the amount of recharge and pumping.

Table 4-29 sets out the total withdrawals from the Aquifer from 2000 through 2010. In response to the Court's judgment in *Sierra Club v. Lujan*, in May 1993, the Texas Legislature directed EAA to cap the withdrawals authorized by permits to 450,000 ac-ft annually, but required EAA to limit withdrawals to 400,000 ac-ft by December 31, 2007, by proportionally reducing issued permits or by purchasing and retiring issued permits. In 2007, the Texas Legislature raised the pumping cap to 572,000 ac-ft (effective September 1, 2007).

YEAR	Total Pumping (1000 ac-ft)	Estimated Groundwater Recharge to the Edwards Aquifer (1000 ac-ft)[5]
2000	414.8	614.5
2001	367.7	1069.4
2002	371.3	1573.7
2003	362.1	669.0
2004	317.4	2176.1
2005	388.5	764.0
2006	454.5	201.6
2007	319.9	2162.3
2008	428.6	212.9
2009	395.8	210.9
2010	372.8	813.5
Average Pumping and Recharge 2000-2010	381.2	951.6

Table 4-29. Total Withdrawals from the Aquifer 2000-2010. (EAA 2010; personal communication, Rick Illgner, EAA (2010 data)).

Total pumping from the Aquifer averaged 381,000 ac-ft from 2000 through 2010. In the eight years prior to SB 3's enactment (2000 through 2007), total pumping averaged 374,500 ac-ft, with a maximum total pumping of 454,500 ac-ft in 2006 and a minimum total pumping of 317,400 ac-ft in 2004. (EAA 2009a).

To analyze the effect of incidental take, the HCP will utilize two approaches with respect to water quantity aspects of the baseline: a "no action" and "existing conditions" baseline. The "no action" approach assumes that none of the flow protection measures in the HCP are being implemented but that pumping at the full amount allowed by SB 3 (572,000 ac-ft) will occur subject to the existing critical period management requirements and that non-permitted exempt pumping will also occur.[6] The assumption of full pumping of the permitted amount does not reflect current pumping levels.

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[5] Groundwater recharge between 1934 and 2009 averaged 717,500 ac-ft. (*See* Section 3.3.3).

[6] As discussed above in Section 1.6, this approach also is not a true "no action" alternative because EAA's enabling legislation requires it, by December 31, 2012, to "implement and enforce management

In this respect, the "No Action" Baseline does not fall squarely within the definition of environmental baseline. While it is a past state action, the SB 3 withdrawal cap currently has had no impacts that can be evaluated in the baseline. (*See* 50 C.F.R. § 402.02 (defining the environmental baseline" as the "past and present impacts of all Federal State and private actions and other human activities in the action area.")(emphasis added)) Further, the 572,000 ac-ft pumping cap neither contributes to a "snapshot" of the current health of the species nor is it a factor that "[lead] to the current status of the species." (*See, supra*, n. 3).[7]

To provide a comparison of the effects of the Covered Activities with the flow protection minimization and mitigation measures in place to a baseline that more realistically reflects the current impacts of past and present pumping, a second baseline, the "Existing Baseline," was developed. This baseline assumes total pumping of 381,000 ac-ft, the average total level of pumping over the period from 2000-2010.

4.2.1.3. Comparisons of the Hydrographs of the No Action and Existing Baselines with the HCP

Comal Springs

Figure 4-8 compares the modeled, total monthly average springflow projected at Comal Springs for the 1947-2000 time period for the No Action Baseline, Existing Baseline, and the Phase 1-Covered Activities with springflow protection measures. (HDR 2011). For comparison, the actual historical monthly average springflows at Comal Springs are also presented. The HCP Phase II results are not depicted in Figure 4-8 for the entire modeled period as they essentially mirror the Phase I results outside of the drought of record.

The most sensitive period for the Covered Species at Comal Springs occurs during the drought of record. Figure 4-9a compares the modeled, total monthly average springflow projected at Comal Springs for the 1947-1957 time period for the No Action Baseline, Existing Baseline, and HCP (Phase I and II), along with the historically observed conditions. (HDR 2011).

To assess daily average conditions, the monthly average springflows were converted to daily average flows. (*Id.*). HDR (2011) analyzed existing discharge data for Comal Springs and concluded that at a total Comal discharge below 100 cfs, a 15 cfs plus or minus adjustment is warranted to convert a monthly average to a daily average. For example, to achieve a 30 cfs daily average at Comal Springs, as specified in the Management Objectives (Table 4-2), a monthly average flow of 45 cfs would be necessary.

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practices, procedures, and methods to ensure that, not later than December 31, 2012, the continuous minimum springflows of the Comal Springs and the San Marcos Springs are maintained to protect endangered and threatened species to the extent required by federal law." (EAA Act § 1.14(h)). That deadline has not arrived, and the EAA has not made a specific determination as to how it would satisfy this requirement. Thus, it is difficult to substitute a flow number in the "No Action" Baseline as a surrogate for the continuous minimum flow requirement. (*See* Section 1.6).

[7] As discussed further below, a simulation of the hydrograph of the historical record shows that with the "No Action" Baseline, the Covered Species, at least at Comal Springs, are likely to be extirpated because the springs cease to flow for approximately 38 months and will be significantly adversely affected, if not extirpated, at San Marcos Springs. Accordingly, almost any Covered Activities with minimization and mitigation measures which ensures minimum continuous springflow probably would not appreciably reduce the likelihood of the survival and recovery of the Covered Species even if the effects of those actions and measures would themselves jeopardize the survival and recovery of those species.

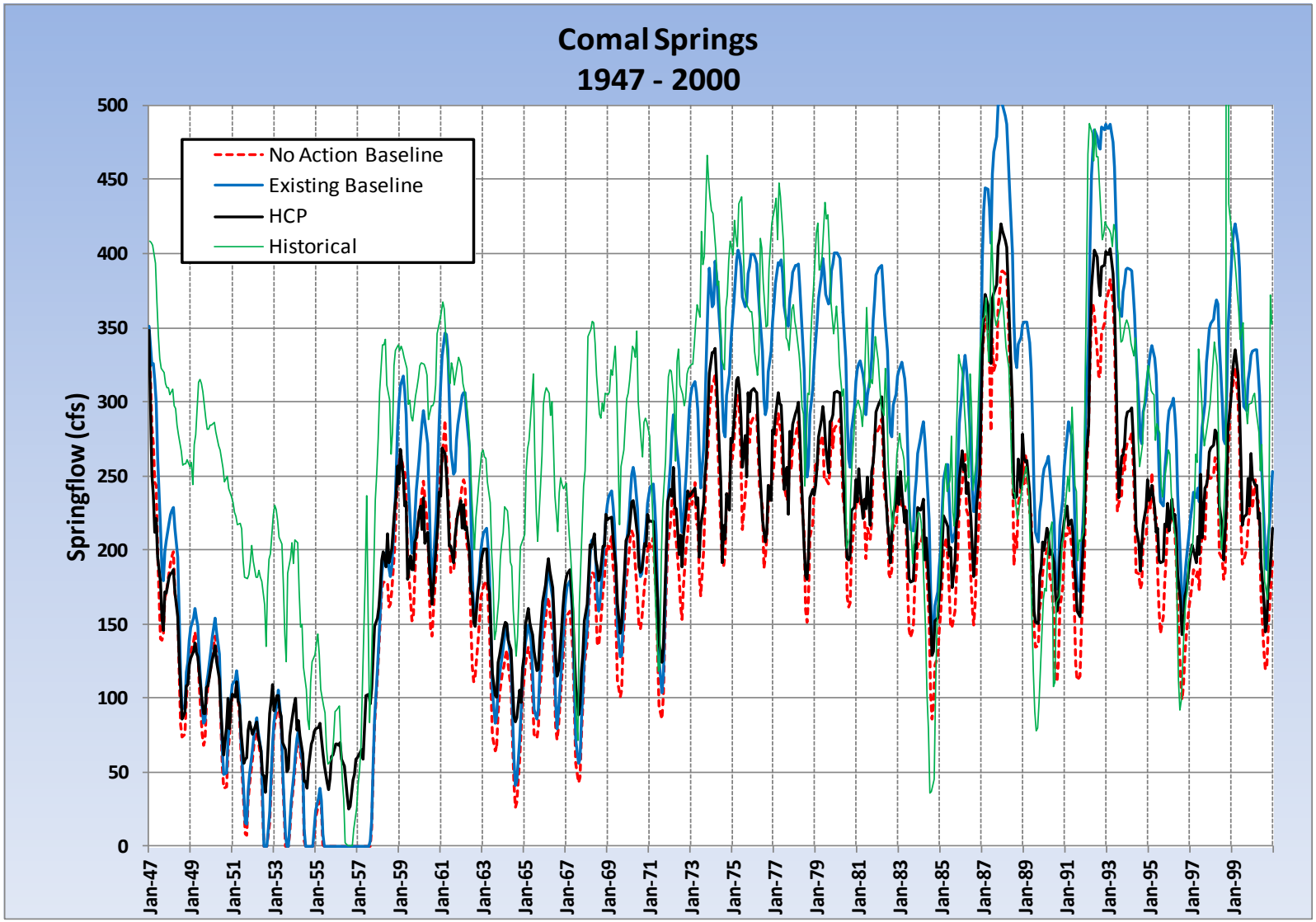


Figure 4-8. Modeled Comal Total Springflow for No Action Baseline, Existing Baseline, and HCP (Phase I) for 1947-2000 model period

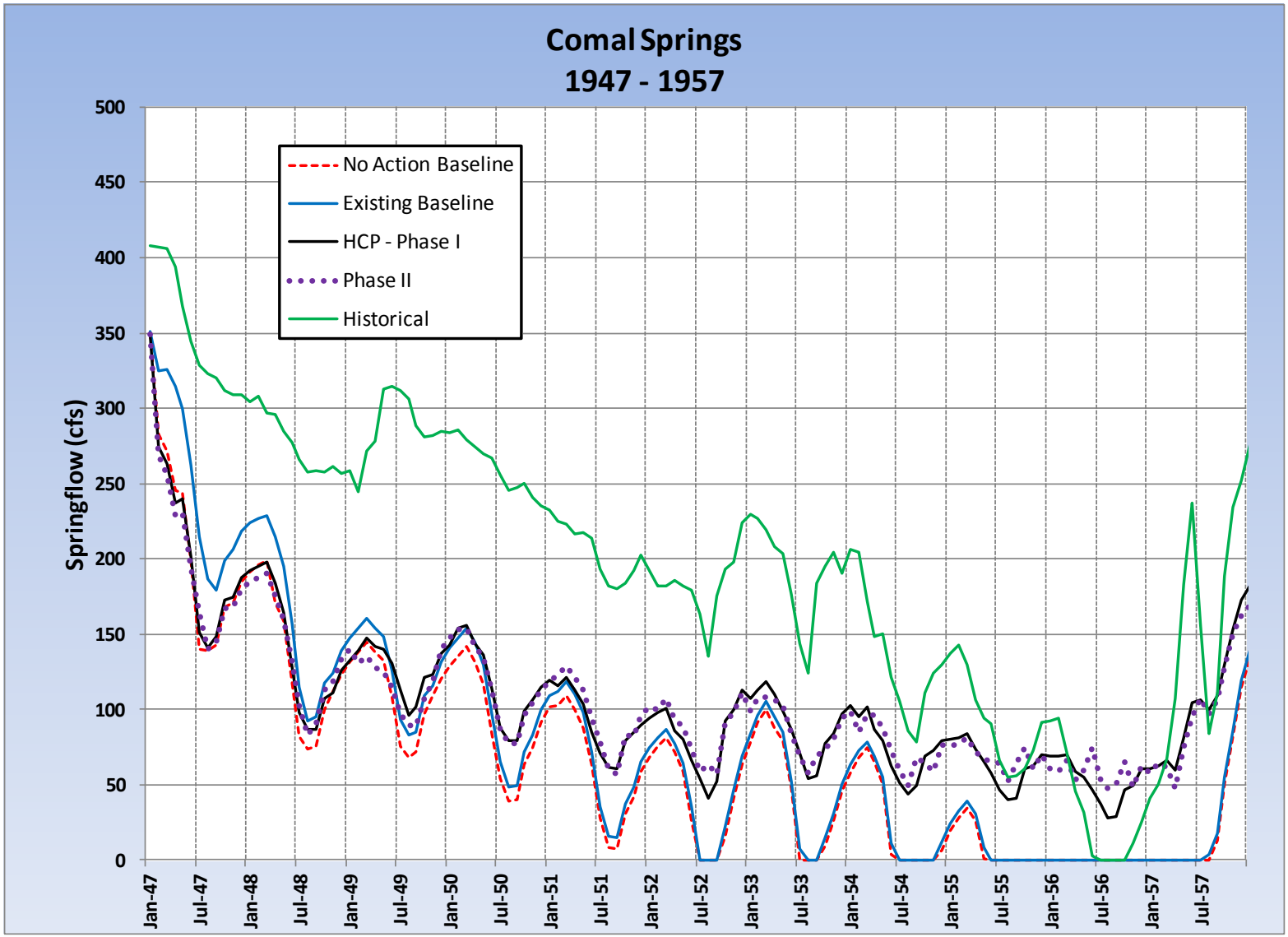


Figure 4-9a. Modeled Comal Total Springflow for No Action Baseline, Existing Baseline, and HCP (Phase I and II) for 1947-1957 model period

Table 4-30 summarizes springflow statistics from Figure 4-9(a) that are relevant to the analysis of the flows relative to the Comal flow-related management objectives described in Table 4-2.

TABLE 4-30
COMAL SPRINGS TOTAL DISCHARGE STATISTICS FOR THE MODELED NO ACTION BASELINE, EXISTING BASELINE, AND HCP (PHASE I and II) ALONG WITH THE HISTORICALLY OBSERVED DISCHARGE FROM 1947-2000.[8]

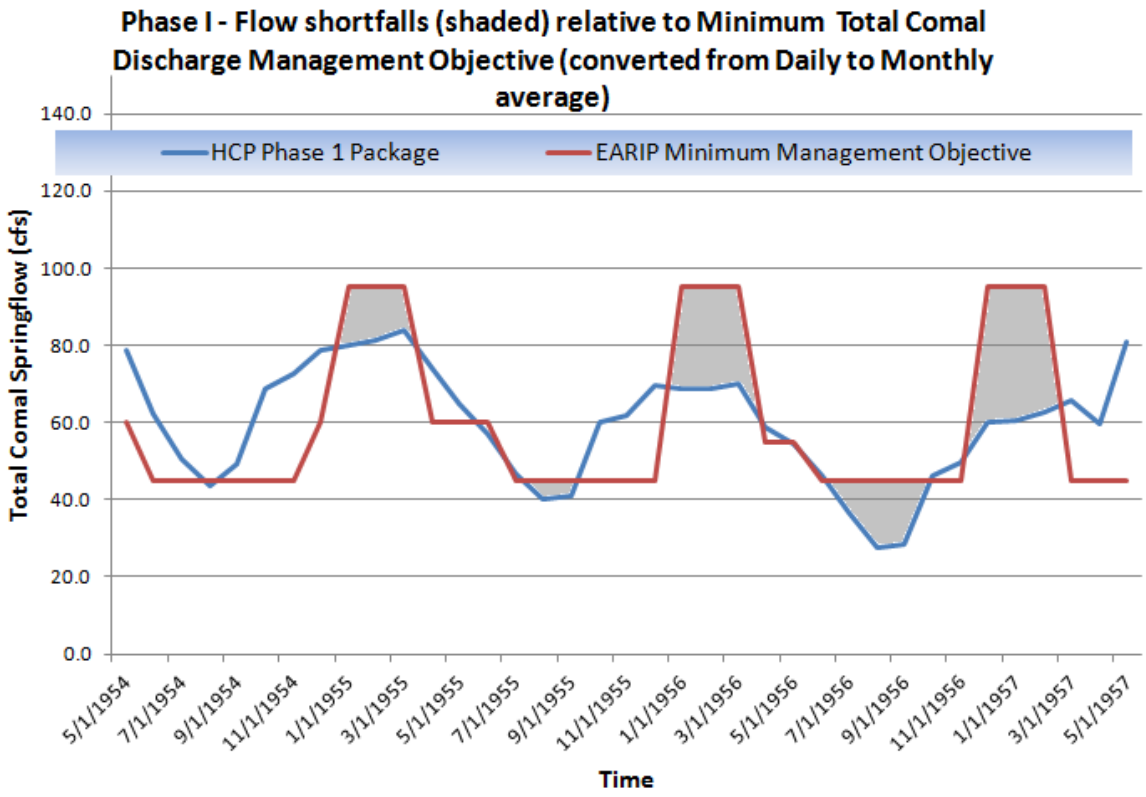
SPRINGFLOW STATISTICS (Evaluated for 1947-2000)		SCENARIO				
		No Action Baseline	Existing Baseline	HCP – Phase I	Phase II	Historical
Minimum Monthly (cfs)		0	0	27	47	0
Minimum Rolling 6 month Average (cfs)		0	0	39	54	2
Long-term Average (cfs)		178	237	196	196	274
Number of Months below	150 cfs	221	165	185	185	69
	120 cfs	157	128	127	125	51
	80 cfs	99	82	53	53	26
	45 cfs	62	56	7	0	12
	30 cfs	54	47	2	0	7
	0 cfs	38	36	0	0	4
Largest Consecutive number of Days below (approximated for modeled monthly flows)	150 cfs	3,510	2,850	2,760	2,760	1,063
	120 cfs	2,790	2,760	2,370	2,340	750
	80 cfs	1,650	1,620	780	795	384
	45 cfs	1,230	1,230	150	30	265
	30 cfs	930	885	75	0	213
	10 cfs	870	855	0	0	164

[8] Green shaded boxes represent Phase II minimum flow improvements over Phase I.

	0 cfs	855	810	0	0	144

Continuous Minimum Springflow

The minimum monthly springflow projected for the HCP Phase 1 is 27 cfs[9] and is one of only two months that is projected to fall below 30 cfs on a monthly average. (Table 4-30). By comparison, the No Action Baseline and Existing Baseline are both projected to go to zero flow for over three years. The projection that the Phase I package will maintain continuous minimum springflow is a key factor in the assessment that Covered Activities and springflow protection measures offered by the HCP will provide a significant benefit to the Covered Species at Comal Springs. The HCP during Phase I, however, falls short of achieving the minimum Comal Springs flow objective of 30 cfs daily average. Figure 4-9b highlights when the shortfalls are predicted to occur.



[9] The City of New Braunfels has a diversion used for irrigation water for its Landa Park Golf Course. (*See* Section 2.3.3). The total diversion rate allowed is 2 cfs. (*Id.*). Thus, the minimum flows could be 2 cfs less than the projected 27 cfs during a repeat of the drought of record. Taking the Phase I lowest modeled monthly flow of 27 cfs and subtracting the daily average adjustment factor of 15 cfs leaves 12 cfs in the Comal system. At this total discharge level, the flow-split management would send all 12 cfs Old Channel for the protection of fountain darter habitat within the ERPA and downstream. The potential impacts of such a low flow is minimized because the diversion is well downstream of the Old Channel ERPA and habitat and water temperature impacts would be limited in these downstream areas.

Figure 4-9b. Modeled HCP – Phase I Comal Total Discharge relative to the flow-related management objective.

During drought of record-like conditions with Phase I flow-related measures implemented, summer periods for three years would fall just short of the 45 cfs monthly average (converted from the management objective of 30 cfs daily average). Additionally, the higher flows (management objective of 80 cfs daily average – converted to 95 cfs monthly average for Figure 4-9b) for three months following any six month minimum period would also fall short as depicted in Figure 4-9b.

By comparison, Phase II achieves the minimum Comal Springs flow management objective of 30 cfs daily average but is not projected to meet the 80 cfs higher flows for 3 months following the lower flow periods (Figure 4-9c).

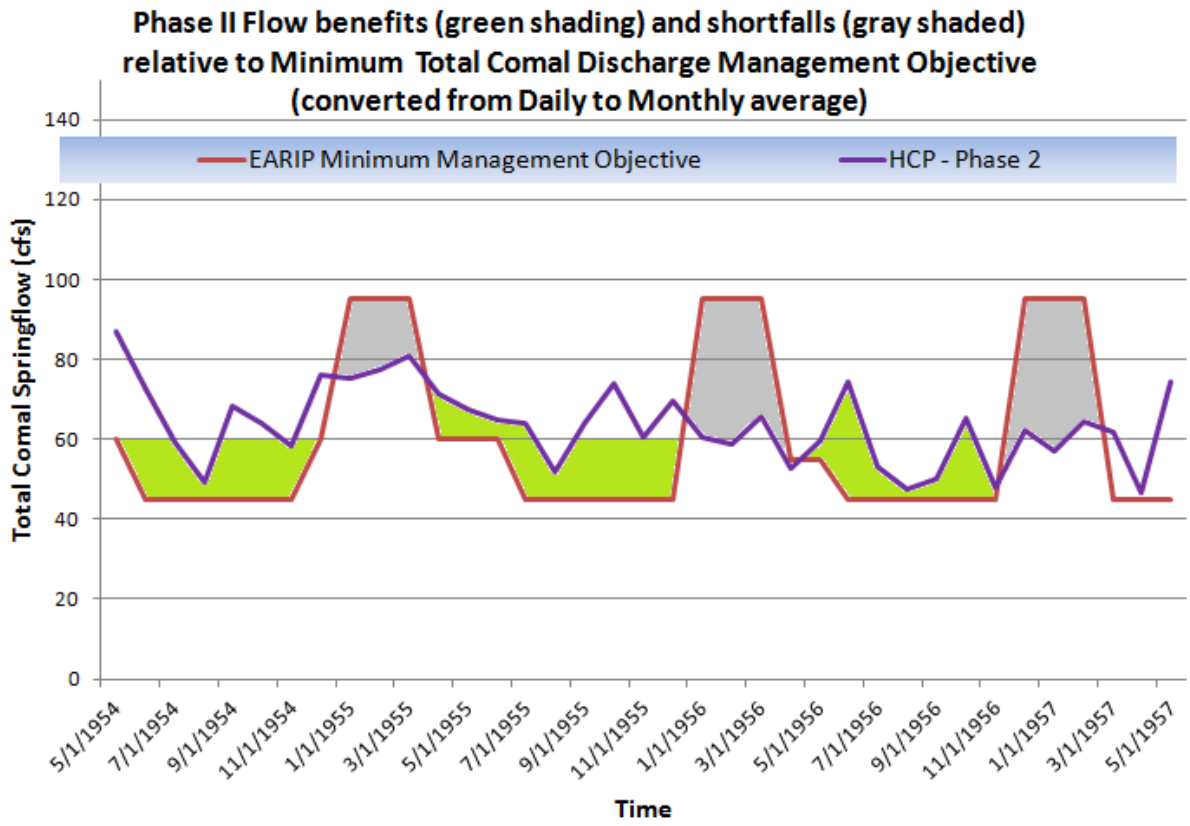


Figure 4-9c. Modeled HCP – Phase II Comal Total Discharge relative to the minimum flow management objective.

During the historical conditions, the fountain darter was extirpated from the Comal system but the other Covered Species were not. The shortfalls described in Figures 4-9b and 4-9c are not considered to be a detriment to the Comal Springs dryopid beetle, Edwards Aquifer diving beetle, Peck's Cave amphipod, or Comal Springs salamander. A key reason for the 80 cfs higher flow periods following extended minimum conditions is to provide surface flow in Spring Run 3 and break up the periods of extended low flows in the system. As discussed in the long-term average section below, the results of this flow management objective shortfall (Figures 4-9b and 4-9c) is currently unknown relative to the Comal Springs riffle beetle spring run populations. However, the improvement of minimum flows relative to historical conditions and the overall projected habitat remaining along the western shoreline and around Spring Island

(see Section 4.2.2.3) is considered sufficient to support the survival of the Comal Springs riffle beetle in the Comal system during Phase I AMP activities.

Relative to the fountain darter, the high quality habitat to be maintained in the Old Channel ERPA and in Landa Lake during this three year period will be adequate to support seasonal reproduction and survival of the fountain darter. Further, the documented ability for fountain darter habitat to recover quickly with a return to more normal discharge conditions was a key factor in determining the potential for recovery. An additional factor is that within the seven years of Phase I, it is not possible to have multiple, extended drought of record-like conditions.

Long-Term Average Flows

Although the minimum flows should not be a concern, the overall health of the system going into those periods needs further evaluation before such a conclusion can be reached with respect to the projected long-term average flows. The flow-related measures in the HCP (Phase I and II) are projected to achieve a long-term average of 196 cfs compared to the current Management Objective of 225 cfs for a long-term average at Comal Springs. (Table 4-2). At this time, it is uncertain whether 196 cfs as a long-term average would be supportive of the conditions necessary to rejuvenate the system to the degree that would be necessary to prepare the system for repeated low-flow periods or extended low-flow periods. This rejuvenation of habitat is important not only to the fountain darter, but to all Covered Species at Comal Springs. This question will be examined in the AMP.

In addition, the projected extended periods of consecutive days below 150 cfs, 120 cfs, and 80 cfs for the HCP will require additional evaluation during the Phase I AMP. Each of those three flow levels is a take threshold. At 150 cfs, take for the fountain darter starts to occur in the Upper Spring Run reach. At 120 cfs, Spring Runs 1 and 2 start to constrict and go subsurface, and below 80 cfs Spring Run 3 also constricts and goes subsurface. Relative to the fountain darter, during the drought of record the system was below 150 cfs for 1,063 straight days (nearly 3 years). With the Phase I and Phase II flow-related measures in the HCP, the consecutive period below 150 cfs is projected to be approximately 2,760 days (or over 7.5 years). That is longer than the Phase I period itself, and approximately 3 times the life span of a fountain darter in the wild. With respect to the Comal Springs riffle beetle, during the drought of record, springflow in the Spring Runs 1 and 2 were below 120 cfs for 750 consecutive days (just over 2 years straight) and the riffle beetle as well as the other Covered invertebrate species survived. However, even with the flow-related measures (Phase I and II), flows below 120 cfs are projected for approximately 2,400 consecutive days (over 6.5 years).

During Phase I, applied research on the effects of low flows on the species and their habitat will be conducted, mechanistic ecological models with be developed and applied, and the MODFLOW model used to simulate the effects of the Phase I package will be improved. Until the Phase I AMP decision-making process is complete, it will not be known what durations might be acceptable or the amount of additional flows that might be needed. To address the need now to demonstrate the ability to achieve the current Comal System minimum flow objective, the Applicants have committed to implement a “presumptive” action that, when combined with the Phase I activities, is adequate to achieve the current minimum flow Objective if such an action is needed.

In summary, incidental take of the Covered Species at Comal Springs will occur under the HCP and uncertainty regarding extended periods of low-flow is present should a repeat of drought of record-like conditions occur for the entire Phase I period. However, considering the low risk of that occurrence and the improvements over baseline that the HCP provides regarding minimum flows, the Phase I package is not anticipated to appreciably reduce the likelihood of survival of

the Covered Species at Comal Springs or affect their potential for recovery. With the AMP activities scheduled during Phase I and the presumptive action to meet the minimum flow objective during Phase II, incidental take will continue to occur during Phase II, but should not appreciably reduce the likelihood of survival of the Covered Species at Comal Springs or affect their potential for recovery.

San Marcos Springs

Figure 4-10a depicts the modeled, total monthly average springflow projected at San Marcos Springs for the 1947-2000 time period for the No Action Baseline, Existing Baseline and the HCP (Phase I - springflow protection measures). (*See* HDR 2011). For comparison the actual observed monthly average springflows at San Marcos Springs are also presented. The HCP Phase II results are not depicted in Figure 4-10a for the entire modeled period as they essentially mirror the Phase I results outside of the drought of record. The most critical period for the Covered Species at San Marcos Springs occurs during the modeled condition surrounding the drought of record. Figure 4-10b compares the modeled, total monthly average springflow projected at San Marcos Springs for the 1947-1957 time period for the No Action Baseline, Existing Baseline, and HCP (Phase I and II), along with the historically observed conditions. (*Id.*).

To assess daily average conditions, the monthly average springflows were converted to daily average flows. (*Id.*). A detailed analysis of existing discharge data for San Marcos Springs concluded that at Total San Marcos Discharge below 100 cfs, a 7 cfs plus or minus adjustment is warranted relative to converting a monthly average to a daily average. HDR (2011). For example, to achieve a 45 cfs daily average as specified in the Flow-Related Management Objectives (Table 4-13), a monthly average flow of 52 cfs would be necessary.

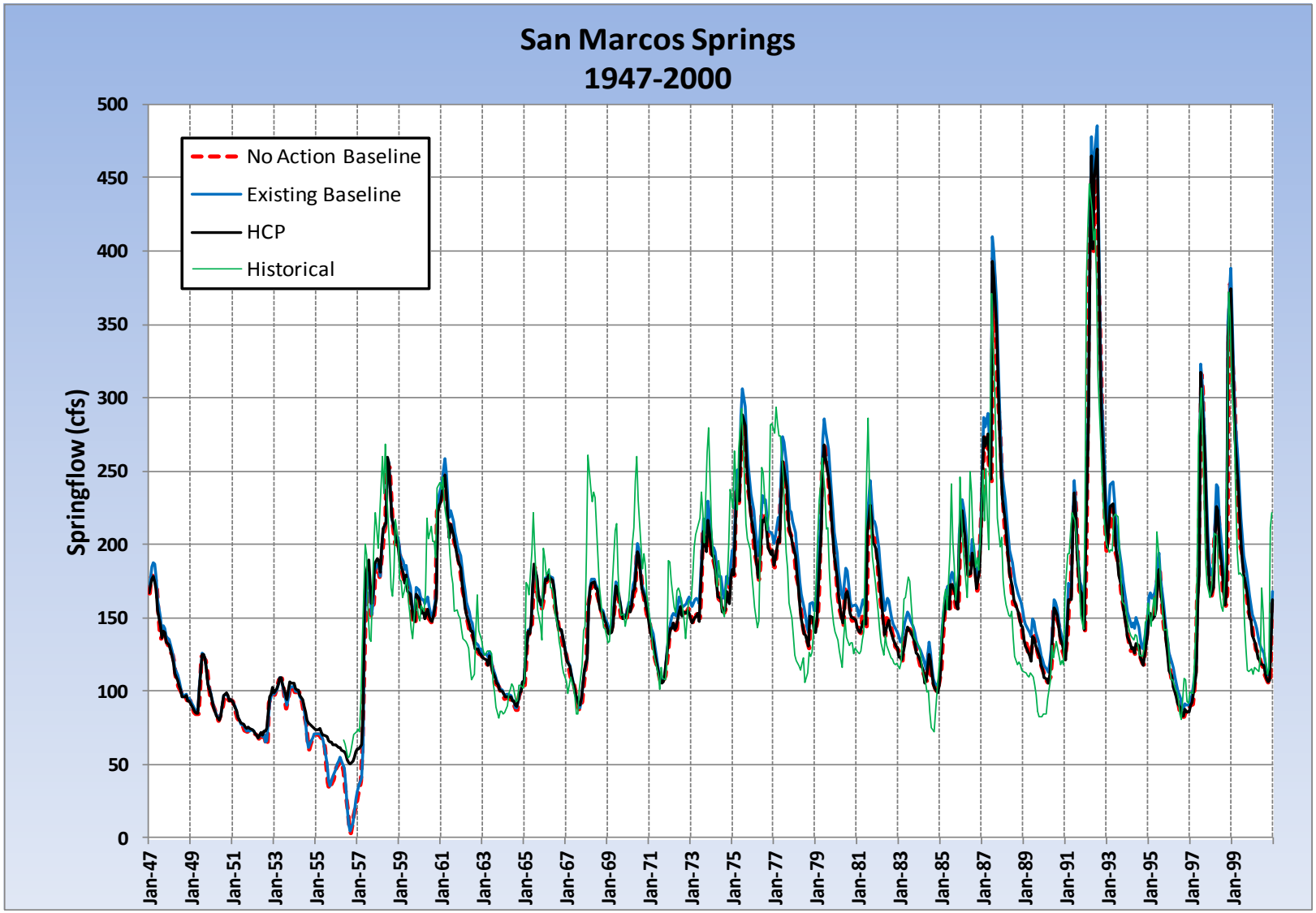


Figure 4-10a. Modeled San Marcos Total Springflow for No Action Baseline, Existing Baseline, and HCP (Phase I) for 1947-2000 model period. (Historical record starts in summer 1956 following gage installation)

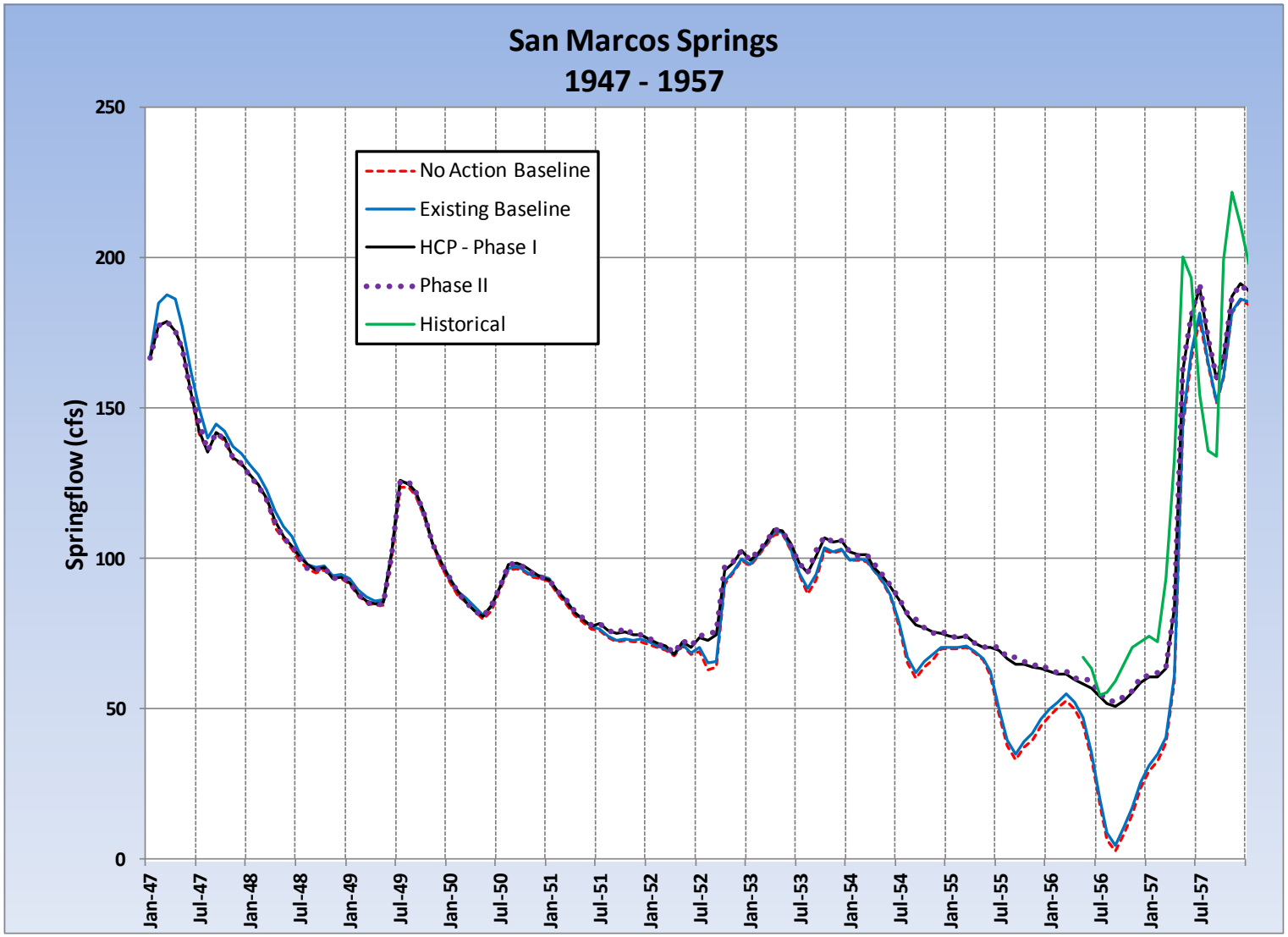


Figure 4-10b. Modeled San Marcos Total Springflow for the No Action Baseline, Existing Baseline, and HCP (Phase I and II) for 1947-1957 model period. (Historical record starts in summer 1956 following gage installation)

Table 4-31 summarizes certain springflow statistics from Figure 10a that are relevant to the Total San Marcos Discharge Management Objectives described in Table 4-13.

TABLE 4-31
SAN MARCOS SPRINGS TOTAL DISCHARGE STATISTICS FOR THE MODELED NO ACTION BASELINE, EXISTING BASELINE, AND HCP (PHASE I and II) ALONG WITH THE HISTORICALLY OBSERVED DISCHARGE FROM 1947-2000.

SPRINGFLOW STATISTICS (Evaluated for 1947-2000)		SCENARIO				
		No Action Baseline	Existing Baseline	HCP – Phase I	Phase II	Historical
Minimum Monthly (cfs)		2	5	51	52	54
Minimum Rolling 6 month Average (cfs)		12	14	53	55	60
Long-term Average (cfs)		153	160	155	155	168
Number of Months below	100 cfs	121	113	114	114	*
	80 cfs	52	51	48	47	*
	50 cfs	19	17	0	0	*
	30 cfs	7	6	0	0	*
	10 cfs	3	2	0	0	*
Largest Consecutive number of Days below (approximated for modeled monthly flows)	100 cfs	1,215	1,215	1,125	1,125	*
	80 cfs	1,020	1,020	960	945	*
	50 cfs	375	345	30	15	*
	30 cfs	240	210	0	0	*
	10 cfs	120	75	0	0	*
	0 cfs	30	30	0	0	*

* Not an equal comparison to calculate the number of months below or longest consecutive days for the observed springflows as the gage was not active until May 1956 when the greatest number of months below and longest consecutive days for all modeled runs occurs from 1954 through 1956.

Continuous Minimum Springflow

The minimum monthly springflow projected for the Phase I Package is 50.5 cfs and is one of only two months that is projected to fall below the Management Objective of 52 cfs on a monthly average (50.5 and 51.5 cfs monthly averages). By comparison, the No Action Baseline and Existing Baseline are projected to decline to a 2 and 5 cfs monthly average, respectively. The HCP Phase I is not projected to have a monthly average less than 50 cfs, while the No Action Baseline projects 19 months below 50 cfs and the Existing Baseline projects 17 months below 50 cfs.

Phase II provides an improvement over Phase I in that no months fall below the 52 cfs San Marcos minimum flow management objective.[10] That the projected springflow closely approximates the minimum flow objective is a key factor in the impact assessment in that Covered Activities and springflow protection measures offered by the HCP will provide a significant benefit to the Covered Species at San Marcos Springs from a minimum flow perspective. Although Phase II meets the minimum flow management objective, neither Phase I or Phase II meet the higher flows (management objective of 80 cfs daily average – converted to 87 cfs monthly average for Figure 4-10c) for three months following any six month minimum period. Figure 4-10c highlights when the shortfalls are predicted to occur.

[10] Under TCEQ Certificates 18-3865 and 18-3866, Texas State University's total diversion rate from the headwaters of the San Marcos River for consumptive use is limited to 8.1 cfs. (*See* Section 2.5.5). The total diversion rate from Spring Lake is limited to 4.88 cfs; the total diversion rate from the San Marcos River at Sewell Park is limited to 3.22 cfs. (Section 2.5.5.1 and 2.5.5.2 respectively). Texas State will reduce the rate of diversion by 2 cfs at flows of 80 and 60 cfs and suspend the diversion of water entirely at 45 cfs based on a daily average. (*See* Section 4.5.4). Thus, Texas State's diversions will not affect the projection that the flows at San Marcos during Phase I will not fall below the minimum flow management objective.

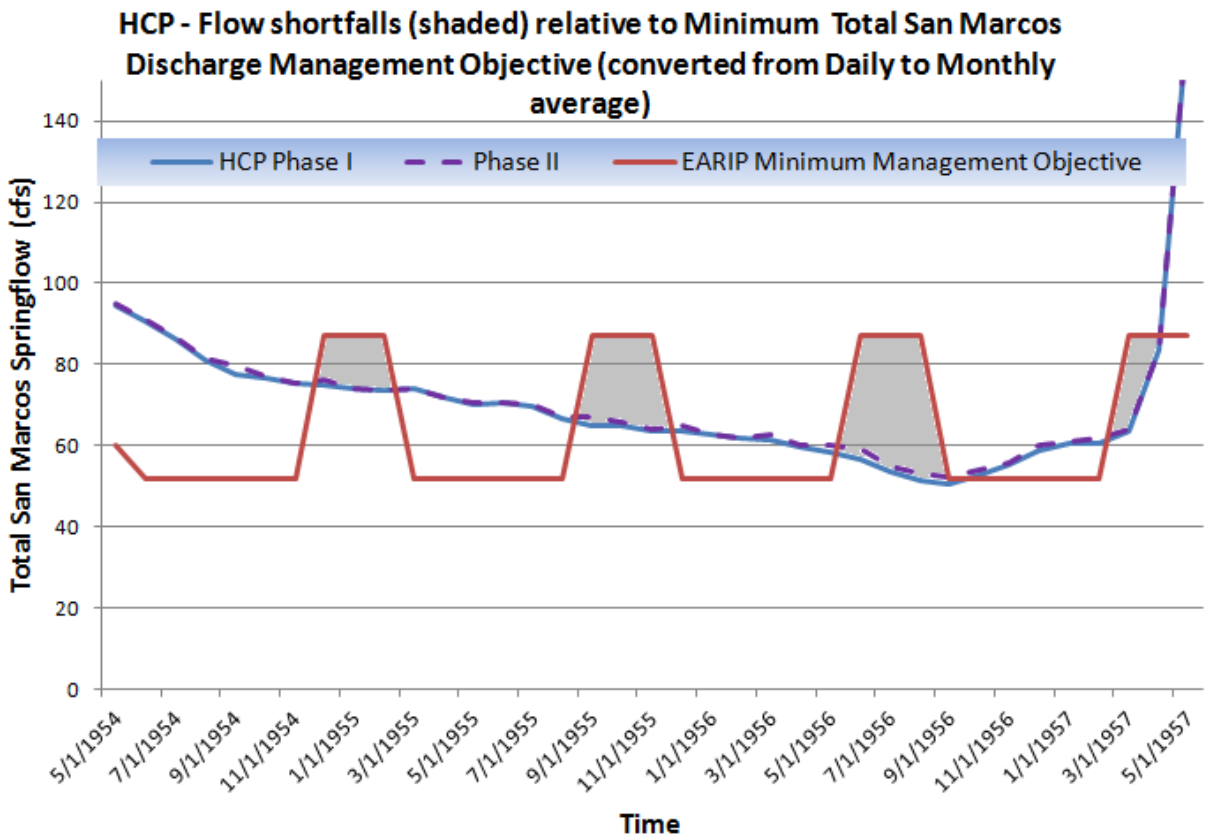


Figure 4-10c. Modeled HCP – Phase I and Phase II San Marcos Total Discharge relative to the higher flows component of the minimum flow objective.

A discussion of the potential effects of not achieving this component of the management objective is discussed in the long-term average section below.

Long-Term Average Springflow

Unlike for the Comal System where the long-term average Flow Management Objective is not met by the HCP, the 154 cfs long-term average projected for the HCP at San Marcos is greater than the Management Objective of 140 cfs. Therefore, the overall health of the system going into these limited minimum flow conditions should be protected by springflow and additional mitigation and minimization measures and subsequently, the ability of the system to rejuvenate quickly following said events will also be benefited by a long-term average of greater than the Management Objective.

Although the projected long-term average flows are not concerns, the extended periods of consecutive daily average flows under 100 cfs and 80 cfs were examined. At 100 cfs, take for the fountain darter and impacts to Texas wild-rice have been documented. At 80 cfs, take is anticipated for the San Marcos salamander. Unfortunately, there is not a duration factor (*i.e,* memory) incorporated into any of the basic habitat modeling conducted for the incidental take analysis presented below. As such, a future evaluation of these potential impacts will be addressed with Phase I applied research and mechanistic ecological modeling. In the interim, the amount of high quality habitat predicted by Hardy (2011) for the fountain darter at flows between 50 and 100 cfs coupled with recreation control in key areas provides comfort that the fountain darter will tolerate these extended periods of flows in this range. The majority of San

Marcos salamander habitat is in Spring Lake and thus, the assessment of 50 to 100 cfs applies mainly to the small area of salamander habitat below Spring Lake Dam. As for the fountain darter, the habitat projected for the San Marcos salamander below Spring Lake Dam between 50 and 100 cfs coupled with recreation control in that area provides comfort that extended periods of flows in these ranges would be tolerated by this species.

Texas wild-rice is the one Covered Species that would be adversely affected if extended periods of flows below 100 and/or 80 cfs would occur under current conditions. For instance, the HCP scenario projects, during drought of record-like conditions, approximately 1,125 consecutive days (just over 3 years) of springflow below 100 cfs, and approximately 960 consecutive days (just over 2.5 years) below 80 cfs. During 2009, total San Marcos discharge was below 100 cfs for 243 days; this is the second highest number of days under 100 cfs during the period of record for the San Marcos River. During that period in 2009, reduced springflow and intense recreational pressure resulted in nearly a 17 percent reduction in overall coverage of Texas wild-rice in the San Marcos River. (BIO-WEST 2010a). As such extensive mitigation and minimization measures directed specifically at Texas wild-rice are included in the HCP. These measures include recreational control in key areas during low-flow periods, the development of state scientific protection areas, sediment and non-native vegetation removal, and Texas wild-rice restoration throughout the river in high quality habitat areas. The protection of minimum continuous springflows and long-term average flows coupled with the minimization and mitigation measures was determined to be protective of Texas wild-rice in the San Marcos River relative to the long-term biological goals and management objectives.

As discussed for Comal Springs, during Phase I, applied research on the effects of low flows on the Covered Species and their habitat at San Marcos Springs will be conducted, mechanistic ecological models with be developed and applied, and the MODFLOW model used to simulate the effects of the Phase I Package will be improved. Until the Phase I AMP decision-making is complete, it is not known whether additional flow protection measures might be necessary or what duration might be acceptable, or amount of additional flows that might be needed.

In summary, incidental take of the Covered Species at San Marcos Springs will occur under the HCP but is not anticipated to appreciably reduce the likelihood of survival of the Covered Species at San Marcos Springs or affect their potential for recovery. With the AMP activities scheduled during Phase I and the presumptive measure to meet the minimum flow objective during Phase II, incidental take will continue to occur during Phase II, but should not appreciably reduce the likelihood of survival of the Covered Species at San Marcos Springs or affect their potential for recovery.

4.2.2 Impacts of Incidental Take on Individual Covered Species

The following sections describe the individual species analysis that was conducted for the HCP. As a result of the Science Subcommittee's deliberations and flow-regime development process, the subsequent independent analysis of protective flow-regimes by the HCP-team and by Dr. Hardy in conjunction with potential HCP conservation measures, and the development of the long-term biological goals for the HCP, a wealth of data has been compiled, condensed, and evaluated. This incidental take analysis builds on the work from those efforts.

To compare the impacts of incidental take for the No Action and Existing Baselines with the HCP measures a set of "Current Conditions" was developed. These conditions include the range of conditions experienced over approximately the last decade (2000 to 2009) under real-

time pumping conditions, aquifer management, and ongoing activities in the action area. It incorporates biological and water quality monitoring data, Variable Flow Study data, along with the hydraulic/habitat and water quality modeling conducted by Dr. Hardy into a model to make the comparison.

The format of the incidental take assessment includes a description of the approach employed for a specific species, followed by the results of comparative scenarios for the Phase I package as well as the No Action and Existing baselines. It quickly becomes evident that the extended period of zero springflow projected for the No Action Baseline and Existing Baseline (Figure 4-9a) would extirpate the fountain darter at Comal Springs. It is likely that the covered invertebrate species would also encounter this same fate at Comal Springs under the No Action and Existing Baselines. These results will be discussed in the respective "Effects of Action Added to the Environmental Baseline" sections for each Covered Species.

4.2.2.1 Comal Springs/River Ecosystem

For the incidental take analysis at Comal Springs the most important system-wide assumptions regarding the minimization and mitigation measures include:

- Restoration of aquatic vegetation in the Old Channel with designated measures to protect high quality habitat at all predicted flow levels (termed "Old Channel ERPA") (Section 5.2.2.1)

- Flow-split management (Section 5.2.1).

Other necessary measures include:

- Restoration of aquatic vegetation in Landa Lake (Section 5.2.2).

- Decaying aquatic vegetation removal and dissolved oxygen management in Landa Lake (Section 5.2.4).

- Protection of aquifer water quality (Sections 5.7.2, 5.7.4, 5.7.6, and 5.7.7).

- Control of gill parasites, non-native species (plant and animal), and predation and competition (native and non-native species) (Sections 5.2.6, 5.2.5, and 5.2.9).

In addition to these system-wide assumptions, there are several species-specific assumptions that will be highlighted and comparisons made with and without those measures will be provided.

Fountain Darter

As discussed in Chapter 3, fountain darters were collected for the first time in the Comal River in 1891, with the last collection of fountain darters in the Comal River before its apparent extirpation in 1954. (EARIP 2009). From February 1975 through March 1976, 457 adult fountain darters collected from the San Marcos River were released into the Comal system. (Schenck and Whiteside 1976). A reproducing population has been reestablished and is now found throughout the entire Comal aquatic ecosystem from the headwaters of Landa Lake to near the confluence with the Guadalupe River.

Habitat Requirements and Current Conditions

Habitat requirements for the fountain darter are summarized in Chapter 3 and described in detail in EARIP (2008 and 2009). On-going research and monitoring continues to confirm the importance of aquatic vegetation to the fountain darter. The type and quality of the aquatic vegetation greatly affects the density of fountain darters in an area and in aggregate. Beyond aquatic vegetation, physical habitat and water temperature have been identified as important habitat components for the fountain darter in the Comal system. The USFWS in conjunction with Utah State University conducted a study in the early 1990s to determine the amount of habitat available to the fountain darter under various streamflow conditions in the Comal Springs ecosystem. This is the same study reviewed and presented in Hardy (2009). Dr. Hardy updated both the hydraulic/habitat model and water quality model for the Comal system and analyzed a Phase I package minimum flow regime (Hardy 2010). In addition to physical habitat, four checkpoint temperature ranges have been identified as critical to the fountain darter life cycle: at and above 77 to 79 °F there is reduction in fountain darter larval production; between 79 and 82 (°F) and above there is a reduction in egg production, and at approximately 91 (°F) and 94 (°F) larval and adult, respectively, thermal death can be expected based on laboratory studies (Brandt *et al*. 1993, Bonner *et al*. 1998, McDonald *et al*. 2007). The specification of a range indicates some uncertainty in the study results about precisely where in the range the effects begin.

Comprehensive biological monitoring conducted over the past decade (BIO-WEST 2002a–2011a) has focused on four reaches of the Comal System: Upper Spring Run (upstream most portion of the system to Spring Island), Landa Lake (Spring Island to the outflow to Old and New channels), Old Channel, and New Channel. (*See* Figure 4-1). Landa Lake supports the highest quality fountain darter habitat in the system at all monitored flows to date, as it maintains a diverse aquatic vegetation community, supports year round reproduction of fountain darters, and exhibits exceptional water quality conditions. (BIO-WEST 2002a–2011a). These factors contribute to the continuance of large populations of fountain darters within Landa Lake.

Prior to 2004, the Old Channel of the Comal River also supported similar conditions. However, the construction of a new culvert system on the Old Channel coupled with an extended period of high flow conditions (facilitated by the new culvert system) led to a scouring of the native filamentous algae from this reach, which was subsequently repopulated with mostly non-native vegetation. (BIO-WEST 2007c). As a result, habitat quality and resulting population numbers have both decreased within the Old Channel. Fountain darter reproduction in recent times in the Old Channel has shifted to primarily seasonal (spring time) peaks, reflecting the lesser quality habitat conditions (BIO-WEST 2008a, 2009a, 2010a) as compared with Landa Lake.

The Upper Spring Run and New Channel in the Comal River have variable habitat conditions for fountain darters relative to spring discharge (BIO-WEST 2002a–2010a). The Upper Spring Run maintains high quality fountain darter habitat during moderate to higher flow (greater than 200 cfs total Comal System discharge) conditions because of the expansion of bryophytes during these periods and subsequent use by fountain darters. Periodic pulses coming down Blieders Creek scour out the bryophytes and make this reach less suitable for darters than it might otherwise be. Additionally, lower flows (less than 200 cfs total Comal System discharge) limit the amount of spring upwelling in this reach, which limits the amount of carbon dioxide (CO_2) in the water column. This limitation also causes a decline in the CO_2 obligate bryophytes leading to lesser quality habitat for fountain darters. The New Channel reach acts somewhat in an opposite fashion to the Upper Spring Run reach. The New Channel supports higher quality habitat at below average flow (~250 cfs total Comal System discharge) conditions because at these flows the establishment of aquatic vegetation is possible throughout much of the reach (*Id.*). More aquatic vegetation leads to higher quality fountain darter habitat in the New

Channel. Total Comal System discharge greater than 350 cfs or high flow pulses coming down Dry Comal Creek cause a combination of factors that lead to lesser quality habitat in this reach. First, high flow pulses or sustained high flows scour out the aquatic vegetation in this highly altered reach. Second, higher flow conditions (resulting in greater depths) coupled with recreational use (which causes more turbidity) collectively cause less light penetration to sustain aquatic vegetation growth. Ultimately these conditions lead to reductions in aquatic vegetation and quality of fountain darter habitat.

Over the past ten years of monitoring (BIO-WEST 2002a–2011a), total Comal System discharge greater than 225 cfs has been shown to provide high quality fountain darter habitat throughout most of its range, not considering short-term high flow events. Considerable habitat alteration has occurred several times over the years as a result of high flow pulses (heavy localized rain events) scouring out extensive areas of aquatic vegetation. These time periods are generally short-lived (hours to days) and the aquatic vegetation typically recovered and/or expanded in one to six months. In most cases these represent flow events that have direct impacts on fountain darter habitat but only on a temporary time scale. BIO-WEST (2007c). One exception was the long-term impact of non-native vegetation that replaced native vegetation after sustained high flow conditions in the Old Channel resulting in lower quality habitat.

Take Thresholds Relative to Springflow

Reduced springflow decreases both the quantity and quality of aquatic vegetation and physical parameters (fountain darter habitat), or causes limitations to the larval success of the fountain darter, both of which are classified as “take” by USFWS. The difficulty is in accurately assessing the point at which take first occurs. Since the USFWS first identified a critical discharge value at which it believed “take” occurs, (see Table 4-28), there has been a wealth of data collected and habitat and water quality modeling conducted to better inform this determination. As discussed above, fountain darter habitat quality varies throughout the Comal Springs/River ecosystem and the HCP designates two categories, prime and less than optimal habitat. Prime habitat areas include Landa Lake and the Old Channel. The upper-most reach of Landa Lake above Spring Island (Upper Spring Run) and the entire new channel are considered less than optimal habitat. This distinction is important for guiding management response plans that attempt to maximize the suitability and availability of the highest quality habitat.

Observations made during the EAA Variable Flow Study suggest that the area where habitat would first decrease in quantity and quality is in the upper-most reach of Landa Lake near the confluence of Blieders Creek (Upper Spring Run) and the critical discharge value at which this begins to occur is approximately 150 cfs. At 150 cfs, total Comal River discharge (observed in the summer of 2000), Spring Runs 4 and 5 (less than optimal habitat near Blieders Creek) ceased flowing and the amount of upwelling flow in the immediate area was also considerably reduced. Under those flow conditions, there is potential for loss of aquatic vegetation quantity and quality and for increases in water temperature in the immediate area. Observations from the Variable Flow Study show that prime habitat areas (Landa Lake and Old Channel) as well as less than optimal habitat throughout the New Channel are maintained at springflows of 150 cfs total Comal River discharge, suggesting that impacts to the fountain darter are minimal in those areas under such conditions.

Based on physical habitat modeling and water quality modeling (Hardy 2010), the Phase I package includes a level of 60 cfs for triggering additional management response. (*See* Section 6.4.3.1). As total Comal springflow approaches 60 cfs, there is potential for considerable take to the fountain darter population through loss of substantial areas of less than optimal habitat in the Upper Spring Run reach and New Channel. Additionally, risk is increased in some areas of

prime habitat (Landa Lake and Old Channel). Hardy (2010) documents that at 60 cfs, over 85 percent of the available fountain darter habitat is maintained in Landa Lake. At that flow level, some areas in the lake do exceed the temperature checkpoints for reduced larval success and egg production during portions of the day for fountain darters. However, no area in Landa Lake exceeds temperatures required for juvenile or adult survival. At 60 cfs total Comal Springflow, under the Phase I package, 40 cfs will be directed down the Old Channel via flow-split management. At 40 cfs in the Old Channel, over 80 percent of the available fountain darter habitat is maintained throughout the Old Channel. None of the temperature checkpoints are exceeded in the portion of the Old Channel above Elizabeth Street, with no portion of the Old Channel experiencing temperatures high enough to cause juvenile or adult darter mortality at this flow level. Therefore, at 60 cfs total Comal discharge, considerable take is likely within marginal habitat areas with take also occurring at a more modest level within prime habitat.

At 30 cfs daily average total Comal discharge (with 20 cfs directed down the Old Channel and 10 cfs down the New Channel), physical habitat in Landa Lake is predicted to be maintained at over 75 percent of the maximum available habitat. However, water temperatures increase considerably and start to pose greater risks relative to increased larval mortality and impacts on egg production. No predicted water temperatures in Landa Lake exceed the mortality values for juvenile or adult fountain darters at this discharge. As discussed in Hardy (2010), 20 cfs in the Old Channel will provide approximately 75 percent of the maximum available fountain darter habitat in the Old Channel from a physical habitat perspective. At 20 cfs, under the extreme ambient temperature conditions modeled in Hardy (2010), the Old Channel ERPA area (Landa Lake to Golf Course Road) will maintain water temperature that does not exceed any water temperature threshold. Downstream of the ERPA, the Old Channel is predicted to have water temperatures that cause adverse impacts to larval success rate and egg production. However, it should be reiterated that even at this flow, nowhere in the Old Channel during the extreme conditions modeled, are water temperatures predicted to exceed levels necessary for adult or juvenile survival. At 30 cfs total Comal discharge, considerable take is likely within less than optimal habitat areas with greater amounts of take occurring in prime habitat as compared to 60 cfs total Comal discharge.

Additional concerns that are heightened during these low-flow periods include the impacts from exotic plant and animal species, gill parasite, aquatic vegetation decay, predation and competition, and recreation which all have consequences on the fountain darter populations and habitat in the Comal Springs/River ecosystem. Therefore, measures to reduce impacts from these threats are included in the Covered Activities and described further in Chapter 5.

Finally, since low-flow data and habitat responses are not available at this time, the applied research and ecological modeling discussed in Section 6.3 will be essential to better understand the impacts to this species over the life of the ITP.

Take Analysis Methodology (Assumptions, Model Development, Status)

Fountain Darter Specific Assumptions

Relative to the Covered Activities, take from recreation, shoreline management, etc. can occur to varying extents regardless of springflow level. Take associated with pumping is most directly tied to springflow reductions which can decrease the quantity and quality of fountain darter habitat. This is first evident in the upper most reach of Landa Lake near the confluence of Blieders Creek (Upper Spring Run) and the critical discharge value at which this begins to occur is approximately 150 cfs total Comal springflow. As total Comal springflows decline below 150 cfs, additional areas are affected and differing levels of take (both discussed above) start to

occur. Similar to the long-term biological goals (Section 4.2.1), the fountain darter incidental take assessment centers on a habitat-based approach within representative reaches of the Comal system. The four reaches include the Upper Spring Run Reach, Landa Lake, Old Channel, and New Channel as described in the previous section (Figure 4-1).

In addition to the system-wide assumptions stated above, the following fountain darter specific assumptions apply to this approach:

- Fountain darter movement away from adverse conditions does not occur (*i.e.*, when vegetation decreases, fountain darters automatically die)

- Fountain darter recruitment is maintained at all flows (*i.e.*, reduction in recruitment is not incorporated into the take analysis)

The former assumption is conservative as fountain darter movement does occur would when a reduction in aquatic vegetation occurs. However, without a mechanistic ecological model to describe all the complexities that these movements would likely cause (*e.g.*, crowding which could limit reproduction, limit growth rate, increase predation and competition) this assumption is in place to simplify a current unknown. The latter assumption regarding recruitment is thought to be true based on the water temperature modeling results presented by Dr. Hardy. However, even if recruitment does continue, recruitment rates will no doubt be affected by changing habitat conditions and the duration of periods of altered springflow. At the present time, there is not a modeling tool available to assess all the potential effects of the Phase I package on fountain darter recruitment.

The approach used for the fountain darter take analysis focuses on the following components:

- Dominant aquatic vegetation changes with flow and time

- Fountain darter density variability with flow and time

- Aquatic vegetation quality adjustments relative to flow

- Includes the effect of recreation, flooding, and springflow

- Fountain darter habitat suitability adjustments relative to flow

- Aquatic vegetation to fountain darter linkage with flow and time

- Application of a fountain darter Stella model

Physical habitat and water quality modeling (Hardy 2010), along with EAA Variable Flow Study actual observations (BIO-WEST 2002a–2011a), and professional judgment were used to quantify the levels of take relative to the HCP phased approach and HCP conservation measures. This was done by incorporating best available scientific information into a fountain darter habitat model.

Fountain Darter Habitat and Population Model Development

A fountain darter and aquatic vegetation linkage model within each of the four representative sample reaches described above was developed using Stella 9.1 (Figure 4-11). The model includes actual field collected data for aquatic vegetation and fountain darters over a nine year period via the EAA Variable Flow Study. Both the spring and fall sampling periods over that nine year span were incorporated into the model. The model was set up on a six-month time

step so that aquatic vegetation measured during the Spring event of a given year would be the base vegetation used versus flow until the Fall aquatic vegetation mapping that same year, at which time that new measurement would be the base vegetation used until the following spring. Each dominant aquatic vegetation type was then evaluated versus flow to establish a habitat quality condition (0 to 1.0 with 1.0 being the best achievable). This exercise was based on Dr. Hardy's habitat model as well as from EAA Variable Flow Study observations over the past decade. For instance, bryophytes in the Upper Spring Run reach received a 1.0 ranking from 210 to 280 cfs total Comal springflow. (Figure 4-11). Therefore, when these flows occur, the full amount of bryophytes measured at a given time step was used in the model.

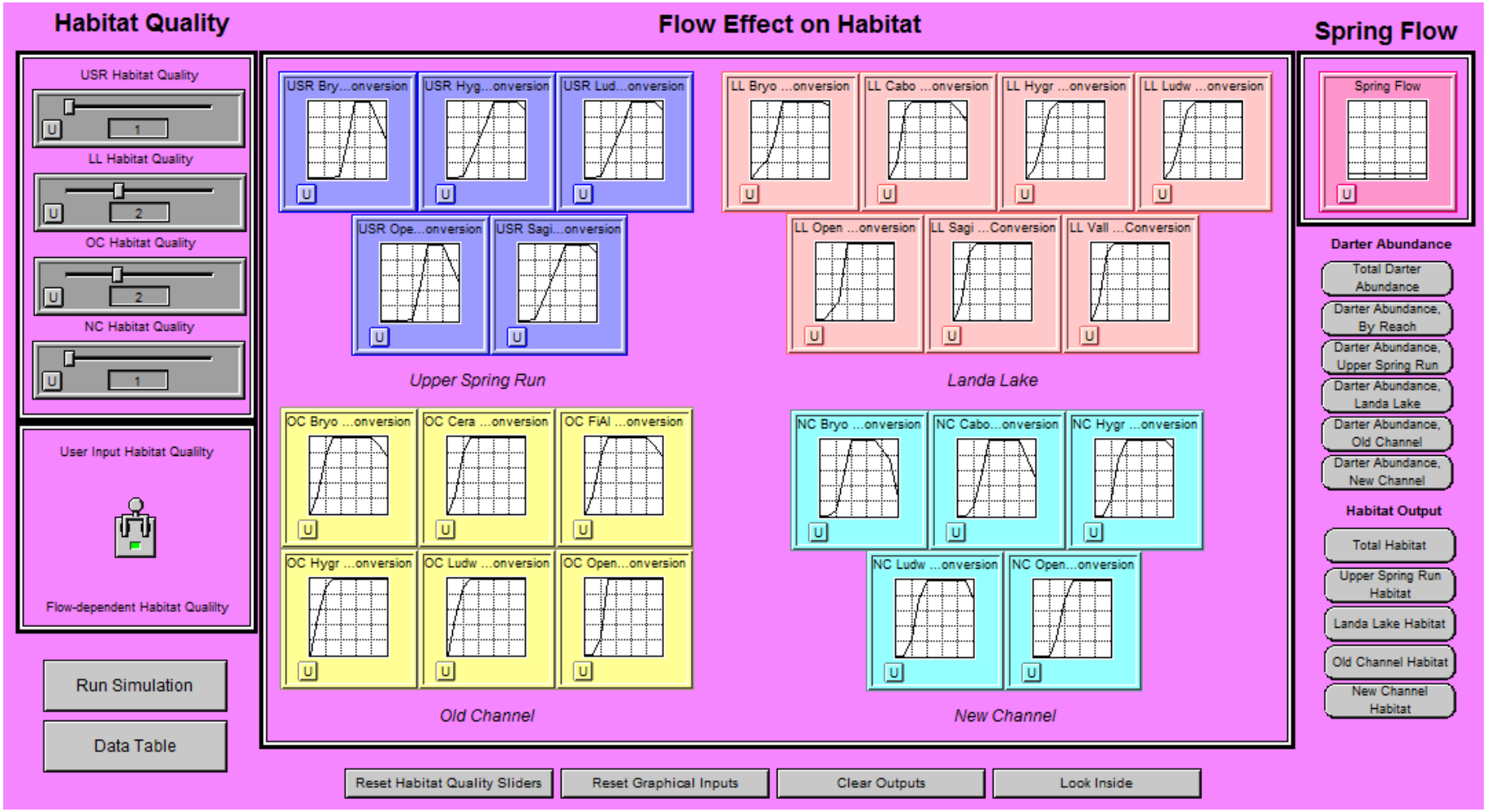


Figure 4-11. Stella Model Interface for Fountain Darter Habitat Model at Comal Springs.

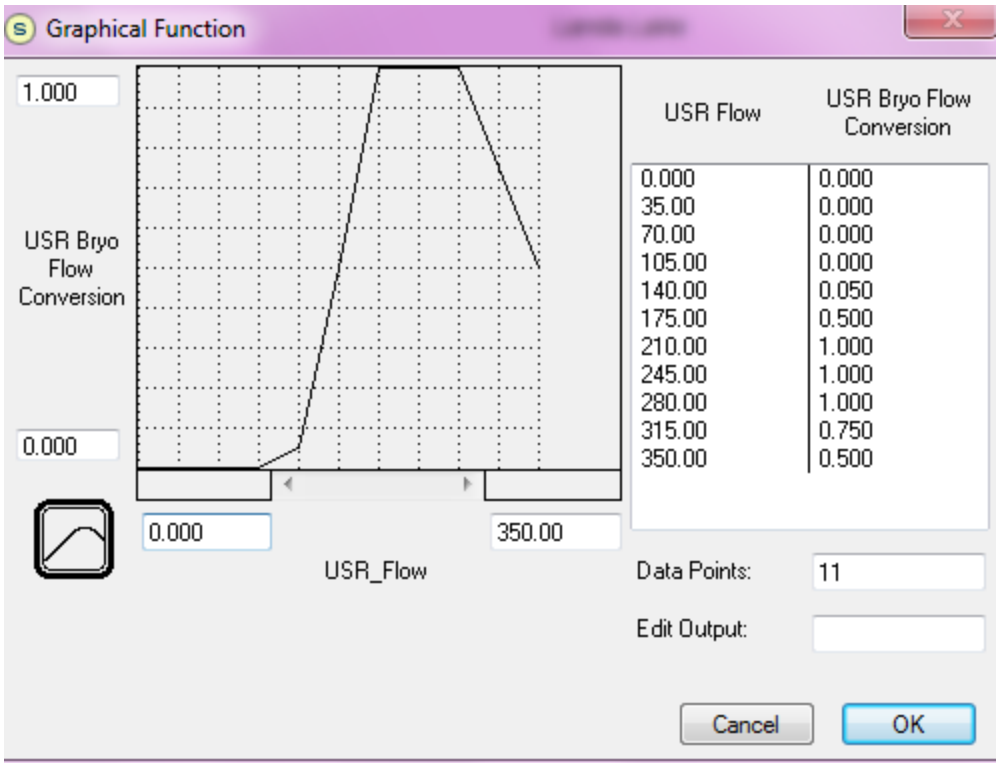


Figure 4-12. Habitat quality relationship for bryophytes versus Total Comal springflow in the Upper Spring Run reach.

At total Comal springflow less than 140 cfs (Figure 4-12), bryophtes were given a 0 (unsuitable) ranking as the Upper Spring Run reach stops significant surface flow at these total springflow levels and bryophytes quickly disappear. So, when total Comal springflow is less than 140 cfs, the amount of bryophytes that was mapped for a given event in the Upper Spring Run reach is nullified in this exercise as no bryophytes are predicted to be present. A reduction in bryophyte quality is also projected at high total Comal springflows as the scouring effect of elevated flows also has an adverse impact on these non-rooted mosses.

The second component entered into the model is the fountain darter density values recorded per dominant vegetation type in the Comal system over the same nine year period. Table 4-32 shows the minimum, 25th, median, 75th, and maximum densities recorded for fountain darters per aquatic vegetation type in the Comal system.

TABLE 4-32
FOUNTAIN DARTER DENSITIES PER AQUATIC VEGETATION TYPE IN THE COMAL SYSTEM OVER TIME

	Algae	Bryophytes	Cabomba	Ceratopteris	Hygrophila	Ludwigia	Open	Sagittaria	Vallisneria
MIN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25th	5.2	9.2	4.5	0.8	1.0	2.0	0.0	0.0	0.0
MEDIAN	13.8	20.3	6.5	2.2	4.0	7.0	0.0	1.0	1.0
75th	34.9	36.0	14.4	3.8	9.8	18.5	0.5	6.3	7.5
MAX	105.0	101.1	48.8	19.4	40.5	94.4	10.0	36.5	58.0

A habitat quality ranking for fountain darter density was then generated based on EAA Variable Flow Study data and from observations in the system. (Table 4-33). A ranking system was incorporated into the model as follows:

TABLE 4-33
HABITAT QUALITY RANKING FOR FOUNTAIN DARTER DENSITIES

Description	Ranking Value for Model	Density Value from Table 4-7
Unsuitable	1	Minimum Density
Low quality	2	25th
Moderate quality	3	Median
High quality	4	75th

The habitat quality ranking per fountain darter density was then incorporated into the model per respective reach relative to the total Comal springflow condition. For example, at total flows of less than 140 cfs, a 1, unsuitable, was assigned to the Upper Spring Run reach. As previously described, flows at this level in this reach would not support any bryophytes, yet they would support other vegetation types (*e.g.*, *Hygrophila, Saggitaria*). However, the ranking of 1 for habitat quality fountain darter indicates no potential for any darters in that reach because a ranking of 1 in Table 4-32 is associated with the minimum values in Table 4-31, which for all vegetation types is 0. Therefore, the model predicts that below 140 cfs, the Upper Spring Run reach does not support fountain darters. As flows go above 140 cfs in the Upper Spring Run reach, the habitat quality is adjusted to 2, which does indicate support of some darters in the reach, and as flows get back to above average conditions, the habitat quality index is adjusted to 3 to reflect typical conditions under average total Comal springflow conditions.

Fountain Darter Species Status

To document a Current Condition of what the approximate fountain darter population has been within the representative reaches in the Comal system from 2002 through 2010, the actual hydrology from that time period was incorporated into the model. Additionally, four constant flows levels (30, 150, 225, and 300 cfs) were incorporated into the model to examine population variability relative to aquatic vegetation conditions experienced over this nine year period. Figure 4-13 shows the comparison of current hydrology for that period with each constant flow condition.

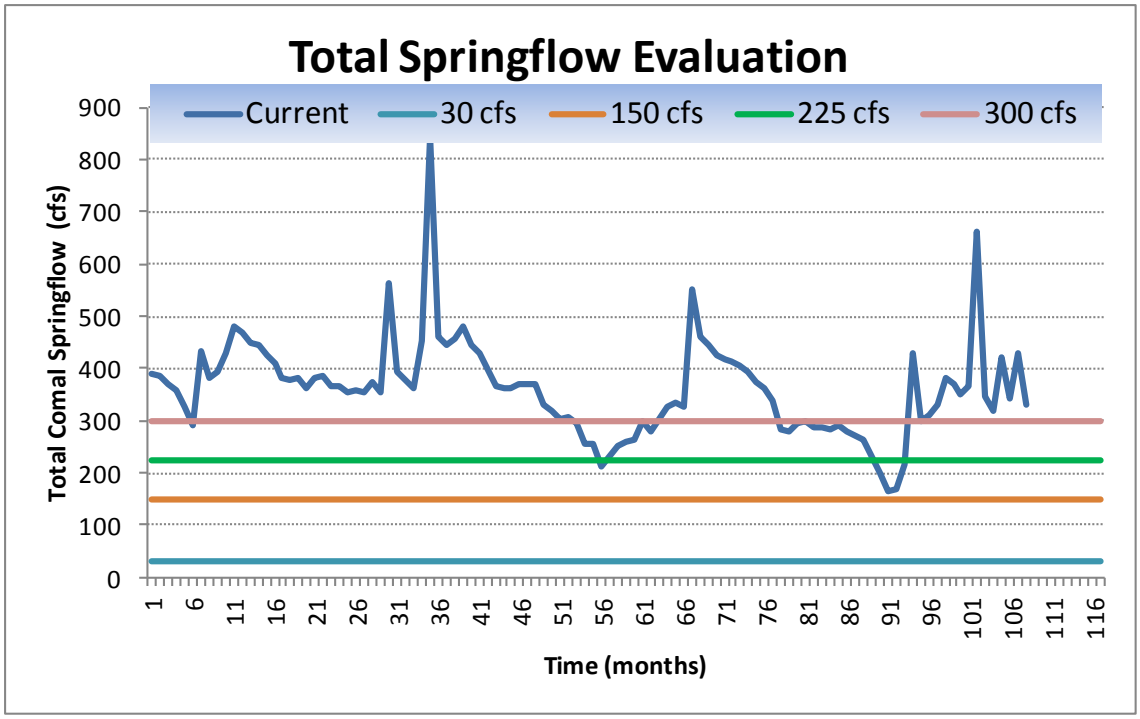


Figure 4-13. Total Comal Springflow scenarios evaluated in Stella. Current pumping is the actual Total Comal Springflow from 2002-2010. Other springflows were held constant.

Figures 4-14 and 4-15 (along with embedded tables with the figure) show the Stella model results for fountain darter numbers within the representative reaches for the Current Conditions (same in both figures) and the No Old Channel ERPA (*see* Figure 4-13) and With Old Channel ERPA (*see* Figure 4-14) scenarios. As discussed throughout the HCP, a key component of the minimization and mitigation measures is the Old Channel ERPA at Comal Springs. The Old Channel ERPA encompasses the EAA Variable Flow Study reach, extending from below Elizabeth Street upstream to the culverts feeding the Old Channel from Landa Lake. Within this reach, non-native vegetation will be removed, native vegetation restored, and some limited channel modification will be undertaken to enhance fountain darter habitat in select areas. To protect this enhanced habitat, the ERPA will have protection measures including flow-split management between the New and Old Channels using the existing culvert structures and the ability to divert more of the flow during wet periods down the New Channel via dam improvements currently underway by the City of New Braunfels to reduce scouring effects in the Old Channel. A concern noted in Hardy (2011) is that at 30 cfs total Comal springflow, there is the potential for cool water inflows from springs along the western margin of Landa Lake flowing down the New Channel instead of entering the Old Channel. This could affect water quality in the Old Channel and the success of the proposed ERPA, and, thus, this flow pattern is proposed for study during Phase I.

For the Current Conditions scenario, no habitat quality adjustments for aquatic vegetation were made for restoration or protection activities and as the flows over this time period were relatively average or above, the habitat quality index (fountain darter density) for each reach was set to 3. For the No ERPA alternative, habitat quality adjustments were made based on flow alone (*see* Figure 4-14 – embedded table in upper right corner), while the With ERPA scenario included both adjustments for flow and for restoration and protection activities in the Old Channel. (*See* Figure 4-15 – embedded table in upper right corner.)

Time step		Constant Flow			
	Current	30 cfs	150 cfs	225 cfs	300 cfs
1	137,574	5,385	110,239	153,931	150,574
2	140,986	5,125	107,136	169,638	162,789
3	147,358	5,255	111,893	173,610	167,484
4	127,464	4,291	92,506	150,509	144,983
5	99,854	2,958	68,465	113,281	110,264
6	56,396	1,504	40,302	69,548	66,174
7	99,171	3,971	83,564	120,478	115,428
8	67,988	2,056	49,021	88,796	83,335
9	97,623	3,319	70,224	102,434	97,853
10	87,078	1,840	46,344	87,004	81,914
11	128,794	3,989	85,668	139,931	132,970
12	116,052	3,845	83,343	145,024	137,709
13	125,911	4,674	98,332	153,262	146,570
14	70,022	862	32,412	71,331	68,295
15	123,346	3,994	86,266	123,346	120,288
16	55,127	1,219	33,691	54,984	52,257
17	94,984	3,802	80,146	116,181	110,967
18	32,829	1,132	30,861	33,769	33,717
Min	32,829	862	30,861	33,769	33,717
Avg	100,475	3,290	72,801	114,837	110,198
Max	147,358	5,385	111,893	173,610	167,484

Flow	Habitat Quality Ranking - Comal Reaches			
	USR	LL	OCR	NCR
30 cfs	1	2	2	1
150 cfs	2	3	3	2
225 cfs	3	3	3	3
300 cfs	3	3	3	3
Existing	3	3	3	3

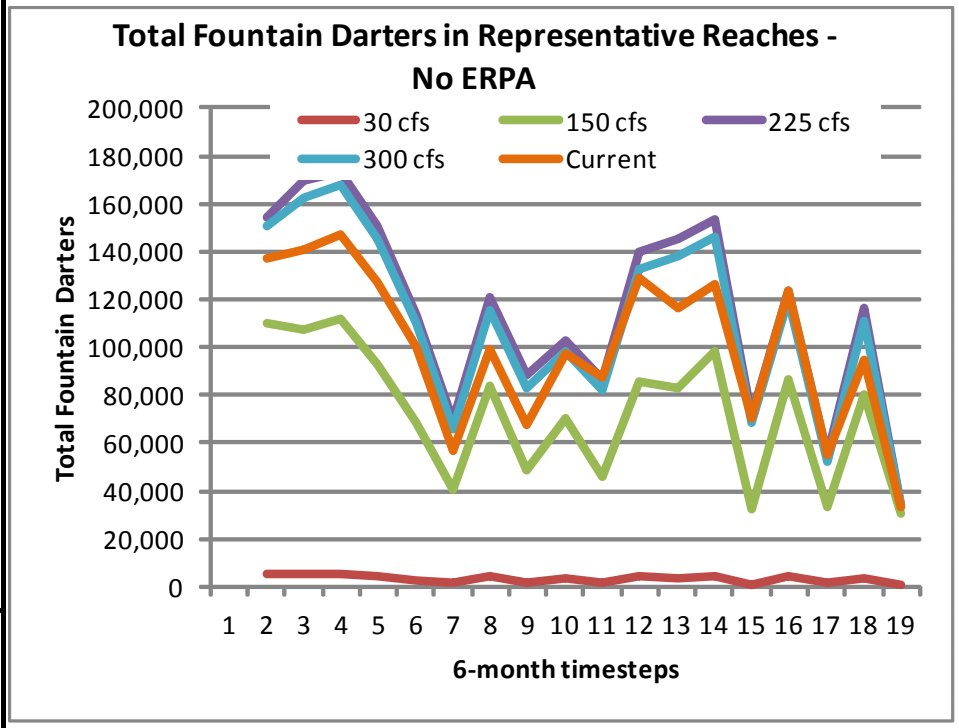


Figure 4-14. Total Fountain Darters within Representative Reaches – Comal System: Habitat Quality Adjusted by Reach – **NO OLD CHANNEL ERPA** - Current = 2002-2010 flows over 18 timesteps; Constant flows of 30, 150, 225, and 300cfs for all 18 timesteps.

Time step		Constant Flow			
	Current	30 cfs	150 cfs	225 cfs	300 cfs
1	137,574	6,704	124,906	157,990	154,633
2	140,986	5,398	126,619	170,993	164,302
3	147,358	5,571	129,830	174,573	168,448
4	127,464	5,318	111,760	153,397	148,030
5	99,854	5,719	85,754	118,962	115,945
6	56,396	4,265	56,052	75,926	72,735
7	99,171	6,894	100,862	125,962	120,912
8	67,988	6,332	71,675	98,129	92,864
9	97,623	7,881	88,746	110,909	106,327
10	87,078	5,321	67,034	94,606	89,689
11	128,794	8,074	109,693	147,559	140,599
12	116,052	7,884	112,194	153,897	146,781
13	125,911	8,464	121,920	160,429	153,737
14	70,022	4,636	52,874	79,760	76,921
15	123,346	8,056	104,292	130,911	127,854
16	55,127	5,648	51,388	64,884	62,383
17	94,984	7,942	99,319	123,838	118,625
18	32,829	4,629	39,850	41,431	41,565
Min	32,829	4,265	39,850	41,431	41,565
Avg	100,475	6,374	91,932	121,342	116,797
Max	147,358	8,464	129,830	174,573	168,448

Flow	Habitat Quality Ranking - Comal Reaches			
	USR	LL	OCR	NCR
30 cfs	1	2	4	1
150 cfs	2	3	4	2
225 cfs	3	3	4	3
300 cfs	3	3	4	3
Existing	3	3	3	3

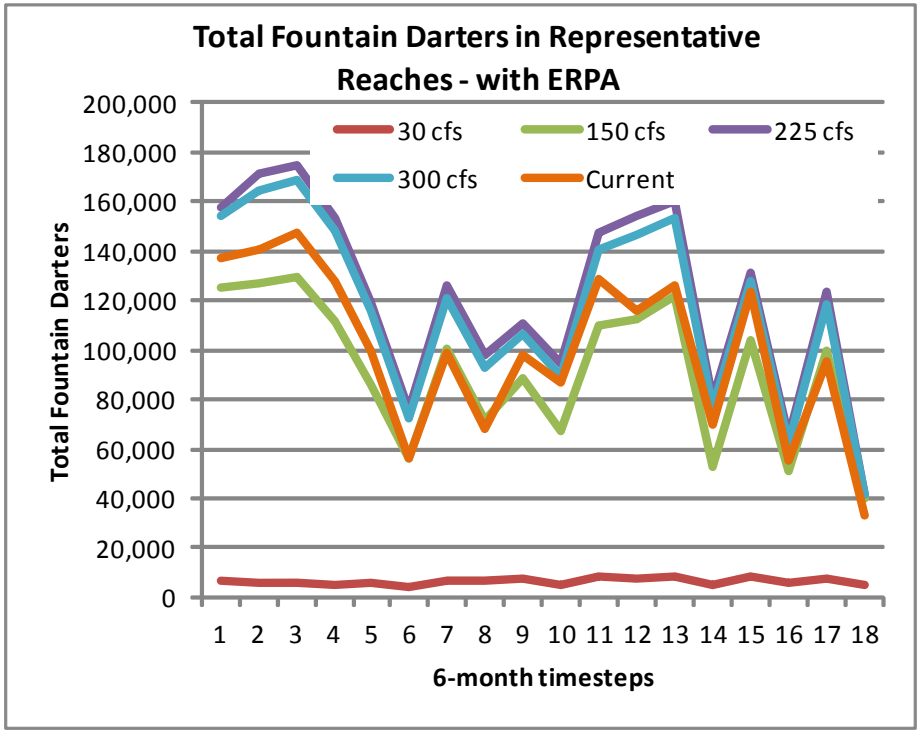


Figure 4-15. Total Fountain Darters within Representative Reaches – Comal System: Habitat Quality Adjusted by Reach – **WITH OLD CHANNEL ERPA -** Current = 2002-2010 flows over 18 timesteps; Constant flows of 30, 150, 225, and 300cfs for all 18 timesteps.

Although not exactly an apples-to-apples comparison, as the Current Conditions scenario has different flows over the 18 – 6 month time steps versus the assumed constant flows over this nine-year period, it is a helpful illustration of the range of variability observed in the system. The variability is reflected in the changes in aquatic vegetation that have been experienced since 2002. Over this time period, the number of total fountain darters predicted within the representative reaches ranged from approximately 33,000 to 147,000 individuals (see Figure 4-13). As previously noted, this population estimate is an approximation based on the assumptions stated above. It refers to populations only within the representative reaches. These assumptions add uncertainty regarding the actual number of fountain darters present in the system and as projected by this modeling exercise. However, for this take analysis, this approach provides a level of consistency amongst scenarios that allows for a meaningful comparison across different modeled flow scenarios.

In Figure 4-14, the 225 cfs and 300 cfs modeled results for constant flows are fairly similar, while the 150 cfs results are lower, with the 30 cfs result projecting large reductions in the fountain darter populations within the representative reaches. Figure 4-13 shows the 30 cfs constant flow scenario to maintain between approximately 900 and 5,000 total darters within the representative reaches. With restoration and high-flow protection activities implemented for the Old Channel, a habitat quality adjustment from 3 to 4 was made for the "With ERPA" scenario. This adjustment was based on a 4 being above average habitat (note that an optimal habitat ranking of 5 was not used in any of the analysis) and the fact that a flow level of 40 cfs in the Old Channel has been observed over time and found to provide high quality fountain darter habitat under current conditions. The assumption embedded in the analysis is that added restoration and protection within the ERPA would allow a reduction in flow below 40 cfs while maintaining an above average habitat quality condition within the ERPA during periods of extreme drought.

Figure 4-14 again shows the same overall trend of fountain darter numbers versus springflow. However, with the habitat quality adjustment for the ERPA, the 30 cfs constant flow results are considerably higher (@4,000 to 8,000 darters). This analysis should not be taken out of context at this point, as it is only presented for perspective and is not a representation of what the Phase I package produces. Hardy's analyses (2010) do not support long-term conditions of flows as low as 30 cfs and, in fact, recommend, as the minimum flow, a period of no longer than six months at 30 cfs daily average, followed by two-to three months of higher flows at 80 cfs or greater.

Evaluation of Effects of Action and Environmental Baseline Versus Current Condition

To assess the Phase I package and No Action and Existing baselines, monthly Comal Springs flow data provided by HDR was used. For the Phase I package, a running 9-year average was calculated from 1947-2000 to be consistent with the nine years of EAA Variable Flow Study data used in the analysis. The lowest nine-year average was 81 cfs (January 1949 – December 1957), the average 9-year rolling average was 202 cfs (January 1966 – December 1974) and the highest 9-year rolling average was 272 cfs (January 1986 – December 1994). For the No Action and Existing baselines, the same time periods were chosen for an equal comparison and modeled flow data from HDR for those time periods based on associated pumping were used. Figures 4-16 through 4-18 show the total Comal springflow for each of the respective nine-year periods for oth the HCP, No Action Baseline, Existing Baseline, and historical conditions.

For the take analysis, these three flow sequences were converted into 6-month time steps to be consistent with the aquatic vegetation data and entered into the Stella model. Table 4-34 shows the model results for all three springflow conditions over the 18 – 6 month time steps for each modeled scenario and historical conditions. The most notable result is that the No Action and

Existing baselines both result in 0 fountain darters in the representative reaches during a repeat of conditions similar to the drought of record. This would most likely translate to the entire system and cause extirpation of the fountain darter from the Comal system.[11]

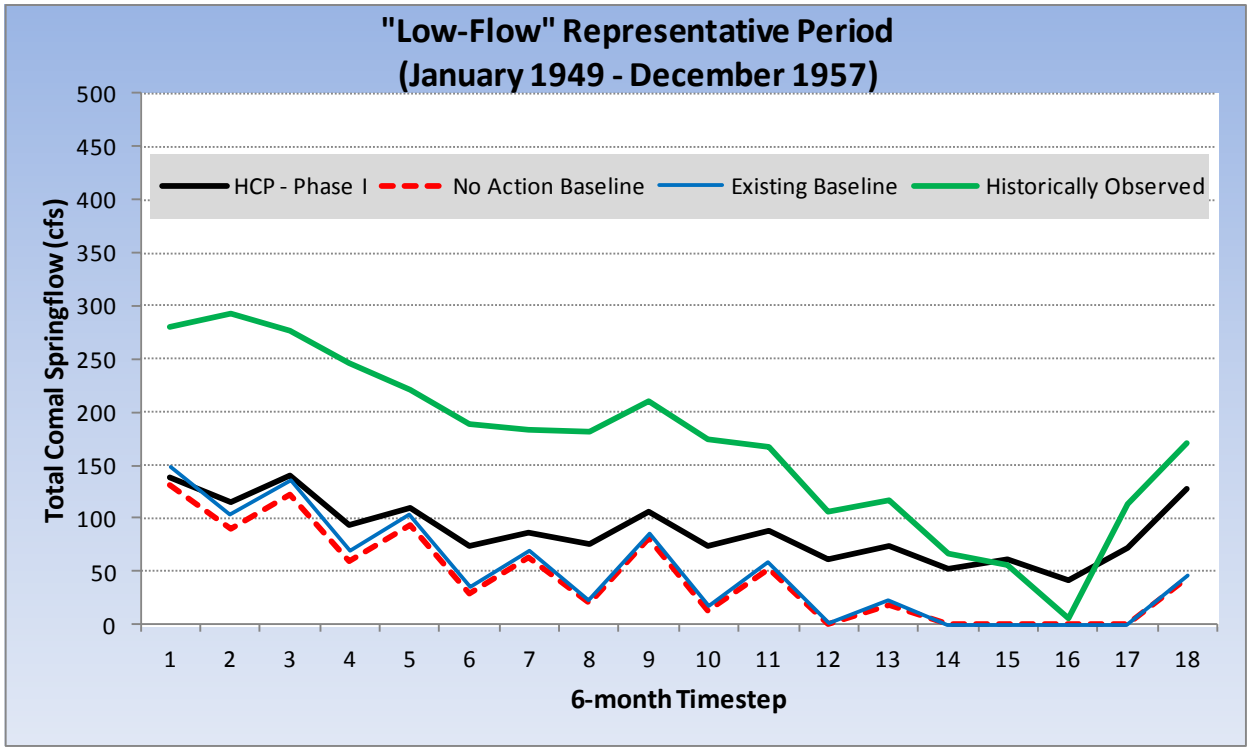


Figure 4-16. Low-Flow representative nine-year rolling average (Total Comal Springflow) for the Phase I package, No Action Baseline, and Existing Baseline modeled scenarios and historically observed.

[11] The model predicts 300 darters (Table 4-34) for the historical condition when in fact the fountain darter was extirpated from the Comal System during those conditions. This is reflective of the six month time-step not actually showing a 0 flow result in Figure 4-16. This highlights the limitations in using this type of modeling for exact numbers rather than just to compare alternatives.

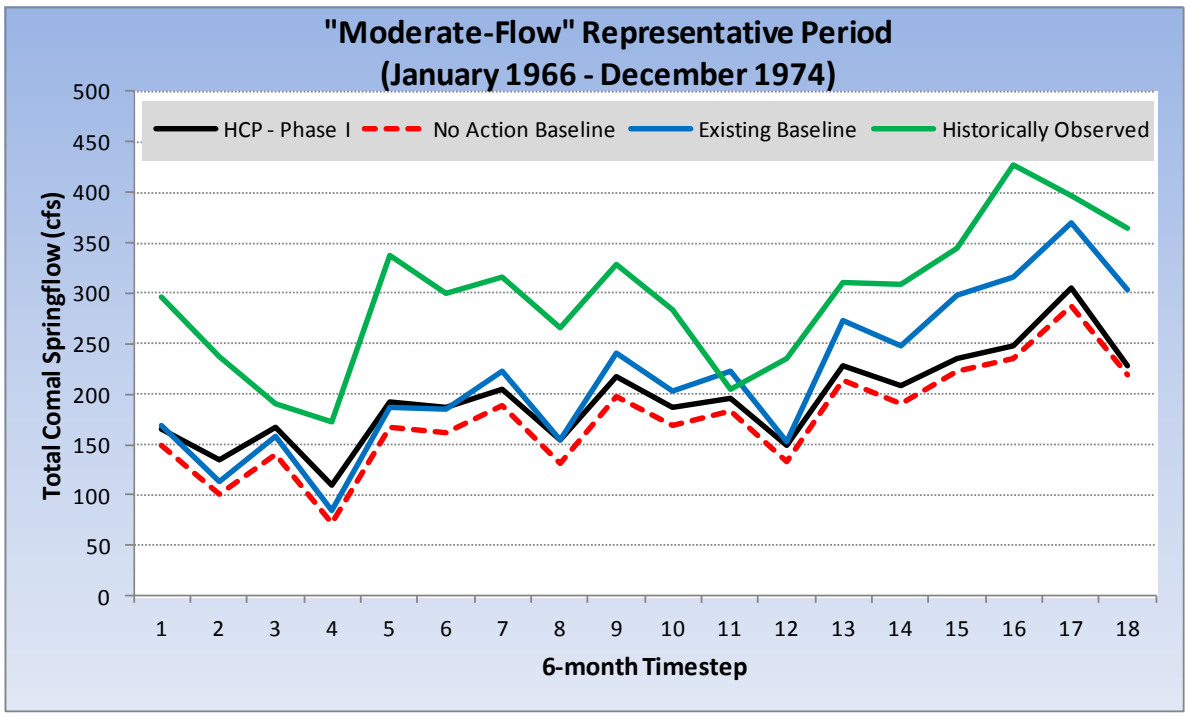


Figure 4-17. Moderate-Flow representative nine-year rolling averages (Total Comal Springflow) for the Phase I package, No Action Baseline, and Existing Baseline modeled scenarios and historically observed.

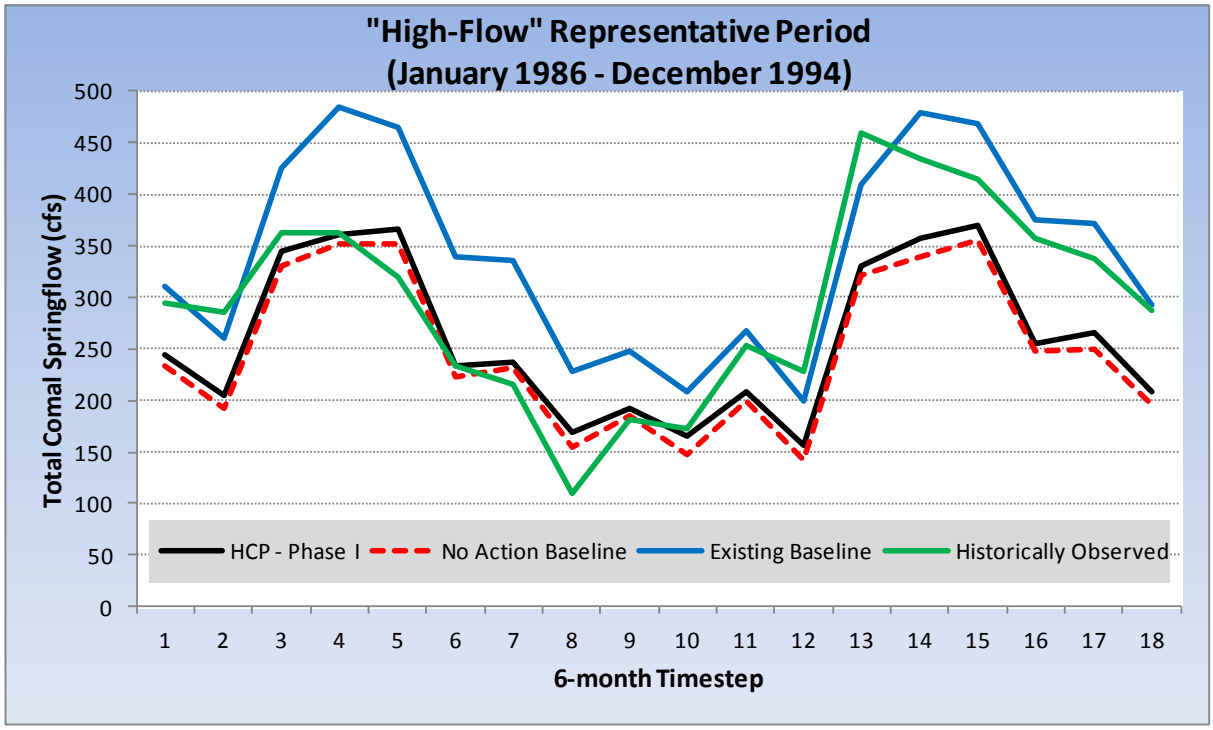


Figure 4-18. High-Flow representative nine-year rolling averages (Total Comal Springflow) for Phase I package, No Action Baseline, and Existing Baseline modeled scenarios and historically observed.

Table 4-34. Total Fountain Darters within Representative Reaches for the Phase I package (with and without ERPA), No Action Baseline, Existing Baseline, and Historical Conditions – Comal System: Habitat Quality Adjusted by Reach — Low, Moderate, High represent 9-year model run periods generated for each alternative.

Time step	HCP - with ERPA	HCP - NO ERPA	No Action Baseline	Existing Baseline	Historical	HCP - with ERPA	HCP - NO ERPA	No Action Baseline	Existing Baseline	Historical	HCP - with ERPA	HCP - NO ERPA	No Action Baseline	Existing Baseline	Historical
	LOW-Flow Representative Period					**MODERATE -Flow Representative Period**					**HIGH-Flow Representative Period**				
1	45,311	39,498	36,331	40,554	40,554	124,857	120,798	114,178	121,921	139,055	157,990	153,931	153,931	148,728	155,472
2	27,440	26,053	16,669	20,270	39,171	99,493	98,553	57,914	71,166	159,046	167,296	166,061	153,744	169,673	169,465
3	41,941	40,463	31,048	37,694	40,463	130,800	129,836	111,093	123,216	145,688	150,581	149,618	155,842	147,358	148,321
4	17,847	14,628	7,930	9,023	32,523	60,093	57,804	33,925	40,048	112,456	130,511	127,464	127,464	127,464	130,511
5	21,557	12,873	10,173	11,541	20,995	93,439	87,757	78,374	85,759	89,381	105,535	99,854	99,854	99,854	112,447
6	10,870	4,161	1,449	1,850	9,820	62,712	56,739	47,331	55,982	68,809	76,010	69,574	69,539	58,464	76,010
7	19,556	12,170	7,907	8,745	28,818	121,525	116,041	107,596	118,607	114,518	125,962	120,478	120,478	104,502	125,962
8	15,656	5,530	1,288	1,519	13,186	64,075	56,027	45,195	56,558	97,139	73,308	64,905	57,279	88,804	44,695
9	25,698	13,014	9,003	9,978	22,824	109,198	100,724	95,204	100,724	97,322	102,971	94,497	90,670	102,434	97,232
10	13,268	4,975	825	1,016	11,874	76,984	69,828	60,210	79,211	90,195	68,114	61,367	51,410	85,717	93,202
11	22,571	12,145	6,613	7,201	28,390	132,459	124,831	114,545	134,154	137,511	146,135	138,507	132,034	139,931	147,559
12	15,575	7,469	136	272	15,118	96,815	89,289	76,108	92,287	146,409	107,439	99,751	87,105	136,177	153,934
13	19,833	10,626	2,756	3,363	23,580	153,267	146,100	146,100	146,100	142,895	142,059	134,892	138,444	125,911	133,078
14	7,919	1,691	0	0	2,342	66,828	58,526	51,014	59,225	63,311	68,624	59,999	61,866	59,999	68,624
15	15,693	7,546	0	0	6,965	119,526	111,960	111,960	109,055	107,021	116,717	109,151	109,151	109,151	116,717
16	8,441	1,798	0	0	300	64,565	54,466	54,403	49,300	53,984	65,253	55,127	55,110	44,502	54,628
17	18,586	8,709	0	0	17,924	116,513	108,856	113,548	94,191	101,849	123,838	116,181	116,181	94,984	106,814
18	15,549	5,776	1,750	1,898	6,510	40,457	32,773	32,743	32,684	39,671	41,213	33,669	33,332	33,764	41,652
Min	7,919	1,691	0	0	300	40,457	32,773	32,743	32,684	39,671	41,213	33,669	33,332	33,764	41,652
Average	20,184	12,729	7,438	8,607	20,075	96,311	90,050	80,636	87,233	105,903	109,420	103,057	100,746	104,301	109,796
Max	45,311	40,463	36,331	40,554	40,554	153,267	146,100	146,100	146,100	159,046	167,296	166,061	155,842	169,673	169,465

Not surprisingly, the second notable result is the increase in the total number of fountain darters with the Old Channel ERPA (@7,900 to 45,000) under the low-flow scenario relative to the NO ERPA scenario (@1,700 to 40,000). Table 4-35 shows that most alternatives are fairly similar to each other and historical conditions during moderate and higher flow conditions, including the with and without ERPA scenario.

As a rough calculation, the aquatic vegetation mapped within the representative reaches in Fall 2009 (EAA Variable Flow Study) represented between 3 and 33 percent of the total aquatic vegetation mapped in the entire Comal System (Hardy 2010) during that same time period. Taking the average of those values (19 percent) as a crude conversion factor for the total system and assuming a one-to-one relationship of aquatic vegetation and fountain darters, one can use the total fountain darter numbers generated in Table 4-34 and divide by 0.19 to get a rough estimate of the total fountain darter population in the system.

Using this approach, the calculated result is (with all the caveats applicable to this analysis) that the number of total fountain darters in the Comal system from 2002 to 2010 ranged from approximately 170,000 to 775,000. Table 4-36 shows the calculation results for system-wide darters, as converted from the representative reach values in Table 4-35.

TABLE 4-35
TOTAL FOUNTAIN DARTERS IN THE COMAL SYSTEM BASED ON A CONVERSION FACTOR OF 0.19 RELATIVE TO MODELED RESULTS FROM THE REPRESENTATIVE REACHES FOR THE PHASE I PACKAGE WITH AND WITHOUT AN OLD CHANNEL ERPA

Scenario	Range of Total Fountain Darters in the Comal System		
	Minimum	Average	Maximum
CURRENT (2002-2010)	172,783	528,818	775,567
HCP – No ERPA			
Low	8,901	66,996	212,963
Moderate	172,489	473,949	768,948
High	177,207	542,405	874,006
HCP – ERPA			
Low	41,679	106,231	238,477
Moderate	212,934	506,903	806,668
High	216,909	575,894	880,505

Effects of Action Added to the Environmental Baseline

Based on the fountain darter habitat and population model results, it is evident that the No Action and Existing baselines will cause incidental take during average to above average springflow conditions, but likely within the range of variability experienced during the Current Conditions. More notably, both the No Action Baseline and Existing Baseline will cause extirpation of the fountain darter from Comal Springs during a repeat of conditions similar to the drought of record. The HCP-Phase I package will similarly result in incidental take during periods of average to above average springflow conditions (again within the range of variability experienced during the current condition), but is not projected to cause extirpation of the fountain darter at Comal Springs. It is evident that a large amount of incidental take will be experienced with the Phase I package (with or without ERPA) relative to the current (2002-2010) conditions under flow conditions similar to the drought of record. During extreme drought of record-like conditions, with all HCP conservation measures other than protection of habitat in the Old Channel (No ERPA), there is the potential for a 95 to 99 percent reduction in fountain darters in the Comal system relative to Current Conditions. This translates into the potential incidental take of approximately 165,000 to 765,000 fountain darters during a repeat of conditions similar to the drought of record, with the potential for approximately 9,000 fountain darters remaining in the system. This modeled population projection probably is not realistic considering all the unknowns regarding the system and assumptions required to conduct this analysis. A projected population of 9,000 darters at Comal Springs may not be enough to protect the population even though the current population of fountain darters in the Comal system got its origin from 457 individuals restocked in the 1970's (*See* Schenck and Whiteside 1976). The concern lies not in the absolute number of darters necessary to repopulate the system, but in the uncertainty associated with the predictions resulting in the 9,000 number.

During extreme drought of record-like conditions with all HCP conservation measures including an Old Channel ERPA, there is still the potential for a 76 to 95 percent reduction in fountain darters in the Comal system relative to current conditions. This translates into the potential take of approximately 130,000 to 735,000 fountain darters during a repeat of conditions similar to the drought of record. However, under this scenario, approximately 40,000 darters are projected to remain in the system. Long-term monitoring, applied research, and mechanistic ecological modeling are all necessary as the HCP moves forward considering the uncertainty surrounding this analysis. At this time, it is impossible to predict the actual level of fountain darter take (in terms of habitat quantities or fountain darter numbers) over the 15-year term of the ITP as natural variability of the population of this species is large, but more importantly, actual conditions regarding use of existing water rights, future hydrology (*i.e.*, rainfall), success of HCP conservation measures, etc. are impossible to predict. As such, a very conservative scenario based on the best available science was presented above. Should water rights not be fully utilized in the 15-year term of the ITP; hydrology remain fairly average; and the conservation measures be nominally successful, then the amount of incidental take will be very low. Conversely, should full utilization of water rights start at the effective date of the ITP in 2013; followed by a 10-year drought similar in nature to the drought of record; in conjunction with the HCP conservation measures not having a chance to be fully tested or implemented, then the potential for take of 735,000 or more darters is possible.

Effects of the Covered Action would be added to the environmental baseline and the condition would typically get slightly worse. Mitigation and minimization strategies would then be employed to offset declines in the overall condition. However, the Phase I package results in an improvement from both the No Action Baseline and Existing Baseline presented here based on springflow protection alone. To describe this improvement, a 15-year hydrograph was created. The hydrograph was developed to be within the range of potential conditions that could be

observed. For instance, the best case scenario or upper bracket of the range would be average or above average springflows over the entire 15-year HCP period which would result in minimal take for the HCP, No Action Baseline, and Existing Baseline. On the opposite end of the spectrum or lower bracket, a near worst-case example would involve drought of record-like springflows for the entire 15-year HCP period which would result in extirpation of the Covered Species for the No Action Baseline and Existing Baseline and very large take and potential extirpation of the Covered Species under the Phase I package.

The hydrograph created for illustrative purposes includes the following high (above average), moderate (average), and low (drought of record-like) flow years:

- Years 1-3 – High total springflows
- Years 4-6 – Moderate total springflows
- Years 7-11 – Low or drought of record-like total springflows
- Years 12-13 – Moderate total springflows
- Years 14-15 – High total springflows

The analysis is relative to the total system fountain darter numbers generated in Table 3-35 for the HCP alternative and the total system darters for the No Action Baseline converted from Table 3-34. A review of Table 4-34 shows that the projected Existing Baseline fountain darter results are very similar to the No Action Baseline and thus, only one example baseline was carried forward in the example. Although endless hydrograph scenarios can be created and evaluated, the goal of this example was to include a 5-year period similar to drought of record conditions in the middle of the HCP period to evaluate how the fountain darter population (as modeled with existing tools) would respond. As shown in Figure 4-19, there is an across the board improvement for both the EARIP – with ERPA and without ERPA scenarios relative to the No Action Baseline. As such, relative to the No Action Baseline, no appreciable reduction in the fountain darter population would occur from the Phase I package. Although true relative to the No Action Baseline, incidental take from pumping will occur during the ITP relative to a no pumping alternative or the Current Conditions described above. Additionally, as this is a recovery program, the Phase I package does not stop at simply improving upon the No Action Baseline based on springflow protection alone. As discussed throughout this HCP, numerous minimization and mitigation measures are proposed for habitat enhancement, water quality protection, and public education, as well as ecological modeling, applied research, and long-term monitoring. Figure 4-20 shows the projected benefits of the Phase I package relative to the No Action Baseline, but also acknowledges the potential take of fountain darter relative to the Current Condition.

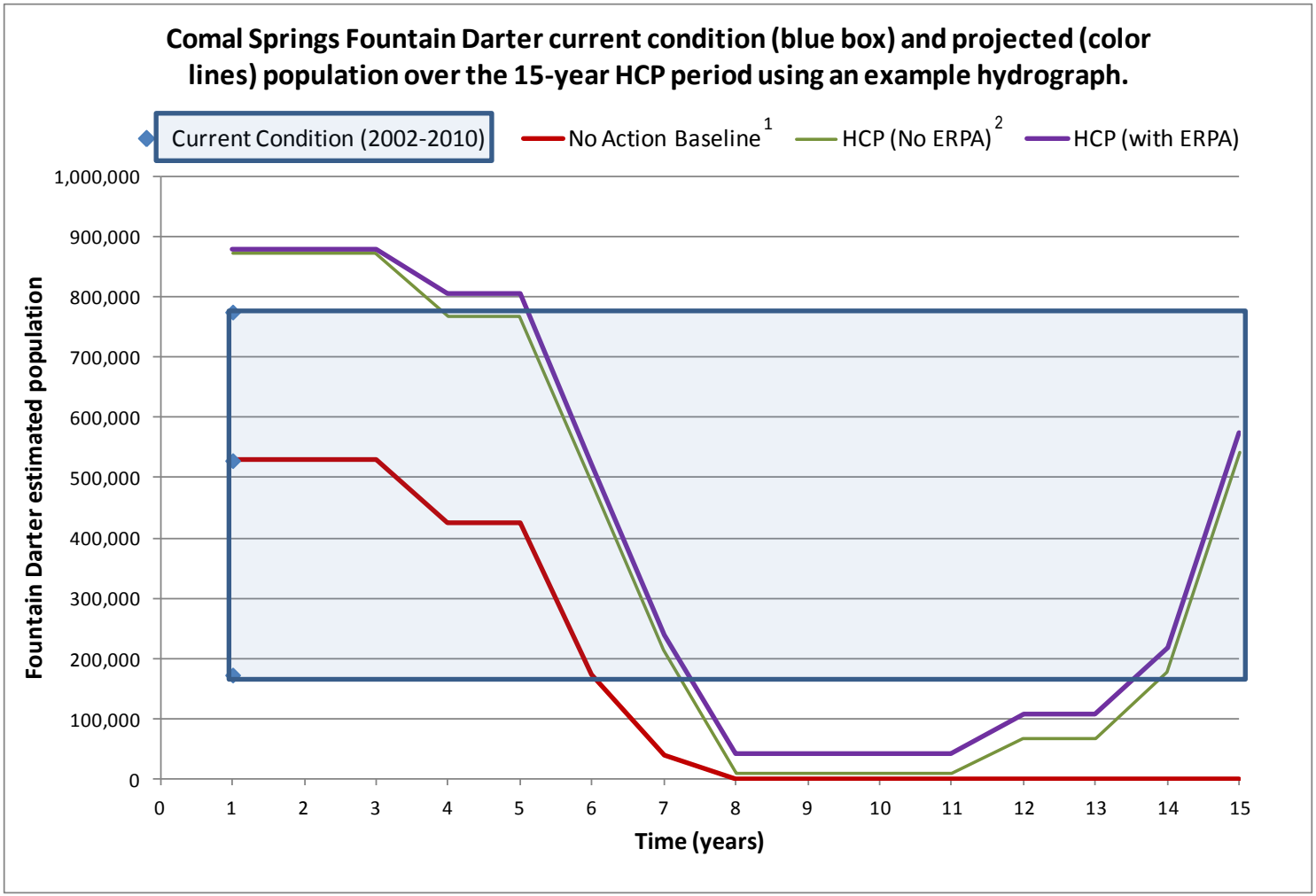


Figure 4-19. Modeled Fountain Darter population at Comal Springs over the HCP period for the HCP (with and without ERPA) and No Action Baseline using an example 15-year hydrograph as described in the text. [1] No Action Baseline causes extirpation of the fountain darter at Comal Springs following year 8 (in this example). [2] HCP (No ERPA) is in danger of causing extirpation of the fountain darter (approximately 9,000 individuals) at Comal Springs from year 8 to 11 (in this example).

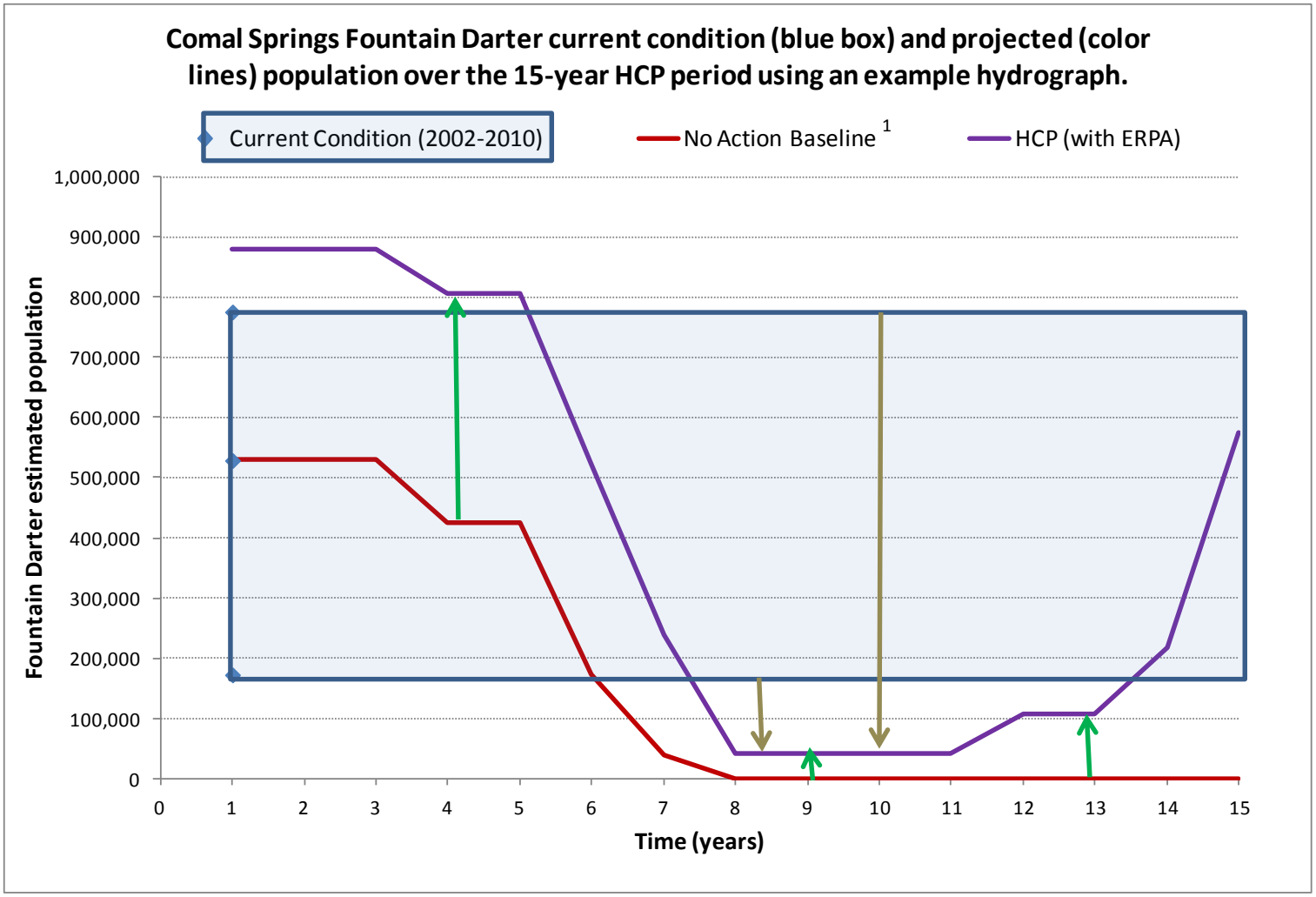


Figure 4-20. Modeled Fountain Darter population at Comal Springs over the ITP for the HCP - Phase I package and No Action Baseline using an example 15-year hydrograph as described in the text. [1] No Action Baseline causes extirpation of the fountain darter at Comal Springs following year 8 (in this example). Arrows added to highlight benefits of the HCP relative to the No Action baseline (Green Arrows) and potential reductions (Brown Arrows) from the range of Current Conditions.

Figure 4-20 is a hypothetical example of HCP impacts to the fountain darter over the life of the ITP. Impacts in the example are very dependent on the hydrology as will be future impacts over the course of the ITP. With the presumptive action to achieve the Minimum Flow-related Management Objective in Phase II, the purple line (Figure 4-20) would be higher across the chart with considerable improvement during the low-flow periods.

To summarize the scientific findings (Hardy 2011), at a daily average of 30 cfs total Comal springflow (20 cfs – Old Channel, 10 cfs – New Channel), physical habitat and water quality conditions throughout Landa Lake proper, the Old Channel and New Channel are sufficient to support adult and juvenile fountain darters and recruitment in key but limited areas. At 80 cfs, which are the flows prescribed for a few months following a maximum 6-month period of 30 cfs minimum daily flows, suitable conditions are extended into the spring runs and farther downstream in the Old and New Channels (Hardy 2011).

Three main concerns noted in Hardy (2011) regarding this flow regime were 1) the potential for aquatic vegetation die-off and subsequent dissolved oxygen (DO) problems in Landa Lake, 2) the reduction in larval production of fountain darters that would likely be experienced, and 3) the potential for cool water inflows from springs along the western margin of Landa Lake flowing down the New Channel instead of entering the Old Channel, which could result in water quality impacts, including higher temperatures, greater than currently predicted in the Old Channel. Regarding the first concern, the aquatic vegetation question remains unanswered and assessing aquatic vegetation dynamics relative to springflow is a critical applied research component in the AMP. Additionally, mitigation measures are proposed to remove dying vegetation in an attempt to alleviate any DO concerns in Landa Lake. (*See* Section 5.2.4). Regarding the second concern, the reduction in larval production has been thoroughly documented in laboratory studies (Bonner *et al*. 1998, McDonald *et al*. 2007) and can be assumed to occur at these flow conditions in the wild based on temperature modeling (as no actual water quality data is available at 30 cfs total Comal springflow). Therefore, based on the temperature modeling, at a daily average of 30 cfs total Comal springflow, only the upper portion of the Old Channel and possibly pockets of cooler water along the bottom of Landa Lake (Hardy 2011) are projected to remain below three of the four temperature threshold ranges at all times. At this flow level, reduction in fountain darter larval production is possible in these cooler areas during portions of the day while all other areas of the system are projected to experience temperature conditions resulting in reductions in fountain darter larval and egg production. (Hardy 2011). At these flow levels, temperatures throughout most all of the Comal system are still below conditions necessary for survival of adult and juvenile fountain darters and a reduction in larval production within the threshold range (77 to 79°F) does not translate to “total” larval mortality. McDonald *et al*. 2007 projects reductions in larval production of up to 63 percent within these temperature ranges. The third concern is directly related to uncertainty associated with the temperature modeling and will require additional hydrodynamic modeling with follow-up water temperature modeling in addition to intensified spatial monitoring during low-flow events, which are proposed HCP research components.

Through 10 years of monitoring conducted for the EAA Variable Flow Study, the ecological response of the Comal Springs ecosystem has been documented several times following extensive flooding or relatively short drought periods experienced during the study period. The response/recovery typically starts with the reestablishment or expansion of aquatic vegetation within the system. This typically occurs within six months of the disturbance upon return to springflows between 200 and 400 cfs coupled with more stable flow conditions. Concurrent with the recovery of aquatic vegetation is the reestablishment of invertebrates (darter food source) within the vegetation. Subsequent to the aquatic vegetation and food source recovery, fountain

darters quickly move back into these recovered habitat areas. It is difficult to predict the recovery of habitat from conditions similar to the drought of record, but one can assume it would be slower than witnessed following the less extreme drought conditions experienced during the past 10 years.

It can also be assumed that recovery following an extreme drought would be slower than recovery following a massive flood event. Although extreme floods may cause the same amount or more destruction of aquatic vegetation relative to overall areal coverage, the key difference is that during an extreme flood event, the entire system maintains water and thus connectivity which should enhance the potential for reestablishment of both plant and invertebrate communities. In contrast, during an extreme drought, areas of the Comal system will be dry or stagnant for extended periods of time which will limit the connectivity and likely cause longer recovery periods. With longer recovery periods necessary, repeat occurrences of these types of events could provide cumulative impacts beyond what is projected by the analysis presented herein. This is the basis behind the aquatic vegetation restoration and protection efforts included in the HCP conservation measures and applied research activities and ecological modeling proposed for Phase I.

The best available scientific data supports a finding that a flow regime with a minimum flow of 30 cfs daily average total Comal springflow (with a flow split) for a period not to exceed six months followed by flows of 80 cfs for two to three months would be protective of the fountain darter in the Comal system during conditions similar to a repeat of the drought of record. However, the HCP during Phase I does achieve that exact flow regime, at this time. A monthly average flow of 25 cfs, which might result in a minimum daily average flow of about 10 cfs, is projected to occur during Phase I with conditions similar to a repeat of the drought of record. In addition, the full level of 80 cfs for two-to-three months following the lowest flow occurrence is not achieved under that same scenario. (See Figure 4-9b). As shown in Table 4-31, when modeled under drought of record conditions, only two months with flows as low as 27 cfs monthly average are projected during the 10 year drought of record period with increased flows beyond the lowest levels projected in subsequent months. This represents a near worst case drought scenario modeled and also assumes full pumping of 593,000 ac-ft. The duration of Phase I is only seven years and, thus, multiple months of 27 cfs monthly average total Comal springflows or multiple years of less than 80 cfs for two to three months following the lowest levels is not possible relative to the near worst-case modeled condition. This modeled condition is based on the assumption that all flow protection measures will be fully implemented and effective during Phase I. As discussed in Section 4.2.1.3, the analysis supports the determination that with only two months of 27 cfs monthly average total Comal springflow and slight shortage of higher flows (relative to the Management Objectives) in subsequent months (See Figure 4-9b) the Phase I package should not appreciably reduce the likelihood of survival of the fountain darter at Comal Springs or affect its potential for recovery.

The Phase I package does not satisfy the long-term Flow-Related Management Objective of 225 cfs total Comal springflow as a long-term daily average flow condition. As such, the Phase I package activities (minimization and mitigation measures, applied research, ecological modeling, and long-term monitoring) will guide the continued assessment of the long-term Key-Management and Flow-Related Objectives and assessment of the full HCP period. This additional work will be instrumental in finalizing a determination of what is necessary for long-term protection and the overall long-term recovery of the fountain darter at Comal Springs. Furthermore, as discussed in Chapter 5, additional flow protection strategies will also be investigated as part of the AMP to ensure compliance with the Management Objectives or future determined objectives.

Comal Springs Riffle Beetle

Similar to the fountain darter, assessing take for the Comal Springs riffle beetle is subject to the many habitat and population parameters that potentially affect the population dynamics, but the limited amount of available life history information adds additional complexity. Although considerable contributions to the Comal Springs riffle beetle knowledge base have been made through field and laboratory evaluations associated with the EAA Variable Flow Study, many ecological data gaps still exist for this species.

Habitat Requirements and Current Conditions

In the Comal system, Comal Springs riffle beetles are found in areas where springflow is evident around Landa Lake which includes spring Runs 1, 2, and 3 and spring openings associated with the Western shoreline of Landa Lake, upwelling areas surrounding Spring Island , and deeper water within the lake (EARIP 2009). The primary requirements for Comal Springs riffle beetles relate to high-quality springflow and maintenance of physical habitat (Bowles *et al.* 2002). BIOWEST (2004a–2011a) has documented the affinity for clear flowing water either horizontally or via upwelling.

Primary constituent elements for “critical habitat” of the Comal Springs riffle beetle are (1) high-quality water with pollutant levels of soaps, detergents, heavy metals, pesticides, fertilizer nutrients, petroleum hydrocarbons, and semi-volatile compounds such as industrial cleaning agents no greater than those documented to currently exist and including: (a) low salinity with total dissolved solids that generally range from 307 to 368 mg/L; (b) low turbidity that generally is less than 5 nephelometric turbidity units (NTUs); (c) aquifer water temperatures that range from approximately 68 to 75°F (20 to 24°C); and (d) a hydrologic regime with turbulent flows that provide Adequate levels of dissolved oxygen in the general range of 4.0 to 10.0 mg/L for respiration of the Comal Springs riffle beetle; (2) food supply for the Comal Springs riffle beetle that includes, but is not limited to, detritus (decomposed materials), leaf litter, and decaying roots; and (3) bottom substrate in surface water habitat of the Comal Springs riffle beetle that is composed of sediment-free gravel and cobble ranging in size from 0.3 to 5.0 inches (8 to 128 millimeters)(USFWS 2007).

Comal Springs riffle beetles (adults and larvae) have been collected at least semi-annually over the past six years via a cotton lure methodology employed for the EAA Variable Flow Study. The details of the sampling protocol and results can be found in BIO-WEST 2005a–2011a). In summary, three main areas are sampled in the Comal Springs system including Spring Run 3, a portion of the western shoreline of Landa Lake, and the Spring Island Area (Figure 4-4). Table 4-37 shows the total number of Comal Springs riffle beetles (adult and larvae) collected per event over this time period and the consistency among sample locations. A qualification in that consistency is that the area sampled along the western shoreline and Spring Island area are smaller areas in proportion to the total available habitat in those areas, as compared to the proportion of sample area to total available habitat in Spring Run 3.

TABLE 4-36
TOTAL NUMBER OF COMAL SPRINGS RIFFLE BEETLES (*HETERELMIS COMALENSIS*) COLLECTED WITH COTTON LURES (ADULTS AND LARVAE) FOR EACH EAA VARIABLE FLOW SAMPLING DATE 2004–2010

Sample Period	Spring Run 3	Western Shore	Spring Island	TOTAL
May–June 2004	88	83	122	293

August 2004	169	143	90	402
Nov–Dec 2004	170	175	146	491
April 2005	119	121	121	361
Nov–Dec 2005	262	201	185	648
May–June 2006	256	195	160	611
Nov–Dec 2006	185	92	125	402
May–June 2007	59	161	119	339
Nov–Dec 2007	204	83	132	419
May–June 2008	155	139	156	450
Nov–Dec 2008	144	133	227	504
May–June 2009	136	226	74	436
Nov–Dec 2009	72	56	198	326
May–June 2010	53	110	20	183
Nov–Dec 2010	298	264	104	666
TOTAL	2,370	2,182	1,979	6,531
AVERAGE	158.0	145.5	131.9	458.3

A closer look at the lower flow period experienced in 2009 shows fewer riffle beetles were collected at Spring Run 3 and the Western Shoreline in December, when daily average flows were about 300 cfs, as compared to June, when daily average flows were about 200 cfs, but more riffle beetles were collected at Spring Island in December compared to June. One explanation might be that the riffle beetle population fluctuates with total springflow. Most of the springs sampled in the Spring Island area are upwellings on the lake bottom and possibly less susceptible to the effects of drought than seeps along the margins of the lake, some of which had no measurable flow in June. However, many Comal Springs riffle beetles were collected on the lures along the Western Shoreline in June 2009. Another possible explanation is that riffle beetles in edge habitat retreat further into the Lake or Spring Run or go subsurface during lower flow conditions. This would also explain fewer numbers recorded during lower flow conditions. During 2010, increases in Comal Springs riffle beetle densities were recorded at all sites as flows returned to above historical average conditions.

Take Thresholds Relative to Springflow

One of the main flow-related questions is associated with the survival of Comal Springs riffle beetle during the prolonged drought of the 1950s which included approximately five months of zero flow. Hypotheses regarding their survival include the persistence of a few individuals in Landa Lake and subsequent redistribution to spring run habitats, a localized retreat into the spring heads or subsurface areas of flow, or aestivation carried out in a specific life stage. (Bowles *et al*. 2002; BIO-WEST 2002d). One of the hypotheses, the use of the hyporheos (subsurface habitat) during drought conditions, was tested under laboratory conditions with the findings of that study suggesting that Comal Springs riffle beetle associate strongly with springflow and move down into the substrate in response to upwelling. (BIO-WEST 2002d). The study showed Comal Springs riffle beetle response to a shift in springflow direction and intensity (individuals tended to move downward toward the source of water flow). This would support the hypothesis that the species retreats into spring heads or subsurface habitats with flow during drought and possibly at other times. EARIP (2009) describes examples of a similar taxon of riffle beetle using this behavior, and concludes that this response in a similar taxon and research suggesting movement toward the source of water flow (downward) raises uncertainty about the proportion of the population that may be found below the upper layer of rocks that have been primarily sampled for the species.

In the absence of sufficient data, take and increased risk conditions were evaluated based only upon surface habitat availability. This is likely a conservative approach considering the potential that this species may regularly occupy subsurface habitat or be able to use such habitat for extended periods as a mechanism for drought survival. It is believed that take associated with the reduction of this surface habitat begins to occur at approximately 120 cfs as a daily average at the main spring runs. It has been documented (mostly anecdotally) that during the late 1980s and mid-1990s the spring runs at Comal started to lose wetted area at approximately 120 cfs. Hardy (2009) also documents that wetted area in the spring runs decreases at daily average flows between 150 and 100 cfs. Hardy (2009) results show there are greater reductions predicted in surface habitat in all three spring runs below 100 cfs. Additionally, there is no surface habitat predicted for Spring Runs 2 or 3 at 30 cfs total discharge as a daily average (Hardy 2009). Although the modeling of surface habitat addresses changing conditions within the three main spring runs, it is important to reiterate that a large proportion of Comal Springs riffle beetle habitat exists along the Western Shoreline of Landa Lake and at upwellings around Spring Island. None of these additional habitats were evaluated in that original exercise. The importance of subsurface habitat was also not considered in that original modeling exercise.

Figure 4-21 shows that the Spring Island portions of Landa Lake and the Western Shoreline will remain inundated at 30 cfs whereas Spring Run 3 would likely go subsurface except for near the terminus into Landa Lake.

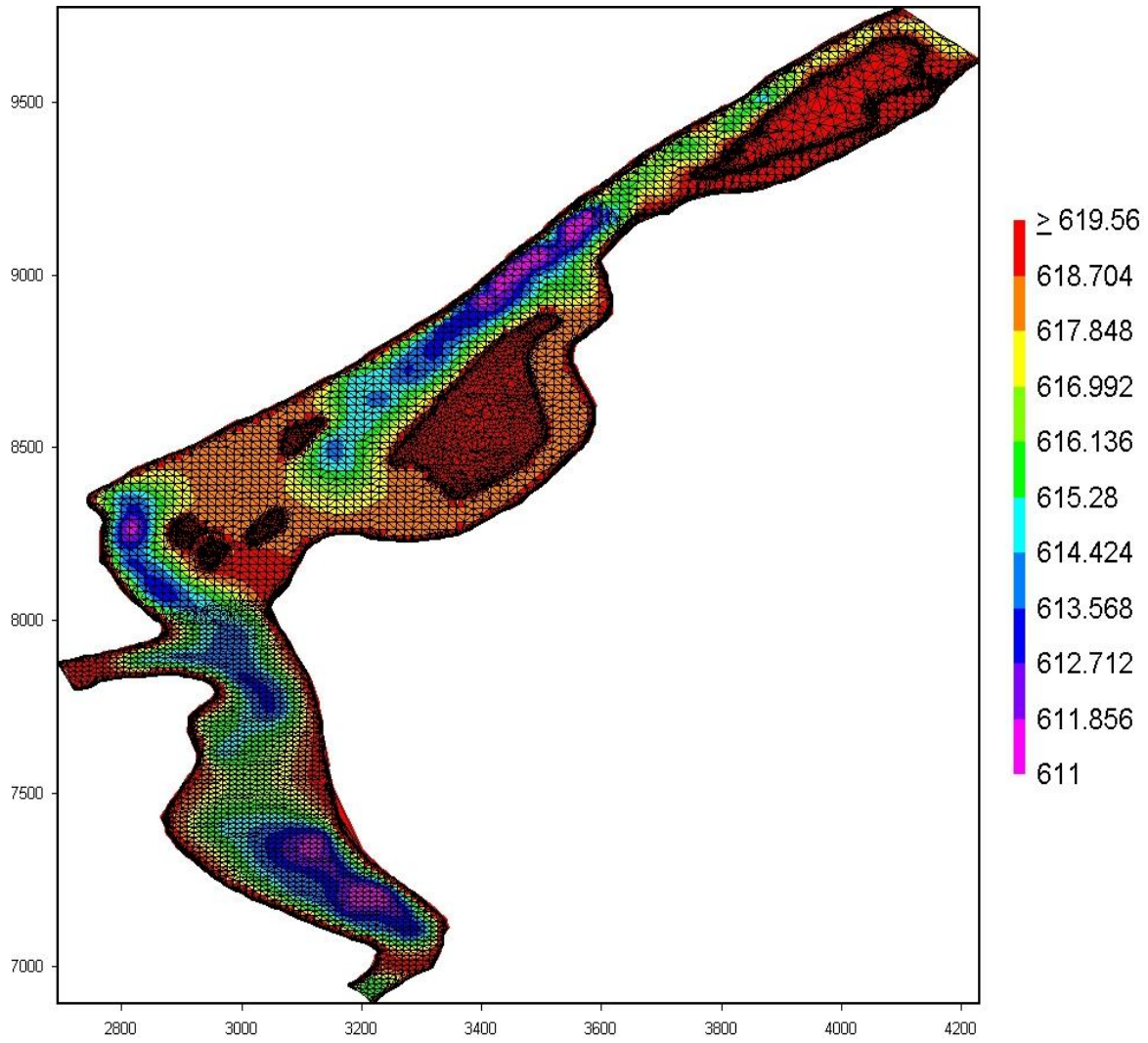


Figure 4-21. Modeled wetted area along western shoreline of Landa Lake and Spring Island at total daily average Comal discharge of 30 cfs*

*Water surface elevation at 30 cfs is set to maximum elevation.

Take Analysis Methodology (Assumptions, Model Development, Status)

Comal Springs Riffle Beetle Specific Assumptions

As discussed in the fountain darter section above, take is occurring at all times. Specific to the riffle beetle and Covered Activities, take from recreation, shoreline management, etc. occur today at varying levels regardless of springflow level. Take associated with pumping is most

directly tied to decreases in quantity and quality of habitat because of springflow reductions. This is first evident in Spring Run 3 and the critical discharge value at which this begins to occur is approximately 120 cfs total Comal springflow as a daily average. As total Comal springflows decline below 120 cfs, additional areas (spring runs and lake) are affected and differing levels of take start to occur. Similar to the long-term biological goals, the Comal Springs riffle beetle take assessment centers on a habitat-based approach within three main sample reaches in the Comal system. The three sample reaches include Spring Run 3, Western Shoreline of Landa Lake, and Spring Island area.

In addition to the system-wide assumptions stated in 4.2.2.1, the following Comal Springs riffle beetle specific assumptions apply to this approach:

- Comal Springs riffle beetle analysis does not include subsurface habitat area.
- Comal Springs riffle beetle recruitment is maintained when wetted surface area is available.

The former assumption is conservative because riffle beetles do use subsurface habitats. However, without a mechanistic ecological model to describe all the complexities that subsurface movement and habitat usage presents, this assumption is used to simplify a current unknown. The assumption regarding recruitment is thought to be true based on the empirical data. However, even if recruitment does continue, recruitment rates will likely be adversely affected by changing habitat conditions and the duration of periods of altered springflow. At the present time, there is not a modeling tool available to the HCP team to assess the potential effects of the Phase I package on Comal Springs riffle beetle recruitment.

The Comal Springs riffle beetle take analysis focuses on the following components:

- Comal Springs riffle beetle density variability with flow and time
- Habitat quantity adjustments (recreation at Spring Island) relative to flow
- Comal Springs riffle beetle habitat quality adjustments relative to flow

Physical habitat (Hardy 2009) and water quality modeling (Hardy 2010), along with actual observations (BIO-WEST 2002a–2011a) were used to estimate the levels of take relative to the HCP phased approach and HCP conservation measures. This was done by incorporating best available scientific information into the development of a Comal Springs riffle beetle habitat model.

Comal Springs Riffle Beetle Habitat and Population Model Development

A Comal Springs riffle beetle habitat model within each of the three sample reaches described above was developed using Stella 9.1 (Figure 4-22). The model includes actual field collected data for Comal Springs riffle beetles from 2004 to 2010. Both the spring and fall sampling periods over that six year span were incorporated into the model. The model was set up on a six-month time step to be consistent with the fountain darter models developed for the take analysis.

Each sample area was then evaluated to develop a wetted area to flow relationship (0 to 1.0 with 1.0 being the best). This exercise was based on Dr. Hardy's habitat model as well as from EAA Variable Flow Study observations over the past decade. For example, at daily average springflows of 60 cfs or less, Spring Run 3 is predicted to lose all surface flow for the portions of the spring run considered quality riffle beetle habitat. As such, flows less than 60 cfs were

deemed unsuitable (Figure 4-23). Flows above 120 cfs (Figure 4-22) were considered to provide the maximum quantity of wetted area for quality riffle beetle habitat in the spring Run. The western shoreline area was considered unsuitable at 20 cfs or less, while the Spring Island area was considered 0.25 suitable at 30 cfs and unsuitable at 0 cfs. The distinction between 20 cfs being unsuitable at the western shoreline, but still maintaining a small fraction of suitable habitat within the Spring Island area is because of the elevation of the springs and susceptibility of sedimentation along the western shoreline. However, with no springflow (0 cfs total Comal springflow as measured downstream at the USGS gage), it is assumed that vertical upwelling flow in the Spring Island area would be extremely minimal and thus, sedimentation of these remaining spring orifices would occur.

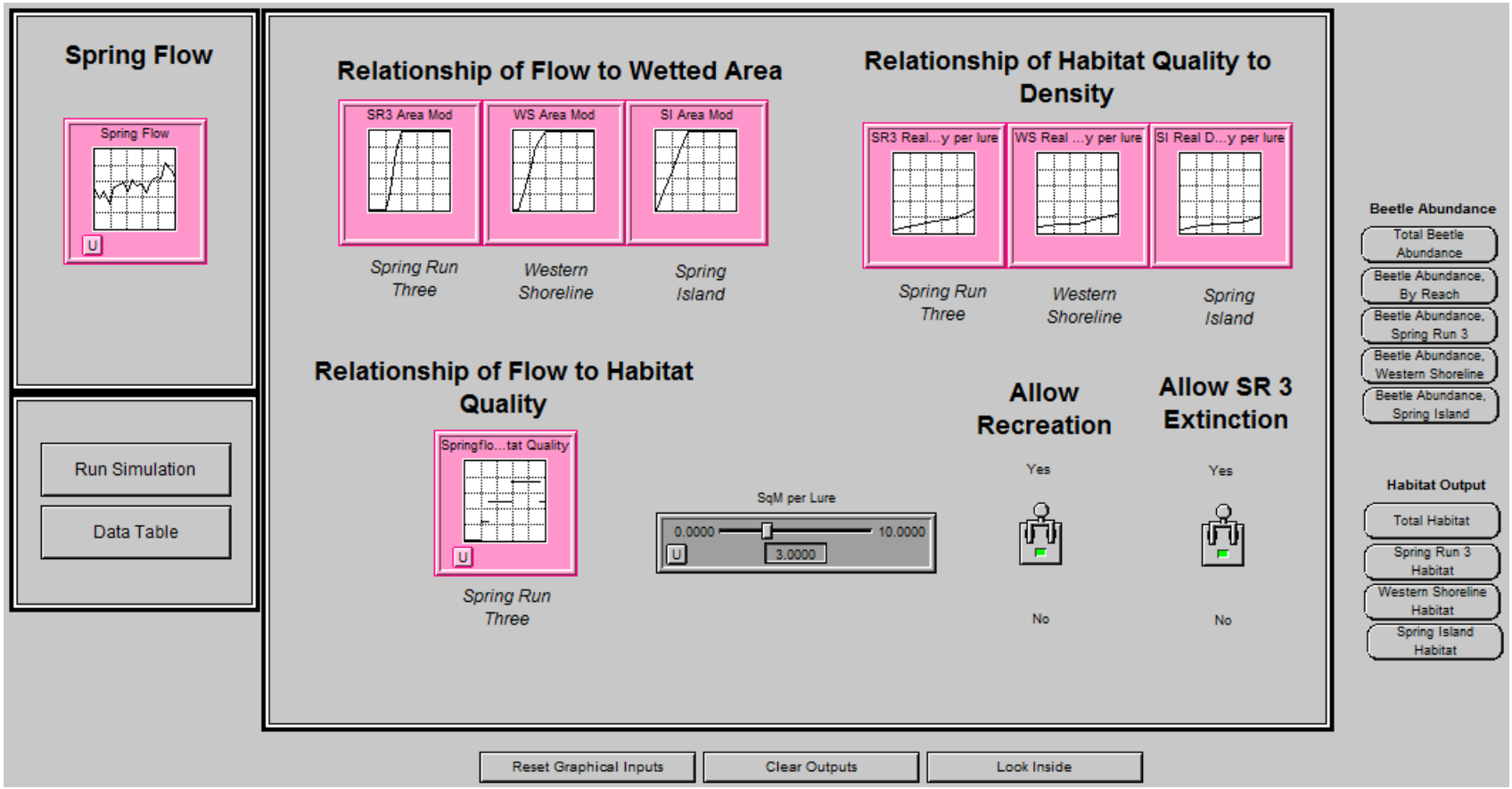


Figure 4-22. Stella Model Interface for Comal Springs riffle beetle Habitat Model at Comal Springs.

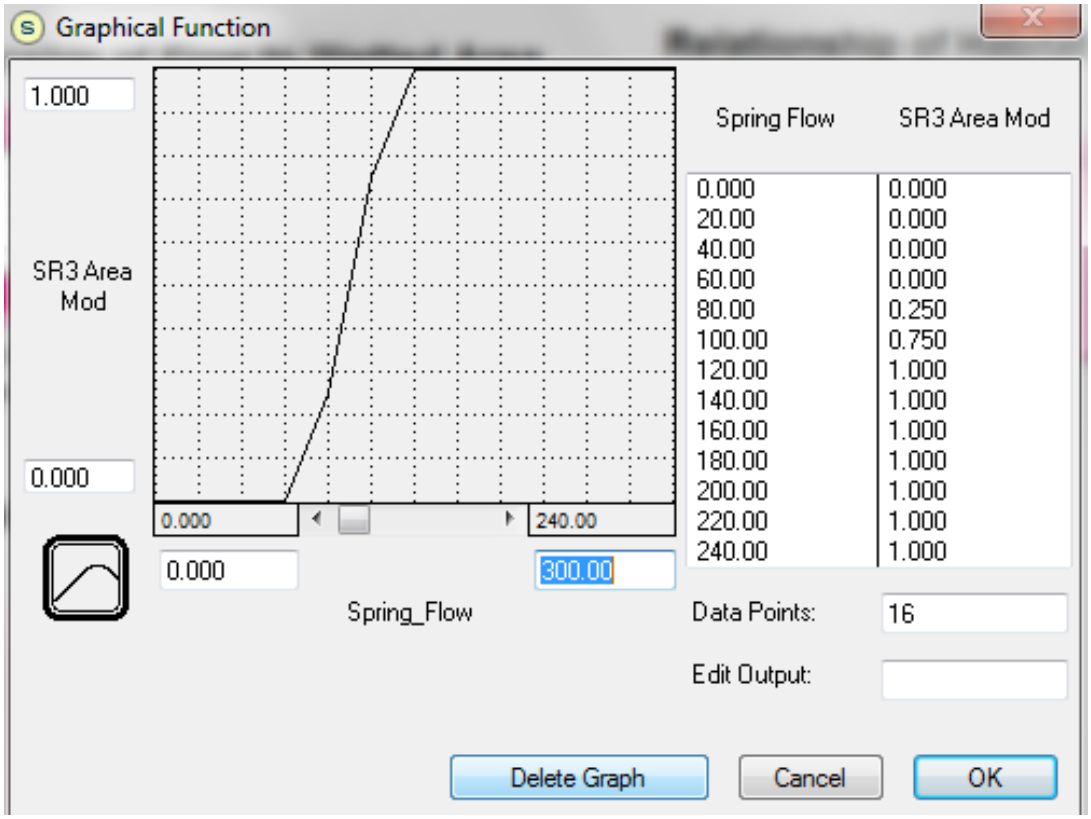


Figure 4-23. Wetted area to flow relationship for Spring Run 3 sample area.

The second component entered into the model is the Comal Springs riffle beetle density values recorded per cotton lure in the Comal system over the six year sample period. Table 4-37 shows the minimum, 25th, median, 75th, and maximum densities recorded for Comal Springs riffle beetles per cotton lure. For the take analysis, it was assumed that riffle beetles were attracted to the lures from a distance of 3 m^2 surrounding the lure. The model is set up to allow for adjustments in this assumption if other interpretations are determined to be appropriate. However, for consistency and equal comparison among the scenarios, the 3 m^2 assumption was used.

TABLE 4-37
COMAL SPRINGS RIFFLE BEETLE DENSITIES PER COTTON LURE PER SAMPLE AREA IN THE COMAL SYSTEM OVER TIME (2004-2010)

	Spring Run 3	Western Shoreline	Spring Island
MIN	7.0	9.0	7.0
25th	12.0	13.0	11.0
MEDIAN	17.0	14.0	13.0
75th	20.5	20.0	15.5
MAX	32.0	26.0	23.0

A habitat quality ranking for riffle beetle density was then generated based on EAA variable flow data and professional experience from observations in the system. A ranking system (Table 4-38) was incorporated into the model as follows:

TABLE 4-38
HABITAT QUALITY RANKING FOR COMAL SPRINGS RIFFLE BEETLE DENSITIES

Description	Ranking Value for Model	Density value from Table 4-36
Unsuitable	1	Minimum Density
Low quality	2	25th
Moderate quality	3	Median
High quality	4	75th

The habitat quality ranking based on riffle beetle density was then incorporated into the model for Spring Run 3 relative to the total Comal springflow condition (*see* Figure 4-21 – lower left box labeled "Relationship of Flow to Habitat Quality"). This adjustment was not included for the western shoreline or Spring Island sample areas in order to overestimate the effect of springflow. Since habitat quality in these two areas is primarily controlled by upwelling springs, it was determined that a quality adjustment based directly on the change in wetted area would be sufficient. However, Spring Run 3 has considerable horizontal springflow and as such it was given a quality factor associated with a change in springflow beyond just the change attributed to a reduction in wetted area. For example, from 120 to 190 cfs, the wetted area of Spring Run 3 receives a habitat quality of 3 and a horizontal springflow habitat quality of 3. However, between 200 and 320 cfs (total Comal springflow), the wetted area habitat quality remains a 3, but the springflow habitat quality is adjusted to a 4 to account for the assumed added benefit of horizontal springflow within this spring run. Above 320 cfs, the springflow habitat quality returns to a 3 to account for the undesirably high velocities generated at these discharges. Again, this analysis and the broad assumptions embedded in it highlight the need for the applied research and mechanistic ecological modeling outlined in Section 6.3.

Two additional factors were included in the Comal Springs riffle beetle model. The first is an adjustment for recreation at Spring Island. (BIO-WEST 2006a). As the wetted area changes very little in this area as springflow declines, the wetted area adjustment is small. However, as this area can experience high levels of recreation, an adjustment factor was incorporated at this sample area to reflect the impact that recreation might have on habitat quality.

Second, a Spring Run 3 extinction factor was built into the model. As is, the model consists of 18, 6-month time steps but the time steps are not connected with memory. As such, a total Comal Springflow of 30 cfs at time step 9 would create no surface flow in Spring Run 3 and the model subsequently predicts no riffle beetle habitat and accordingly, no beetles. However, if time step 10 involved springflow greater than 60 cfs, which would mean restored surface flow to Spring Run 3, the site would again contain habitat as well as a model generated riffle beetle population. The extinction factor overrides that aspect of the step 10 calculation to zero out the model generated population based on the assumption that the loss of surface flow extirpated the population and that re-colonization did not occur. It can easily be argued that this is overly

conservative as we know subsurface habitat is used by the beetles, and they did survive the 1950s drought of record with extended periods of zero surface flow. (BIO-WEST 202b). However, this analysis is not meant to revisit that discussion, but rather provide a worst-case scenario in which all Spring Run 3 riffle beetle habitat was lost and beetles were unable to re-colonize.

Comal Springs Riffle Beetle Species Status

To establish a Current Conditions of what the approximate Comal Springs riffle beetle population has been within the sample reaches in the Comal system from 2002 through 2010, the actual hydrology from that time period (Figure 4-24) was incorporated into the model. Additionally, constant flows from 10 to 450 cfs (in 10 cfs increments) were modeled to evaluate the model response to total Comal springflow.

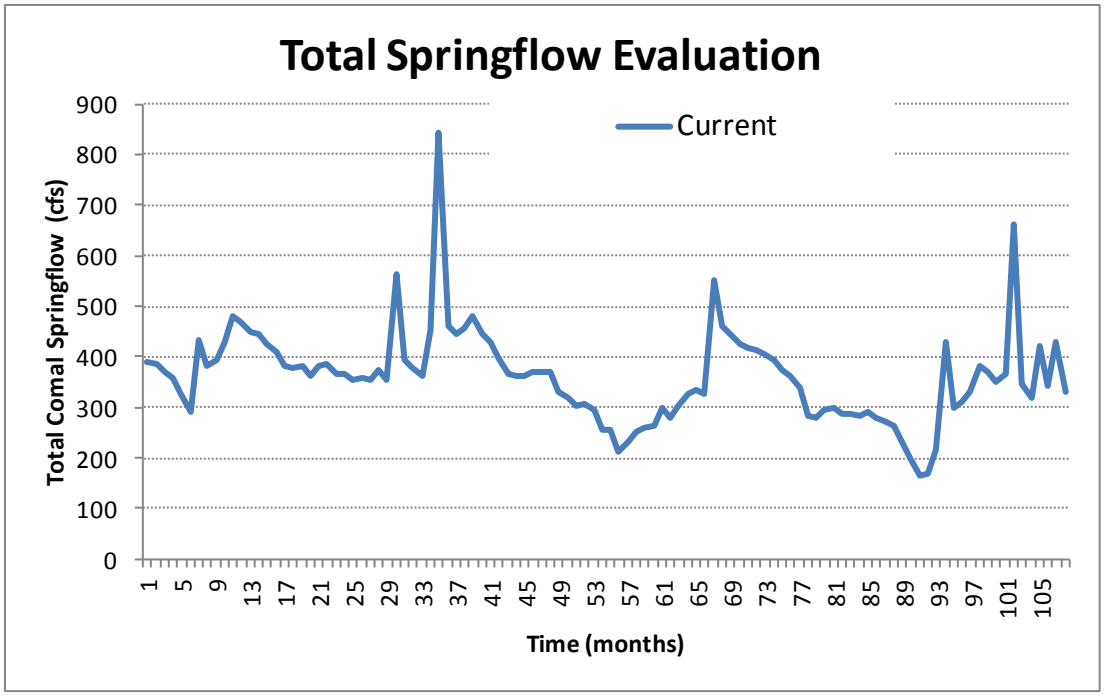


Figure 4-24. Total Comal springflow current scenario (2002-2010) evaluated in Stella.

Figure 4-25 shows the Stella model results for total Comal Springs riffle beetles within the sample areas. For all model runs, the springflow dependent habitat quality adjustment for Spring Run 3 was used. Additionally, the recreation toggle for Spring Island was activated.

The riffle beetle habitat model differs from the fountain darter model in that there is not an aquatic vegetation input that changes over time regardless of flow level. As such, each independent flow level will produce one habitat estimate which in turn calculates the corresponding population number. This difference in the model is of no consequence because the riffle beetle does not use aquatic vegetation as its habitat. Further the detritus that the riffle beetle use as a food source is not from aquatic vegetation but from leaf litter from the riparian areas.. Springflows exhibited during the existing period ranged from 150 cfs to 800 cfs which results in a modeled population estimate of between approximately 25,000 and 30,000 riffle beetles. The population estimate is only for the sample areas and clearly is an approximation based on the assumptions stated above. These assumptions add uncertainty regarding the actual number of Comal Springs riffle beetles present in the system and as projected by this

modeling exercise. However, for this take analysis, this approach provides a level of consistency for scenarios that allows for a meaningful comparison across different modeled flow regimes.

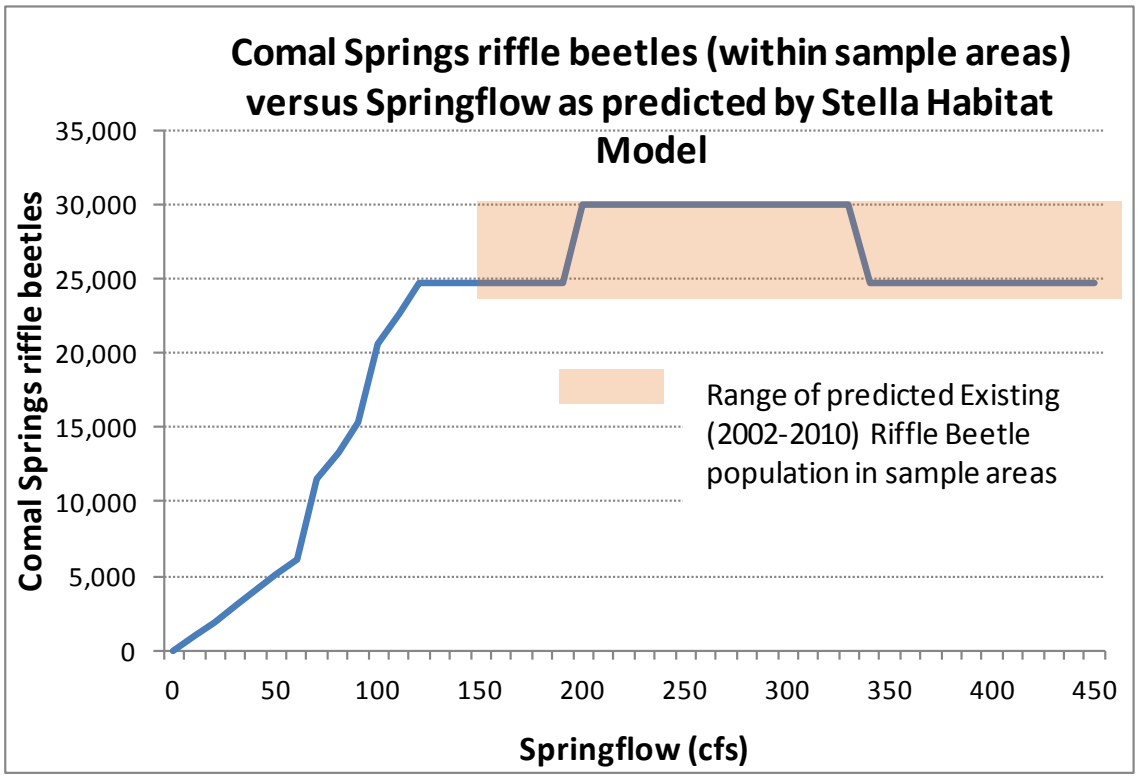


Figure 4-25. Comal Springs riffle beetles (within sample areas) predicted by Stella model (blue line). Shaded area is the predicted range of current (2002-2010) population within sample areas.

Evaluation of Effects of Action and Environmental Baseline Versus Current Condition

To assess the Phase I package, No Action Baseline, and Existing Baseline, the monthly flow data provided by HDR and presented in Section 4.2.1.3.1 was used. (*See* Figure 4-8). Figures 4-16 through 4-18 show the total predicted Comal springflow for each of the respective nine-year periods assuming different flow conditions for each scenario.

For the take analysis, these three flow sequences were converted into 6-month time steps and entered into the Stella riffle beetle model. Table 4-39 shows the model results for all three springflow conditions over the 18 – 6 month time steps. The most notable result is that the No Action and Existing baselines both result in zero Comal Springs riffle beetles in the sample reaches during, and following, a repeat of conditions similar to the drought of record. This would most likely translate to the entire system and result in extirpation of the species. Figure 4-26 graphically depicts the differences between the HCP, No Action Baseline, Existing Baseline, and Historical model during the low-flow period and Current Conditions (2002–2010). The loss of riffle beetles during the No Action and Existing baselines low flow scenarios is visually evident in Figure 4-26, while the HCP low flow scenario still maintains an overall population of riffle beetles. However, neither Table 4-39 or Figure 4-26 illustrate individual sample area breakout. The model predicts the habitat and population estimates for each individual sample area and those results are shown in Table 4-40 which presents the

breakdown of Comal Springs riffle beetles per sample area for Current Conditions, and modeled results during the low-flow representative period for the HCP, No Action Baseline, Existing Baseline, and Historical model scenarios. From this breakout, it is evident that using the Spring Run 3 extinction function in the model, riffle beetles in Spring Run 3 could be lost during the HCP-Phase I package low flow scenario. Again, this function assumes the elimination of the potential for beetle occurrences when wetted surface area is no longer present. It does not allow for subsurface movement or re-colonization from surrounding surface water habitats. This is likely somewhat of a worst-case scenario, as historically the entire system quit flowing for 144 consecutive days and the Comal Springs riffle beetle survived. Under the Phase I package low-flow scenario, monthly springflow estimates for the entire system do not fall below 27 cfs (monthly average), and that occurs for only two months. Regardless, if overly conservative or not, the point is to highlight the potential for impact and be consistent across analysis to allow the USFWS the ability to make a determination on “appreciable reduction” issuance criterion for the Comal Springs riffle beetle with the Phase I package.

Table 4-39. Total Comal Springs riffle beetles within Sample Reaches for the Phase I package, No Action Baseline, Existing Baseline, and Historical Conditions – Comal System: Habitat Quality Adjusted by Sample Reach – Low, Moderate, High represent 9-year model run periods generated for each alternative.

Time step	HCP - Phase 1	No Action Baseline	Existing Baseline	Historical	HCP - Phase 1	No Action Baseline	Existing Baseline	Historical	HCP - Phase 1	No Action Baseline	Existing Baseline	Historical
	LOW-Flow Representative Period				**MODERATE-Flow Representative Period**				**HIGH-Flow Representative Period**			
1	24,765	24,765	24,765	29,974	24,765	24,765	24,765	29,974	29,974	29,974	29,974	29,974
2	23,715	15,316	21,197	29,974	24,765	20,778	23,296	29,974	29,974	24,765	29,974	29,974
3	24,765	24,765	24,765	29,974	24,765	24,765	24,765	24,765	24,765	24,765	24,765	24,765
4	16,109	6,155	7,225	29,974	22,666	12,027	14,126	24,765	24,765	24,765	24,765	24,765
5	22,456	15,158	21,197	29,974	24,765	24,765	24,765	24,765	24,765	24,765	24,765	29,974
6	12,214	2,854	3,591	24,765	24,765	24,765	24,765	29,974	29,974	29,974	24,765	29,974
7	14,721	6,477	11,269	24,765	29,974	24,765	29,974	29,974	29,974	29,974	24,765	29,974
8	12,400	1,863	2,193	24,765	24,765	24,765	24,765	29,974	24,765	24,765	29,974	22,456
9	21,617	12,937	13,889	29,974	29,974	24,765	29,974	29,974	24,765	24,765	29,974	24,765
10	12,027	1,211	1,583	24,765	24,765	24,765	29,974	29,974	24,765	24,765	29,974	24,765
11	14,919	5,404	5,941	24,765	24,765	24,765	29,974	29,974	29,974	24,765	29,974	29,974
12	6,274	93	186	21,617	24,765	24,765	24,765	29,974	24,765	24,765	29,974	29,974
13	12,027	1,677	2,083	24,135	29,974	29,974	29,974	29,974	24,765	29,974	24,765	24,765
14	5,404	0	0	6,987	29,974	24,765	29,974	29,974	24,765	24,765	24,765	24,765
15	6,263	0	0	5,726	29,974	29,974	29,974	24,765	24,765	24,765	24,765	24,765
16	4,116	0	0	559	29,974	29,974	29,974	24,765	29,974	29,974	24,765	24,765
17	11,603	0	0	21,430	29,974	29,974	24,765	24,765	29,974	29,974	24,765	24,765
18	22,521	4,331	4,760	22,521	29,974	29,974	29,974	24,765	29,974	24,765	29,974	29,974
Min	4,116	0	0	559	22,666	12,027	14,126	24,765	24,765	24,765	24,765	22,456
Average	14,884	6,834	8,036	22,591	26,963	25,283	26,697	27,948	27,080	26,501	27,080	26,952
Max	24,765	24,765	24,765	29,974	29,974	29,974	29,974	29,974	29,974	29,974	29,974	29,974

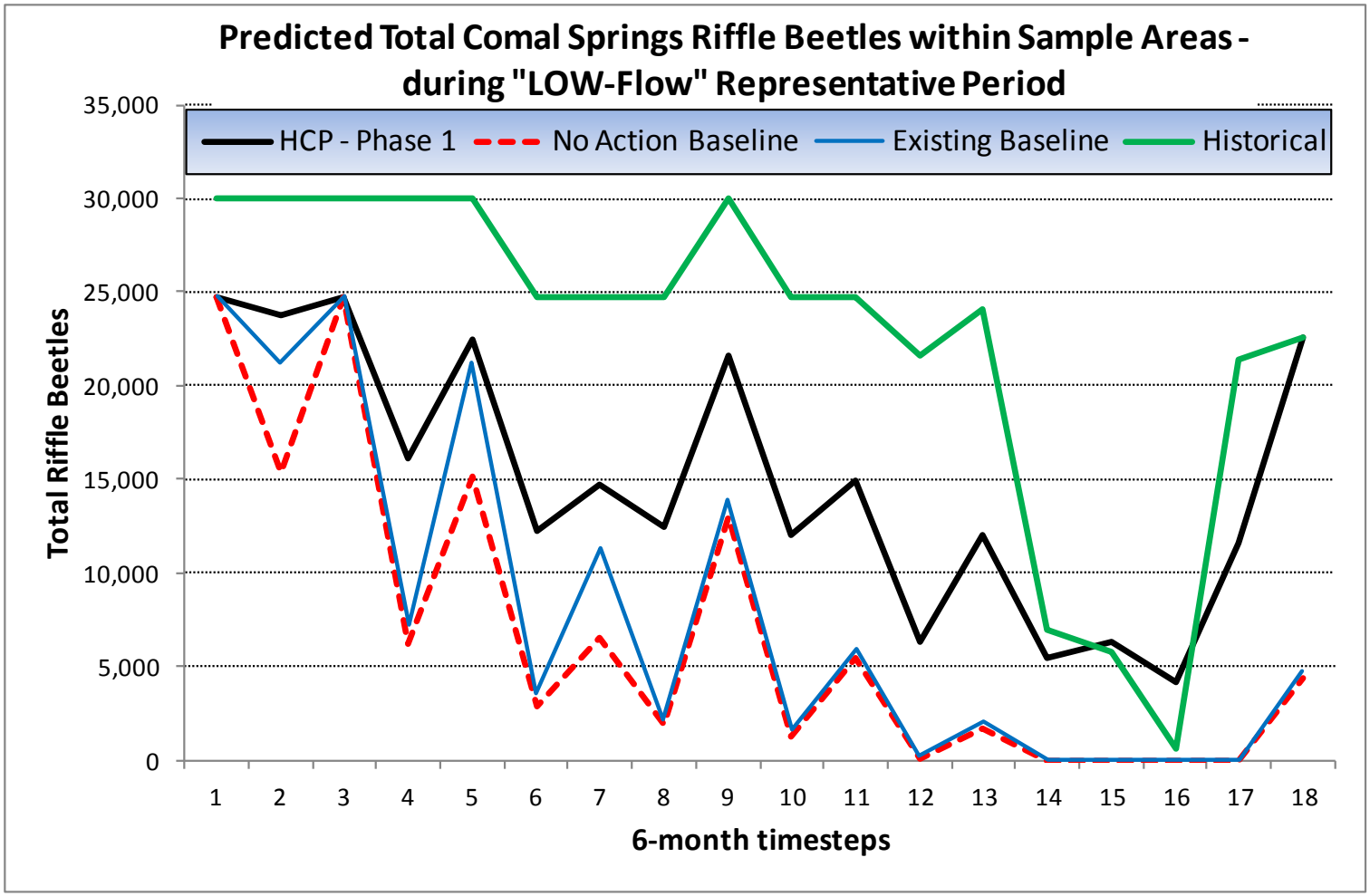


Figure 4-26. Total Comal Springs riffle beetles within sample areas predicted during the Low-flow representative period for the Phase 1 Package, No Action Baseline, Existing Baseline, and Historical Conditions – Comal System: Habitat Quality Adjusted by sample area

Table 4-40. Total Comal Springs riffle beetles per sample area for Current Conditions, Phase I package, No Action Baseline, Existing Baseline, and Historical model scenarios for the Low-Flow representative period.

Scenario	Range of Comal Springs Riffle Beetles in Sample Areas of the Comal System		
	Minimum	Average	Maximum
CURRENT (Total)	24,765	26,791	29,974
Spring Run 3	2,244	2,424	2,706
Western Shoreline	1,764	2,058	2,520
Spring Island	20,757	22,309	24,748
HCP – Phase 1 (Total)	4,116	14,884	24,765
Spring Run 3	0	766	2,244
Western Shoreline	298	1,208	1,764
Spring Island	3,819	12,910	20,757
No Action Baseline – (Total)	0	6,834	24,765
Spring Run 3	0	293	2,244
Western Shoreline	0	535	1,764
Spring Island	0	6,005	20,757
Existing Baseline (Total)	0	8,036	24,765
Spring Run 3	0	451	2,244
Western Shoreline	0	612	1,764
Spring Island	0	6,972	20,757
Historical Model (Total)	559	22,591	29,974
Spring Run 3	0	1,751	2,706
Western Shoreline	0	1,776	2,520
Spring Island	559	19,065	24,748

Unlike for the fountain darter, there is not presently a way to translate the riffle beetle population estimates per sample area to the total Comal system. Table 4-41 presents the size of each Comal

Springs riffle beetle sample area and the percentage of total sample area it represents. Using just the sizes of the sample areas, if the Spring Run 3 sample area habitat was completely lost during the Phase I package low-flow scenario, approximately seven percent of the total sample area would be lost. Assuming some areas within the Western Shoreline and Spring Island sample areas would be unsuitable during 30 cfs total Comal springflow as a daily average, approximately 70 to 80 percent of these three main (sampled) areas would likely sustain riffle beetle habitat. Considering Spring Runs 1 and 2 also host Comal Springs riffle beetles and would be dry at similar times to Spring Run 3, this percentage would decrease if they were included in the overall assessment and same assumptions maintained. However, because the same level of long-term data for these other spring runs and for other upwelling areas within Landa Lake where beetles have also been found is lacking, no attempt was made to translate the populations found in the three sample areas to the entire system.

Table 4-41. Size (m^2) of three Comal Springs riffle beetle sample areas and percentage of total sample area.

SAMPLE AREA	SIZE (m^2)	Percentage of Total
Spring Run 3	397	7%
Western shoreline of Landa Lake	378	7%
Spring Island	4,790	86%

Effects of Action Added to the Environmental Baseline

Based on the Comal Springs riffle beetle habitat and population model results, it is evident that the No Action Baseline and Existing Baseline will both cause incidental take during average to above average springflow conditions, but likely within the range of variability experienced during the Current Conditions. More notably, modeling shows that both baseline might cause extirpation of the Comal Springs riffle beetle from Comal Springs during a repeat of conditions similar to the drought of record. The word “might” is used for the riffle beetle versus the use of “will” for the fountain darter in Section 4.3.1.1.3 because of the uncertainty surrounding subsurface habitat use by the beetles. All modeling activities were based on a surface habitat assessment alone.

The Phase I package will similarly result in incidental take during periods of average to above average springflow conditions (again within the range of variability experienced during the Current Conditions). However, even based on an assumption of use of surface habitat alone, the Phase I package is not projected to result in extirpation of the riffle beetle at Comal Springs. A large amount of incidental take may be experienced with the Phase I package relative to the Current Conditions under flow conditions similar to the drought of record. During these extreme conditions, with all HCP conservation measures, there is the potential for a 100 percent reduction in surface habitat in Spring Run 3, and approximately an 80 percent reduction of surface habitat at the Western Shoreline and Spring Island sample areas. Compared to Current Conditions observed over the past nine years and based on the sample areas alone, this translates to potential take of up to approximately 20,000 Comal Springs riffle beetles during these extreme drought conditions, which could potentially leave approximately 4,000 beetles within these sample areas.

At this time, it is impossible to predict the actual level of Comal Springs riffle beetle take (in terms of habitat quantity or Comal Springs riffle beetle numbers) over the 15-year HCP period as natural variability of the population of this species is large. As such, a conservative, near worst case, scenario based on the best science available currently is presented above. Should flows remain fairly

average; and the HCP conservation measures be nominally successful, then the amount of take will likely be very low. Conversely, should full utilization of permitted pumping rights start in 2013; followed by a 10-year drought similar in nature to the drought of record; in conjunction with the HCP conservation measures not having a chance to be fully tested or implemented, then the potential for take of 80 percent or more of the current population is possible. It is critical that long-term monitoring, applied research, and mechanistic ecological models are performed and developed for this species as the HCP moves forward considering the uncertainty surrounding this analysis. A major factor that has the potential to dramatically change this take analysis is achieving a better understanding of riffle beetle use of subsurface habitat.

As discussed above for the fountain darter, when added to the No Action or Existing Baseline, the Phase I package results in an improvement for the Comal Springs riffle beetle based on springflow protection alone. This is highlighted in Figure 4-26 (black line [HCP] versus red or blue line [No Action Baseline and Existing Baseline, respectively]). Thus, compared to either baseline, the HCP should not appreciably reduce the likelihood of the survival and recovery of the Comal Springs riffle beetle even through a repeat of conditions similar to the drought of record. Factors supporting this conclusion include the projected remaining surface habitat and associated modeled population numbers within the sample areas, empirical data of the survival of this species during the drought of record (in which conditions were considerably worse than even the worse-case scenario modeled for the Phase I package), and the additional HCP conservation measures included with the Phase I package.

Applied research and modeling conducted during Phase I are anticipated to provide valuable information on the low-flow requirements and subsurface habitat use of the Comal Springs riffle beetle, which will inform any Phase I and Phase II adjustments that may be necessary. (*See*, *e.g.*, Section 6.3.4.2). From the statistical flow analysis presented in Table 4-30 it is evident that periods of low-flow will be extended for the HCP alternative compared to what was historically observed. As discussed in Section 4.2.1.3.1, this along with the long-term average flow management objective will need to be evaluated during Phase I activities.

Comal Springs Dryopid Beetle and Peck's Cave Amphipod

The Comal Springs dryopid beetle and Peck's Cave amphipod are subterranean species inhabiting the Comal system.

Habitat Requirements and Current Conditions

The habitat requirements of the Comal Springs dryopid beetle are: (1) high-quality water with pollutant levels of soaps, detergents, heavy metals, pesticides, fertilizer nutrients, petroleum hydrocarbons, and semi-volatile compounds such as industrial cleaning agents no greater than those documented to currently exist and including: (a) low salinity with total dissolved solids that generally range from 307 to 368 mg/L; (b) low turbidity that generally is less than 5 NTUs; (c) aquifer water temperatures that range from approximately 68 to 75°F (20 to 24°C); and (d) a hydrologic regime with turbulent flows that provide adequate levels of dissolved oxygen in the general range of 4.0 to 10.0 mg/L for respiration of the Comal Springs dryopid beetle; and (2) food supply for the Comal Springs dryopid beetle that includes, but is not limited to, detritus (decomposed materials), leaf litter, and decaying roots. (72 FR 39,248 (July 17, 2007)).

The habitat requirements of the Peck's cave amphipod are: (1) high-quality water with pollutant levels of soaps, detergents, heavy metals, pesticides, fertilizer nutrients, petroleum hydrocarbons, and semi-volatile compounds such as industrial cleaning agents no greater than those documented to currently

exist and including: (a) low salinity with total dissolved solids that generally range from 307 to 368 mg/L; (b) low turbidity that generally is less than 5 NTUs; and (c) aquifer water temperatures that range from approximately 68 to 75°F (20 to 24°C); and (2) food supply for the Peck's cave amphipod that includes, but is not limited to, detritus (decomposed materials), leaf litter, and decaying roots. (*Id*. at 39,254)

Peck's cave amphipods and Comal Spring dryopid beetles have been collected at least semi-annually over the past 10 years via drift netting over spring orifices employed for the EAA Variable Flow Study. The details of the sampling protocol and results can be found in BIO-WEST 2002a–2011a).

Take Thresholds Relative to Springflow

The subterranean nature and restricted range of the Comal Springs dryopid beetle (to the headwaters of the springs and spring upwelling areas) suggests that it does not require substantial surface discharge from springs to survive and presumes that springflow (of sufficient water quality) that continually covers the spring orifices should prevent harm to the population. EARIP (2009). Similarly, EARIP (2009) concludes that the Peck's Cave amphipod requirements include sufficient springflow covering the spring orifices and adequate water quality to prevent harm to the species.

An assumption carried forward in the HCP is that as subterranean species, mechanisms exist for these species to retreat into the Edwards Aquifer should spring flows cease at the spring outlets at Comal Springs. With that assumption, a modest amount of springflow should be sufficient to protect habitat for these species. Therefore, take is considered to start for the Comal Springs dryopid beetle and Peck's Cave amphipod at the time spring orifices become exposed which is predicted to be around 120 cfs for Spring Runs 1 and 2. At a daily average flow of 30 cfs total discharge in the Comal River, several springs remain flowing and provide habitat for the subterranean species up to the spring openings. As some spring orifices are exposed at this total discharge, management responses discussed in Chapter 6 are recommended below 30 cfs total Comal discharge. The potential for risk greatly increases as flows decrease to near zero flow.

Take Analysis Methodology (Assumptions, Model Development, Status)

The sparse amount of data for these species did not support the development of a Stella habitat or population model at this time. The limited existing data and inability to model these species led to a qualitative assessment of take for these two subterranean species. For surface dwelling species, take can be quantified relative to amounts of and disturbance to surface habitats. However, for subterranean species, the assessment is very different with the focus shifting to providing continuous springflow and protection of water quality.

Evaluation of Effects of Action and Environmental Baseline Versus Current Condition

Although a considerable number of Peck's cave amphipods have been expelled from the aquifer and collected in drift nets over the years, it is difficult to describe the current population within the aquifer with any confidence. Additionally, there is insufficient data for the Comal Springs dryopid beetle to even attempt this exercise. As such, no attempt was made to quantitatively describe a known Current Condition to compare against.

A concern identified, during these low-flow periods which will require further research includes the impacts to the energy flow regime in the Aquifer and near the springs. Aquifer species do not typically use live green plants as their primary nutrient source, but instead rely on carbon sources that are carried through the Aquifer in conduits. Organic carbon is measured in terms of POC/DOC (Particulate/Dissolved Organic Carbon), FBOC/CBOC (Fine/Coarse Benthic Organic Carbon), and in other ways. The natural flow of this carbon through the Aquifer may be altered during times of drought, when fewer rain events are pushing material through recharge features and pumping is removing disproportionately large volumes from wells. The natural energy flow allows for nutrients to

remain in the system until the flow reaches the downstream most point (the spring), while this altered regime could interrupt that system and potentially impact the species. Other carbon sources include native terrestrial vegetation along the banks of the spring and spring runs that provides habitat and food sources for the parts of the populations that occur at the spring orifice. Rootlets extend directly into the water and terrestrial plant material falls into the water and is the source of organic carbon that is part of the food chain for many aquatic invertebrates. Finally, the importance of dissolved organic matter from other sources within the Aquifer (*e.g.*, geomicrobial) to these spring and Aquifer species is also not well understood. However carbon by-products from these chemolithoautotrophs are recognized as the base of the food chain for deep Aquifer species, and their presence at spring openings suggests they may play a significant role in the food chain of spring species.

Effects of Action Added to the Environmental Baseline

For subterranean species, average to above average springflow conditions projected for both the Covered Activities and No Action Baseline (Figure 4-22) would likely have only minimal take associated with Covered Activities. During conditions similar to a repeat of a drought of record, neither the No Action Baseline, nor Existing Baseline are projected to maintain continuous springflows whereas the Phase I package does maintain such flows. (Figure 4-9a). The complete cessation of springflow for either Baseline would likely lead to considerable take and possibly jeopardize the continued existence of one or both species. Compared to average and above springflows, the springflows projected during a repeat of conditions similar to the drought of record for the Covered Activities and Phase I package would lead to additional take as spring orifices in the main spring runs would cease flowing for short periods of time. However, this increase in take would not approach that expected under the No Action or Existing baseline scenarios. There is uncertainty regarding this qualitative analysis, which again highlights the necessity of applied research, expanded biological and water quality monitoring, and ecological modeling.

As discussed for the other Comal species, when added to the No Action Baseline or Existing Baseline, the Phase I package results in an improvement for the likelihood of the survival and recovery of both the Peck's cave amphipod and Comal Springs dryopid beetle based on springflow protection alone. The Phase I package is protective of these subterranean species through a repeat of conditions similar to the drought of record during the initial phase of the permit because of the continuous springflow and resulting habitats throughout upwelling areas in the Landa Lake, empirical data of the survival of these species during the drought of record (in which conditions were considerably worse than even the worse-case scenario modeled for the Proposed Action), and the additional minimization and mitigation measures included with the Phase I package.

The hydrology associated with the Phase I package and hydraulic modeling shows that during conditions similar to those experienced during the drought of record, the main spring runs will not maintain surface flow and thus, habitat will be impacted. However, hydraulic modeling (Hardy 2010) projects that upwelling areas along the western shoreline of Landa Lake and near Spring Island will be maintained. Although impact to habitat is likely in areas of decreased or diminished surface flow during extreme conditions, continuous springflow should be sufficient to maintain the subsurface physical habitat necessary to prevent destruction or adverse modification to critical habitat. As these are subterranean species, the larger threat to the primary constituents of critical habitat is contamination of aquifer water quality. However, as described in Chapter 5, specific HCP conservation measures will be implemented to protect aquifer water quality and to expand the existing water quality monitoring network at Comal Springs.

Edwards Aquifer Diving Beetle

Habitat Requirements and Current Conditions

The Edwards Aquifer Diving Beetle is a subterranean species in the family *Dytiscidae*, and occurs both at Comal Springs and in the Artesian Well in the San Marcos Springs area. To prevent duplication, impacts to the species in both systems will be addressed in this subsection. The species is not currently listed, but may be listed in the future due to a positive 90-day finding to a petition (USFWS 2009a and 2009b).[12] The state of knowledge of this species is similar to the Comal Springs dryopid beetle although this species has not previously been included in any species-specific monitoring during the EAA Variable Flow Study.

Take Thresholds Relative to Springflow

The subterranean nature of this species suggests that it does not require substantial surface discharge from springs to survive and presumes that springflow (of sufficient water quality) that continually covers the spring orifices should prevent harm to the population related to habitat loss from dewatering. Given that assumption, take is considered to start for the Edwards Aquifer diving beetle at the Comal Spring system at the time spring orifices become exposed, which is predicted to be around 120 cfs as a daily average flow. (Hardy 2010) At 30 cfs as daily average for total discharge in the Comal River system, several springs remain flowing and provide habitat for the subterranean species up to the spring openings. As some spring orifices are exposed at this total discharge, management responses (*i.e.*, additional monitoring and potentially off-site refugia) discussed in Chapter 6 are recommended below a daily average of 30 cfs total Comal discharge. The potential for risk greatly increases as flows decrease to near zero flow. In the San Marcos Spring system, a conservative measure for take for the Edwards Aquifer diving beetle is a daily average of 50 cfs total discharge in the San Marcos River. As the flows decline below 30 cfs, the potential for risk increases and management responses are included as a component of the AMP and described in Chapter 6.

Take Analysis Methodology (Assumptions, Model Development, Status)

The sparse amount of data for this species did not support the development of a Stella habitat or population model at this time. The limited existing data and inability to model this species led to a qualitative assessment of take described below with the focus on providing continuous springflow and protection of water quality.

Evaluation of Effects of Action and Environmental Baseline versus Current Condition

As there is insufficient data for the Edwards Aquifer diving beetle, no attempt was made to quantitatively describe a known Current Condition against which to compare. As with the Comal Springs dryopid beetle and the Peck's Cave amphipod, the details of the Aquifer food chain are not well understood and additional concerns beyond the preservation of habitat related to springflow include the maintenance of a natural flow of carbon through the system. This carbon flow may be disrupted with combined drought and high levels of pumping.

Effects of Action Added to the Environmental Baseline

An informal qualitative take assessment was attempted but the sparse amount of data for this species limited that evaluation. As with the listed Comal subterranean species, take of this species is

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[12] The concept of "take" applies only to listed species, and, thus, does not directly apply to species such the Edwards Aquifer Diving Beetle. However, non-listed species included as Covered Species are to be treated as though they were listed. Accordingly, "take" is used here to describe impacts to those species.

anticipated to occur with the drying of surface habitat near spring orifices during periods of extreme drought. As a subterranean species, the larger threat is likely contamination of aquifer water quality. As such, specific HCP conservation measures will be implemented to protect aquifer water quality and to expand the existing water quality monitoring network at Comal and San Marcos springs.

As discussed for the other Comal species, when added to the No Action Baseline or Existing Baseline, the Phase I package results in an improvement for the Edwards Aquifer diving beetle based on springflow protection alone. Following the same rationale as described above for the listed Comal subterranean species, it is expected that the HCP conservation measures relative to aquifer water quality described in Chapter 5 addressing issues such as impervious cover, low impact development, minimizing the impacts of contaminated runoff, and increased monitoring will be sufficient to minimize and mitigate the impacts of any cumulative effects from increased development. Thus, the Phase I activities should not appreciably reduce the likelihood of the survival and recovery of the species during the initial period of the permit and contribute to attaining the long-term biological goals for the species.

Comal Springs Salamander

A population of salamanders occurs at Comal Springs, and for the purposes of this HCP we use the common name 'Comal Springs Salamander' that refers only to this population, in accordance with the federal listing petition for the species *Eurycea* sp. 8 (USFWS 2009a and USFWS 2009b). The species is not currently listed as endangered, but may be listed in the future as FWS has made a positive 90-day finding in response to the petition.

Habitat Requirements and Current Conditions

The EAA Variable Flow Study has been collecting data on the Comal Springs salamander since fall 2000. (BIO-WEST 2002a-2011a). The range and locations of habitat in the Comal system is similar to that of the Comal Springs riffle beetle but with somewhat larger areas and an extension upstream of Spring Island. Generally the habitat needs are similar to the San Marcos salamander which includes preference for silt-free rocks for cover, aquatic vegetation for cover and the support of invertebrate prey items, and a natural quantity and quality of water from the springs.

Take Thresholds Relative to Springflow

Similar to the Comal Springs riffle beetle, it is believed that take of Comal Springs salamander surface habitat begins to occur at approximately 120 cfs as a daily average at the main spring runs. Hardy (2009) documents that wetted area in the spring runs decreases between 150 and 100 cfs. Hardy (2009) predicts greater reductions in surface habitat in all three spring runs below 100 cfs. Additionally, there is no surface habitat predicted for Spring Runs 2 or 3 at a daily average of 30 cfs total discharge. (Hardy 2009). Although the modeling of surface habitat addresses changing conditions within the three main spring runs, it is important to reiterate that a large proportion of Comal Springs salamander habitat exists along the Western Shoreline of Landa Lake and at upwellings within Landa Lake. Figure 4-21 shows that the spring upwelling areas in Landa Lake and the Western Shoreline will remain inundated at 30 cfs whereas Spring Run 3 would likely go subsurface except for near the terminus into Landa Lake.

Take Analysis Methodology (Assumptions, Model Development, Status)

As this salamander is not presently a listed species, the development of a Stella habitat or population model was not conducted. Rather a qualitative assessment of take was conducted for the Comal Springs salamander. As discussed previously, take is an on-going reality for surface dwelling species at Comal Springs from both Covered Activities and ongoing activities outside the purview of the HCP.

Evaluation of Effects of Action and Environmental Baseline versus Current Condition

As this salamander is not presently listed, and a quantitative modeling approach was not employed, there was no attempt to quantitatively describe a known Current Condition for which to compare against. Rather, based on the overlap of Comal Springs salamander and Comal Springs riffle beetle populations, a qualitative assessment of salamander take was conducted based partially on the quantitative assessment of riffle beetle habitat discussed above.

Effects of Action Added to the Environmental Baseline

Based on the underpinnings (hydraulic modeling of surface habitat) of the Comal Springs riffle beetle assessment, it is likely that the No Action Baseline and Existing Baseline will cause incidental take of Comal Springs salamanders during average to above average springflow conditions. More notably, habitat modeling for the riffle beetle suggests that the No Action Baseline and Existing Baseline might cause extirpation of the Comal Springs salamander from Comal Springs during a repeat of conditions similar to the drought of record. The word “might” for the salamander is used here because of the uncertainty surrounding subsurface habitat use by the salamander and the fact this assessment is based in part on surrogate modeling efforts.

The Phase I package will similarly cause incidental take during periods of average to above average springflow conditions. However, even based on surface habitat alone, the Phase I package is not projected to cause extirpation of the Comal Springs salamander at Comal Springs. Similar to the riffle beetle, it is likely that a large amount of incidental take (habitat and salamanders) could be experienced with the Phase I package relative to the Current Condition under flow conditions similar to the drought of record. During these extreme conditions, with all HCP conservation measures, there is the potential for a 100% reduction in Spring Run 3 surface habitat.

As discussed for the riffle beetle, when aggregated with the No Action Baseline or Existing Baseline, the Phase I package results in an improvement for the Comal Springs salamander based on springflow protection alone. Thus, similar to the riffle beetle, the Phase I package should be protective of the Comal Springs salamander in the Comal System through a repeat of conditions similar to the drought of record because of the projected remaining surface habitat, empirical data of the survival of this species during the drought of record, and the additional HCP conservation measures included with the Phase I package.

4.2.2.2 San Marcos Springs/River Ecosystem

The following sections describe the individual species analysis that was conducted for the HCP. As a result of the EARIP EARIP deliberations and flow-regime development process, the subsequent HCP team’s and Dr. Hardy’s independent analysis of protective flow-regimes in conjunction with potential minimization and mitigation measures, and the development of the long-term biological goals for the HCP, a wealth of data has been compiled, condensed, and evaluated. This take analysis builds on the work from those efforts, with the EAA Variable Flow Study data collected over the past decade, along with the hydraulic/habitat and water quality modeling conducted by Dr. Hardy. However, even with this level of data and analysis, a complete interactive analysis is not possible with the existing

tools available. As such, a mechanistic ecological model will be developed during Phase I of the HCP.

For the take analysis at San Marcos Springs several system-wide assumptions are embedded. These assumed management actions include:

- Restoration of native aquatic vegetation in select segments of the San Marcos River (Section 5.3.8).
- Sediment removal in the San Marcos River within Sewell Park (Section 5.3.6).
- Re-establishment of Texas wild-rice in key habitat areas throughout the river (Section 5.3.1).
- Protection of aquifer water quality (Sections 5.72, 5.74, and 5.7.6)
- Control of gill parasites, non-native species (plant and animal), and predation and competition (native and non-native species) (Sections 5.3.5 and 5.3.9).

In addition to these system-wide assumptions, there are several species-specific assumptions that will be highlighted in their respective sections below.

The format of the incidental take assessment includes a description of the approach employed for a specific species, followed by the results of comparative scenarios for the Phase I package as well as the No Action Baseline. For the Comal System, there was a considerable difference in the modeled discharge for Comal Springs relative to the No Action Baseline and Existing Baseline (Figure 4-8 and 4-9a). Those considerable differences led to an independent analysis of impacts associated with the Environmental Baseline for Comal Springs. However, as evident in Figures 4-10a and 4-10b there is essentially no difference in the modeled No Action Baseline and Existing Baseline hydrographs at San Marcos Springs. Slight differences are evident in the Table 4-31 breakdown but these are not large enough to result in any meaningful difference in the impact assessment as conducted for this take analysis. Therefore, throughout the San Marcos Covered Species assessments, only the No Action Baseline was carried forward.

In the event where achievement of species-specific assumptions is essential for the protection of the species, they are highlighted and a comparison with and without those assumptions is provided. As with Comal Springs, the San Marcos Springs assessment is complicated by the extremely low flows projected by the No Action Baseline and Existing Baseline during conditions similar to the drought of record. It is possible that those springflow levels would extirpate the fountain darter at San Marcos Springs. It is likely that other covered species at San Marcos Springs might also suffer the same fate under the No Action Baseline and Existing Baseline. This will be discussed in the respective “Effects of Action Added to the Environmental Baseline” sections for each covered species.

Fountain Darter

Fountain darters were first collected in the San Marcos River in 1884 from immediately below the confluence with the Blanco River and have a current distribution in the San Marcos River from Spring Lake to an area between the San Marcos wastewater treatment plant outfall and the confluence with the Blanco River. (*See* EARIP 2009). Biological monitoring for fountain darters conducted over the past ten years (BIOWEST 2002b - 2011b) has focused on three main reaches of the San Marcos Springs system: Spring Lake (adjacent to the old hotel/current TPWD offices), City Park (near Lions Club tube rental), and Interstate 35 (below Cheatham Street to near IH-35). (*See* Figure 4-2).

Habitat Requirements and Current Conditions

Data collected from the EAA Variable Flow Study since 2002 suggest that the highest quality fountain darter habitat is located within Spring Lake. Spring Lake maintains exceptional water quality conditions, a diverse aquatic vegetation community, and supports year round reproduction of fountain darters which contributes to the continuance of large populations of fountain darters in the lake (EARIP 2009). The City Park and IH-35 reaches both maintain more variable habitat conditions for fountain darters that are related to total San Marcos River discharge (BIO-WEST 2002b–2011b) with seasonal fountain darter reproduction peaking during the spring. Compared to Spring Lake or Landa Lake of the Comal Springs system, the habitat in these downstream reaches is of lesser quality to fountain darters due to swifter currents, vegetation types, and recreational activities. As such, Spring Lake is considered prime habitat with downstream habitat being considered less that optimal with decreasing quality extending downstream. Flow conditions and recreation, both of which influence the aquatic vegetation community within the San Marcos river are the key contributors to why downstream habitat in the San Marcos River is considered less than optimal compared to prime habitat in Spring Lake.

Monitoring since 2002 (BIO-WEST 2002b–2011b) shows a total San Marcos Springs System discharge of greater than 125 cfs provides high quality fountain darter habitat throughout most of its range, excluding periods of high flow pulses. Indirect impacts associated with recreational activities in City Park occur each year regardless of flow condition but are magnified during lower flows as described in EARIP (2009). Considerable habitat alteration has occurred several times since 2000 as a result of high flow pulses (heavy localized rain events) scouring out extensive areas of aquatic vegetation. These time periods are generally short-lived (hours to days) and the aquatic vegetation typically recovered and/or expanded in one to six months. (EARIP 2009). BIO-WEST (2007c) has concluded that these represent flow events that have direct impacts on fountain darter habitat, but only on a temporary time scale.

On-going monitoring continues to confirm the importance of aquatic vegetation to the fountain darter. The type and quality of the aquatic vegetation in the system appears to be a primary factor affecting the density of darters in the San Marcos Springs/River ecosystem. Therefore, take as defined by the USFWS is triggered at the level at which aquatic vegetation declines or adverse temperature effects are possible as a result of reduced springflow. For the San Marcos Springs/River ecosystem, this potential for decline first occurs in the downstream-most areas of fountain darter habitat because of increasing water temperatures and potential impacts on aquatic vegetation.

Take Thresholds Relative to Springflow

The focus of this assessment is on the incidental take associated with Covered Activities with emphasis on springflow reductions and recreation. It is clear that reduced springflow decreases both the quantity and quality of aquatic vegetation and physical parameters (fountain darter habitat), or causes limitations to the larval recruitment success of the fountain darter. The difficulty is in accurately assessing the point at which this first occurs. Since the time when the USFWS first identified a critical discharge value at which “take” is believed to occur, there has been a wealth of data collected and habitat and water quality modeling conducted to help inform this decision. Based on data collected over the past decade, it appears that the combination of sedimentation, low water levels, and recreation first cause take in the form of fountain darter habitat impacts as total discharge declines to approximately a daily average of 100 cfs in the system. At this total discharge level, conditions within Spring Lake remain relatively unchanged; however, conditions within Sewell Park and City Park start showing reductions in aquatic vegetation (EARIP 2009). For the San Marcos River (downstream of Spring Lake), approximately 90, 80, and 75 percent of the available weighted

usable area predicted at average San Marcos River total discharge remains at 100, 50, and 30 cfs total San Marcos River discharge, respectively. Hardy (2010).

Hardy (2010) water temperature modeling shows that, at a 80 cfs daily average total discharge, Spring Lake and the river downstream through Sewell Park remain suitable for fountain darter reproduction at all times. From City Park downstream, as a result of temperature increases during portions of each day (under worst case modeled conditions), increased larval mortality and reduced egg production are indicated. However, at no location in the river does water temperature exceed conditions for juvenile or adult fountain darter survival. At a daily average flow of 45 cfs, water temperature in Spring Lake habitats does not exceed any of the aforementioned water quality checkpoints (Hardy 2010). At 45 cfs, the San Marcos River from Spring Lake dam to the extent of fountain darter habitat from City Park downstream is predicted to have portions of each day (under worst case modeled conditions) with water temperatures high enough to cause increased larval mortality and reduced egg production. However, as noted for 80 cfs, a daily average flow of 45 cfs does not result in any locations in the river where water temperatures are predicted to exceed conditions for juvenile or adult fountain darter survival. Although take is first evident at 100 cfs in the river, considering that Spring Lake harbors a large amount of high quality habitat and large fountain darter population, considerable take for the fountain darter relative to the total population is not anticipated in the San Marcos system until around 50 cfs total San Marcos discharge.

Gill parasites, the presence of exotic species (primarily suckermouth catfishes and ramshorn snails), water quality degradation, and recreation all have consequences on the fountain darter populations. One additional factor for the San Marcos Springs/River ecosystem relevant to fountain darters is increased sedimentation. (EARIP 2009). Minimization and mitigation measures to reduce impacts from these threats are included in the HCP (Chapter 5), and integral to the protection of fountain darters.

Finally, since low-flow data and habitat responses are not available at this time, the applied research and ecological modeling discussed in Section 6.3 will be essential to better project impacts to this species over the life of the ITP.

Take Analysis Methodology (Assumptions, Model Development, Status)

Fountain Darter Specific Assumptions

Relative to the Covered Activities, take from recreation, shoreline management, etc. can occur at varying levels regardless of springflow level. Take associated with springflow reductions is first evident in the San Marcos River at a daily average flow of approximately 100 cfs total San Marcos springflow. As total San Marcos springflows decline below 100 cfs, additional areas are affected and differing levels of take (both in the river and Spring Lake) start to occur. Similar to the long-term biological goals, the fountain darter take assessment centers on a habitat-based approach within representative reaches of the San Marcos system. The three reaches include the Spring Lake Dam Reach, City Park Reach, and IH-35 Reach. Further descriptions of these reaches are presented in BIO-WEST (2002b-2011b).

In addition to the system-wide assumptions stated above, the following fountain darter specific assumptions apply to this approach:

- Fountain darter movement away from adverse conditions does not occur (*i.e.*, when vegetation decreases, fountain darters automatically die) (movement is not incorporated into the take analysis)

- Fountain darter recruitment is maintained at all flows (*i.e.*, reduction in recruitment is not incorporated into the take analysis)

The former assumption is conservative as darter movement does occur and would be expected when a reduction in aquatic vegetation would occur. However, without a mechanistic ecological model to describe all the complexities that these movements would likely cause (*e.g.*, crowding which could limit reproduction, limit growth rate, increase predation and competition, etc.) this assumption is in place to simplify a current unknown. The latter assumption regarding recruitment is thought to be true, and does not affect the analysis, because the temperature and habitat is supportive of fountain darter reproduction for all flows assumed for the HCP in Phase I and II. (Hardy 2010). However, even if recruitment does continue, recruitment rates will no doubt be affected by changing habitat conditions and the duration of periods of altered springflow. There is not a modeling tool available to assess all the potential effects of the Phase I package on fountain darter recruitment.

An additional major assumption embedded in the San Marcos analysis is that the fountain darter population in Spring Lake will not be severely impacted by springflows predicted to occur with the Phase I package. As monthly springflows are predicted to stay above 50 cfs (Figures 10a and 4-10b), which is anticipated to result in daily average flows no lower than 43 cfs, historical and empirical data along with modeled temperature results support this assumption. However, this assumption does not hold for the No Action Baseline or Existing Baseline scenarios where monthly flows fall below 10 cfs (Figure 4-10b). Major impacts to habitat and population would be expected for the fountain darter in Spring Lake under the No Action Baseline and Existing Baseline scenarios. An evaluation of potential mechanistic or alternative ecological modeling of Spring Lake will also be conducted as part of the AMP to assess the potential impacts of springflows lower than 50 cfs in the event model predictions regarding hydrology are inaccurate.

Therefore, the fountain darter take analysis focuses on the San Marcos River below Spring Lake Dam and is based on the following components:

- Dominant aquatic vegetation changes with flow and time
- Fountain darter density variability with flow and time
- Aquatic vegetation quality adjustments relative to flow
- Fountain darter habitat suitability adjustments relative to flow
- Aquatic vegetation to fountain darter linkage with flow and time
- Application of a fountain darter Stella model

Physical habitat and water quality modeling (Hardy 2010), along with EAA Variable Flow Study actual observations (BIO-WEST 2002b–2011b), were used to estimate the levels of take relative to the HCP phased approach and HCP conservation measures. This was done by incorporating best available scientific information into the development of a fountain darter habitat model for the San Marcos system.

Fountain darter habitat and population model development

A fountain darter and aquatic vegetation linkage model within each of the three representative sample reaches described above was developed using Stella 9.1 (Figure 4-27). The model includes actual field collected data for aquatic vegetation and fountain darters over a nine year period via the EAA Variable Flow Study. Both the spring and fall sampling periods over that nine year span were

incorporated into the model. The model was set up on a six-month time step so that aquatic vegetation measured during the Spring event of a given year would be the base vegetation used versus flow until the Fall aquatic vegetation mapping that same year, at which time the results of the Fall mapping would become the base vegetation used until the following spring.

Each dominant aquatic vegetation type was then evaluated versus flow to establish a habitat quality condition (0 to 1.0 with 1.0 being the best). This exercise was based on Dr. Hardy's habitat model as well as from EAA Variable Flow Study observations over the past decade. For instance, *Cabomba* in the City Park reach received a 1.0 ranking for the range from 105 to 245 cfs, as a daily average, total San Marcos springflow (Figure 4-28). Therefore, when these flows occur, the full amount of *Cabomba* measured at a given time step was used in the model. At total San Marcos springflow less than 105 cfs (*see* Figure 4-28), the suitability ranking was lowered for *Cabomba.* A reduction in *Cabomba* quality is also projected at high total San Marcos springflows above 245 cfs as the scouring effect of elevated flows also has an adverse impact on these plants.

The second component entered into the model is the fountain darter density values recorded per dominant vegetation type in the San Marcos system over the same nine year period. Table 4-43 shows the minimum, 25th, median, 75th, and maximum densities recorded for fountain darters per dominant aquatic vegetation type in the San Marcos system.

TABLE 4-42
FOUNTAIN DARTER DENSITIES PER AQUATIC VEGETATION TYPE IN THE SAN MARCOS SYSTEM OVER TIME (POT/HYG = *POTAMOGETON/HYGROPHILA*)

	Cabomba	Hydrilla	Hygrophila	Open	Pot/Hyg	Potamogeton
MIN	0.5	0.0	0.0	0.0	0.0	0.7
25th	3.0	1.3	1.7	0.0	2.0	1.4
MEDIAN	6.5	2.5	3.5	0.0	3.0	2.0
75th	11.5	6.4	6.5	0.0	6.9	8.9
MAX	27.8	133.9	31.0	1.0	18.0	15.7

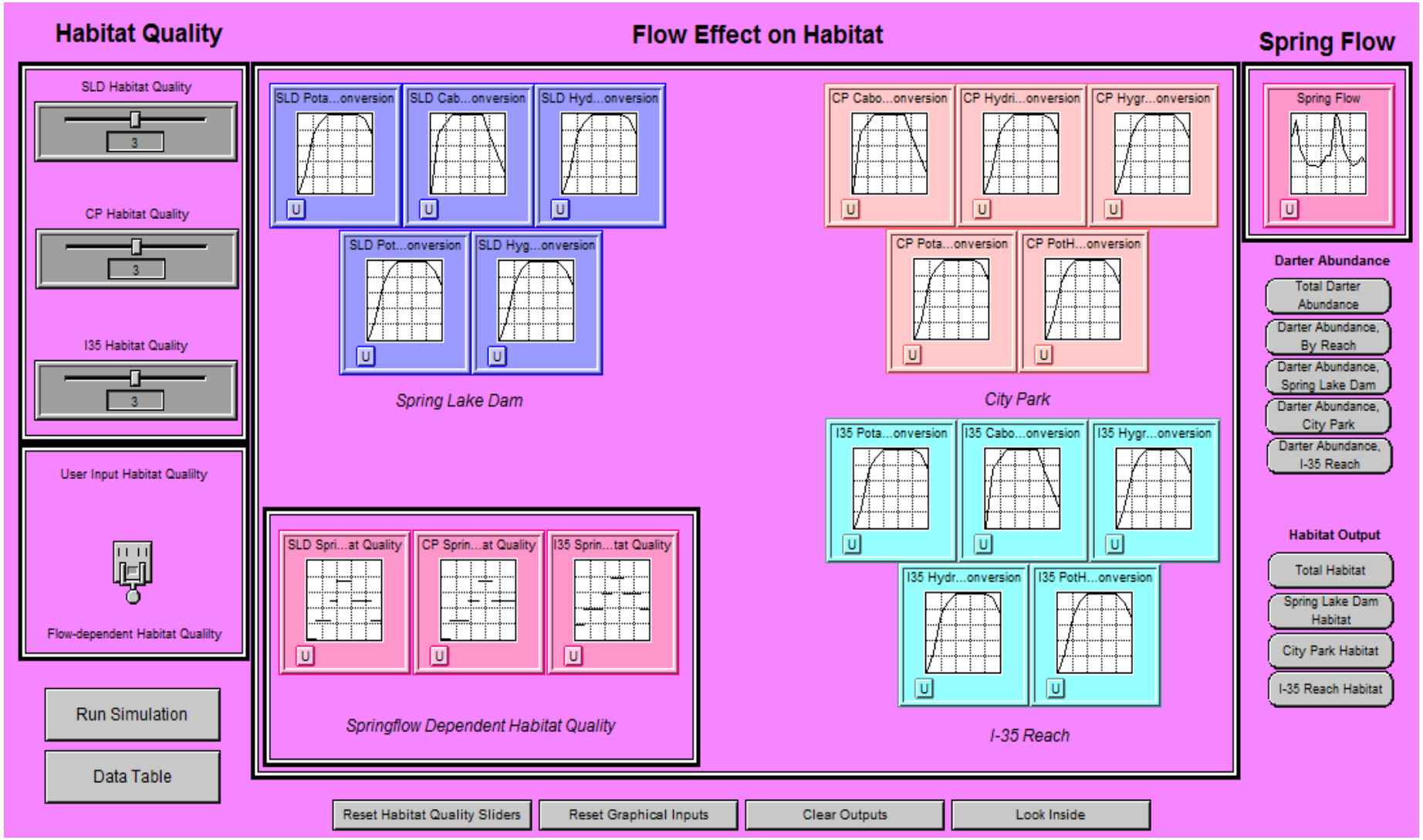


Figure 4-27 Stella Model Interface for Fountain Darter Habitat Model at San Marcos Springs.

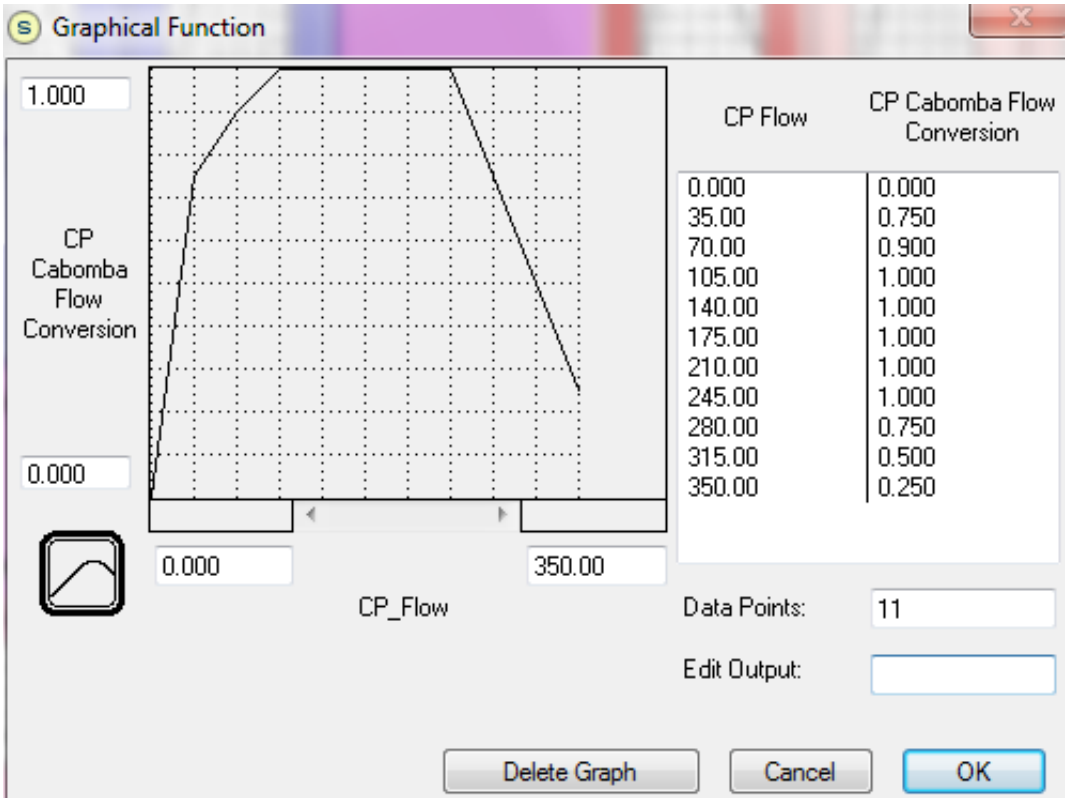


Figure 4-28. Habitat quality relationship for *Cabomba* versus Total San Marcos springflow, as a daily average, in the City Park reach.

A habitat quality ranking for fountain darter density was then generated (Table 4-43) based on EAA variable flow data and professional experience from observations in the system. A ranking system was incorporated into the model as follows:

TABLE 4-43
HABITAT QUALITY RANKING FOR FOUNTAIN DARTER DENSITIES

Description	Ranking Value for Model	Density Value from Table 4-42
Unsuitable	1	Minimum Density
Low quality	2	25th
Moderate quality	3	Median
High quality	4	75th

The habitat quality ranking for fountain darter density was then incorporated into the model per respective reach relative to the total San Marcos springflow condition (Figure 4-27 – lower left box labeled “Springflow Dependent Habitat Quality”). For example at a daily average flow of 30 cfs or lower, all reaches were assigned a habitat quality ranking for fountain darter density of 1 or unsuitable habitat. A low quality (2) habitat ranking was assigned for flows from 30 to 100 cfs

for the Spring Lake Dam reach and 30 to 120 cfs for the City Park and IH-35 reaches. Moderate (3) and high quality (4) habitat ranges were different for each reach based on empirical data and observations over the EAA study period and accordingly applied as such. Each representative reach has differing habitat conditions related to flow because of flow conditions and recreational activities that occur within each reach.

Fountain Darter Species Status

To establish a representative baseline of what the approximate fountain darter population has been within the representative reaches in the San Marcos system from 2002 through 2010, the actual hydrology from that time period was incorporated into the model. Additionally, four constant flows (50, 100, 150, and 200 cfs) were incorporated into the model to examine population variability relative to aquatic vegetation conditions experienced over this nine year period. Figure 4-29 shows the comparison of existing hydrology with each constant flow condition.

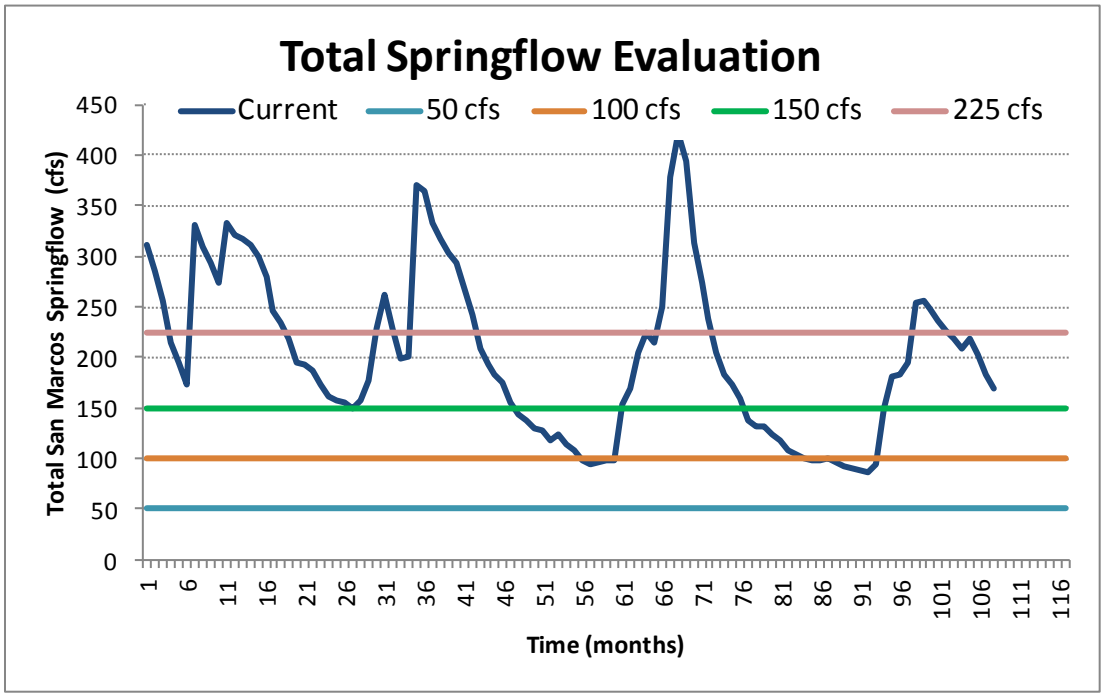


Figure 4-29. Total San Marcos Springflow scenarios evaluated in Stella. Current is the actual Total San Marcos Springflow from 2002-2010. Other springflows were assumed to be held constant. All values shown are daily average flows.

Figure 4-30 (along with embedded tables with the figure) show the Stella model results for fountain darter numbers within the representative reaches. For all scenarios, the springflow dependent habitat quality adjustments in the model were used.

Timestep	Current	50 cfs	100 cfs	150 cfs	200 cfs
1	51,845	6,150	11,513	30,181	61,005
2	17,608	5,647	10,610	28,165	56,937
3	17,249	4,784	8,929	24,207	47,091
4	39,601	4,099	7,599	20,577	39,601
5	21,772	3,975	7,651	20,773	39,919
6	14,991	4,146	7,662	20,122	39,786
7	12,571	3,586	6,759	17,114	34,977
8	18,890	3,677	6,853	17,651	35,147
9	8,523	3,876	7,232	17,795	37,998
10	7,317	4,051	7,356	19,209	38,159
11	34,232	3,904	7,200	18,993	34,232
12	9,672	3,858	7,058	18,119	37,110
13	19,486	3,983	7,375	19,486	40,256
14	7,803	3,750	6,862	17,756	35,022
15	6,442	3,530	6,583	17,196	34,819
16	10,026	2,736	4,816	13,011	23,793
17	30,795	3,741	6,927	18,929	36,602
18	30,503	3,229	5,965	15,524	30,503
Min	6,442	2,736	4,816	13,011	23,793
Average	19,963	4,040	7,497	19,712	39,053
Max	51,845	6,150	11,513	30,181	61,005

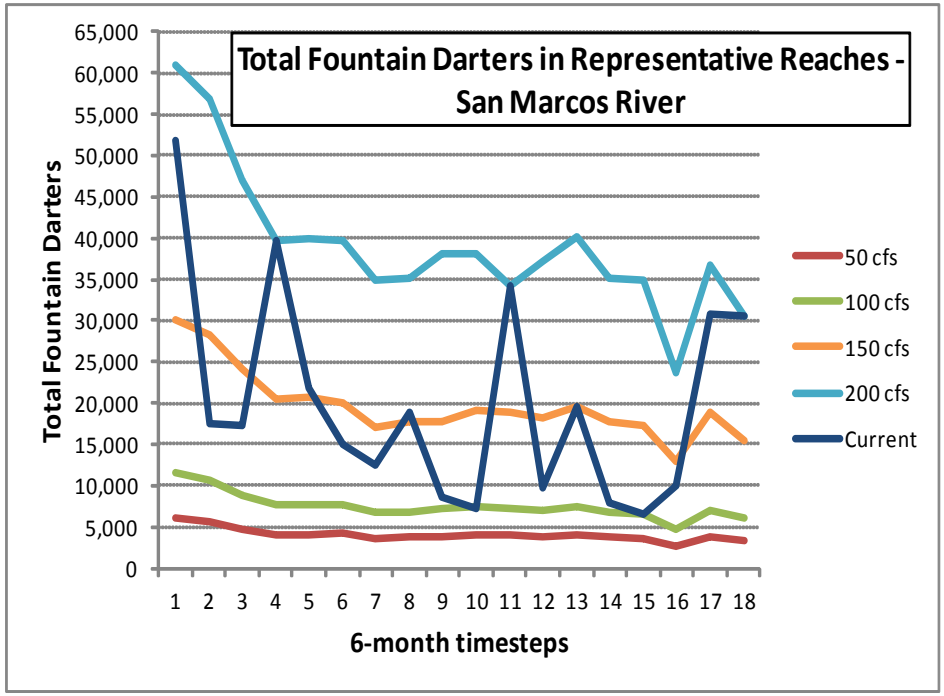


Figure 4-30. Total Fountain Darters within Representative Reaches – San Marcos System: Habitat Quality Adjusted by Reach - Current = 2002-2010 flows over 18 timesteps; Constant flows of 50, 100, 150, and 200cfs for all 18 timesteps. All flow values shown are daily average flows.

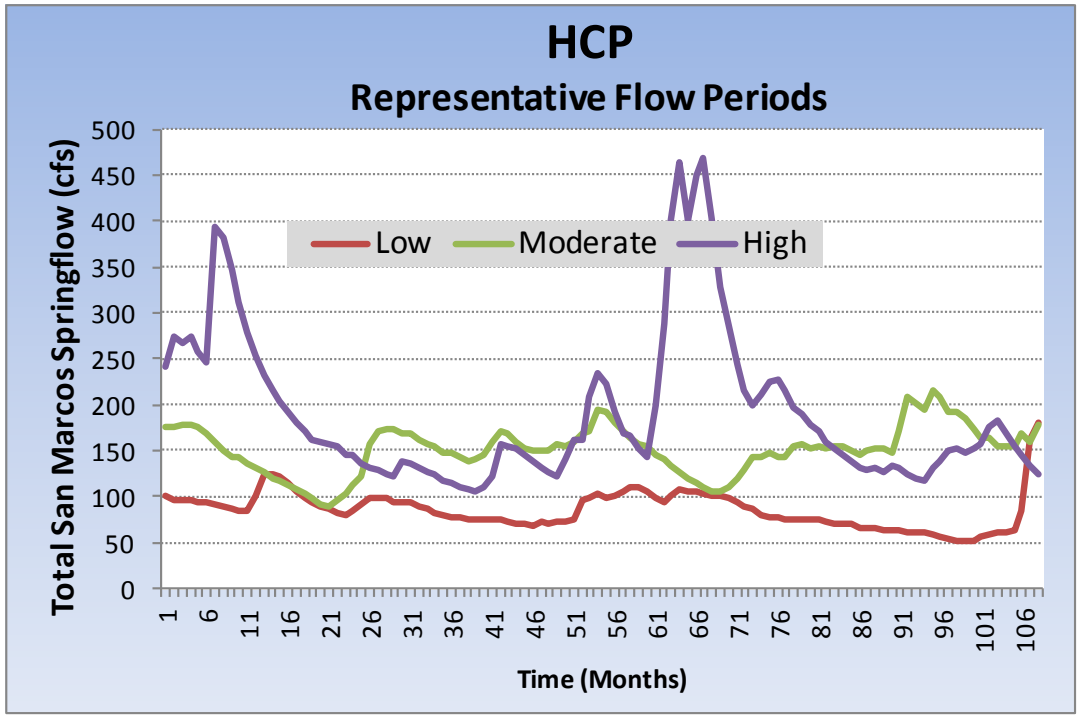
Although not exactly an apples-to-apples comparison, as the current scenario has different flows over the 18 – 6 month time steps versus constant flows over this nine-year period, it is a helpful illustration of the range of variability observed in the system. The variability is reflected in the changes in aquatic vegetation that has been experienced since 2002. Over this time period the number of total fountain darters within the representative reaches ranged from approximately 6,400 to 52,000 individuals. (Figure 4-30). As previously noted, it is re-emphasized that the population estimate is an approximation based on the assumptions stated above. It is acknowledged that these assumptions add uncertainty regarding the actual number of fountain darters present in the system and as projected by this modeling exercise. However, for this take analysis, this approach provides a level of consistency that allows for a meaningful comparison across different modeled flow scenarios.

In Figure 4-30, the 150 cfs (constant) modeled results are fairly similar to the Current Conditions result over time, although with less variability, while the 200 cfs results are higher, and the 100 and 50 cfs results considerably lower as expected. Figure 4-31 shows the 50 cfs scenario to maintain between approximately 2,700 and 6,000 total darters within the representative reaches. These low numbers and the lower numbers resulting from the 100 cfs constant scenario emphasize the importance of the long-term average springflow criteria embedded in the long-term Flow-Related Objectives for the fountain darter in the San Marcos River. Any constant flow, but particularly springflows less than 100 cfs would not be supportive of maintaining fountain darter populations in the San Marcos River over time. Neither the HCP team's nor Dr. Hardy's analyses support maintaining long-term conditions at 50 cfs. In fact, the recommendation for an acceptable minimum flow is a period of no longer than six months at no lower than 45 cfs (daily average), with two-to-three months of pulse flows at 80 cfs (daily average) or greater.

Evaluation of Effects of Action and Environmental Baseline Versus Current Condition

To assess the Phase I package and No Action Baseline (as discussed above, the No Action serves as a surrogate for the Existing Baseline for San Marcos Springs), the project team used the monthly flow data provided by HDR. To be consistent with the nine-year biological data set, a running nine-year springflow average was calculated from 1947-2000 for the HCP. The lowest nine-year average was 86 cfs (July 1948 – June 1956), the average 9-year rolling average was 152 cfs (January 1966 – December 1974) and the highest nine-year rolling average was 189 cfs (June 1987 – May 1995). For the No Action baseline, the same time periods were chosen for an equal comparison. Figures 4-31 and 4-32 show the total San Marcos springflow for each of the respective nine-year periods for both the HCP and No Action Baseline.

For the take analysis, these three flow sequences were converted into six-month time steps to be consistent with the aquatic vegetation data and entered into the Stella model. Table 4-44 and Figure 4-33 shows the model results for all three springflow conditions over the 18–6 month time steps. The most notable result is that the No Action Baseline results in less than 100 fountain darters in the representative reaches during a repeat of conditions similar to the drought of record. Although the flow level is not zero as projected for the No Action Baseline at Comal Springs, this low number in the San Marcos River is not considered protective.



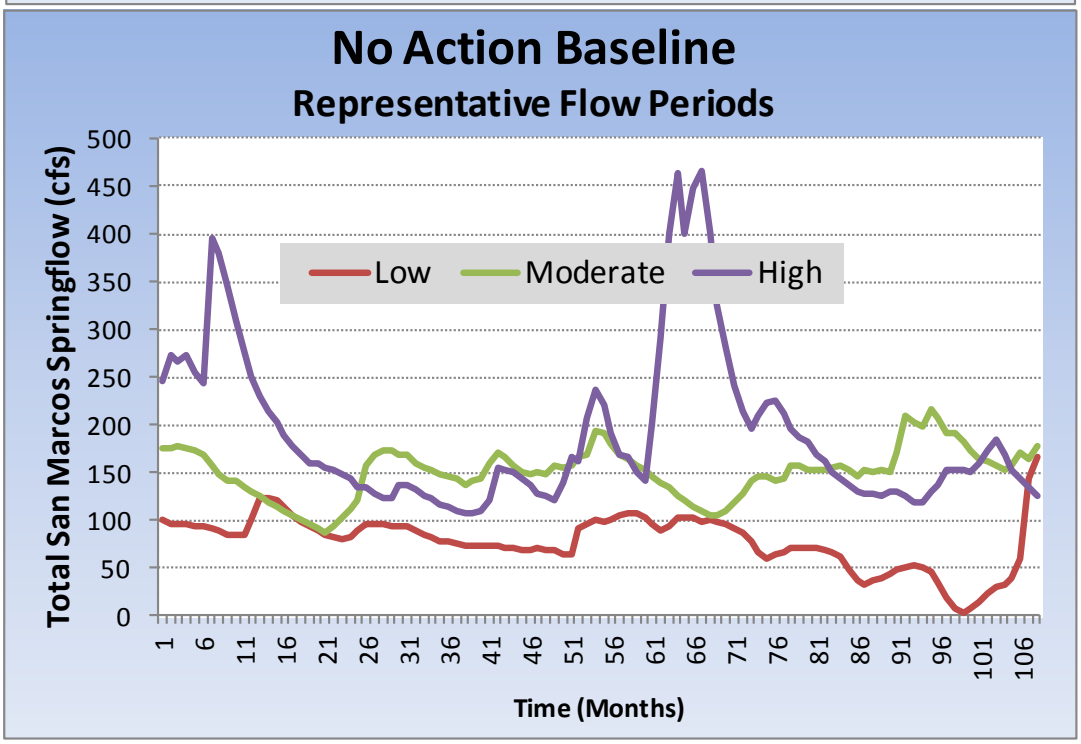


Figure 4-31 and 4-32. Low, Moderate, and High nine-year rolling averages (Total San Marcos springflow) for Phase I package (Top) and No Action baseline (bottom) modeled scenarios.

Table 4-44. Total Fountain Darters within Representative Reaches for both the Phase I package and No Action baseline – San Marcos System: Habitat Quality Adjusted by Reach – Low, Moderate, High represent nine-year model run representative periods generated for each alternative.

Time step	HCP	No Action Baseline	HCP	No Action Baseline	HCP	No Action Baseline
	Low-Flow Representative Period		**Moderate-Flow Representative Period**		**High-Flow Representative Period**	
1	11,258	11,258	32,020	32,020	22,723	22,732
2	9,961	9,961	28,165	28,165	16,081	16,191
3	10,580	10,549	10,549	10,487	47,091	47,091
4	6,976	6,976	7,516	7,475	20,577	20,577
5	7,436	7,393	20,773	20,773	9,557	14,767
6	7,038	6,997	20,122	20,122	9,140	9,140
7	5,818	5,742	17,114	17,114	7,837	7,814
8	5,720	5,720	17,651	17,651	17,651	17,651
9	6,679	6,442	17,795	17,795	19,080	19,080
10	7,513	7,474	22,110	19,209	22,110	22,110
11	7,240	7,077	13,657	13,657	8,140	8,140
12	6,946	6,871	8,032	8,009	10,525	10,738
13	6,401	5,873	19,486	19,486	40,256	40,256
14	5,752	4,651	17,756	17,756	17,756	17,756
15	4,825	2,732	17,196	17,196	7,831	7,809
16	3,195	166	23,793	23,793	10,123	10,123
17	4,364	86	18,929	18,929	18,929	18,929
18	6,966	6,031	15,524	15,524	12,640	12,640
Min	3,195	86	7,516	7,475	7,831	7,809
Average	6,926	6,222	18,233	18,065	17,669	17,975
Max	11,258	11,258	32,020	32,020	47,091	47,091

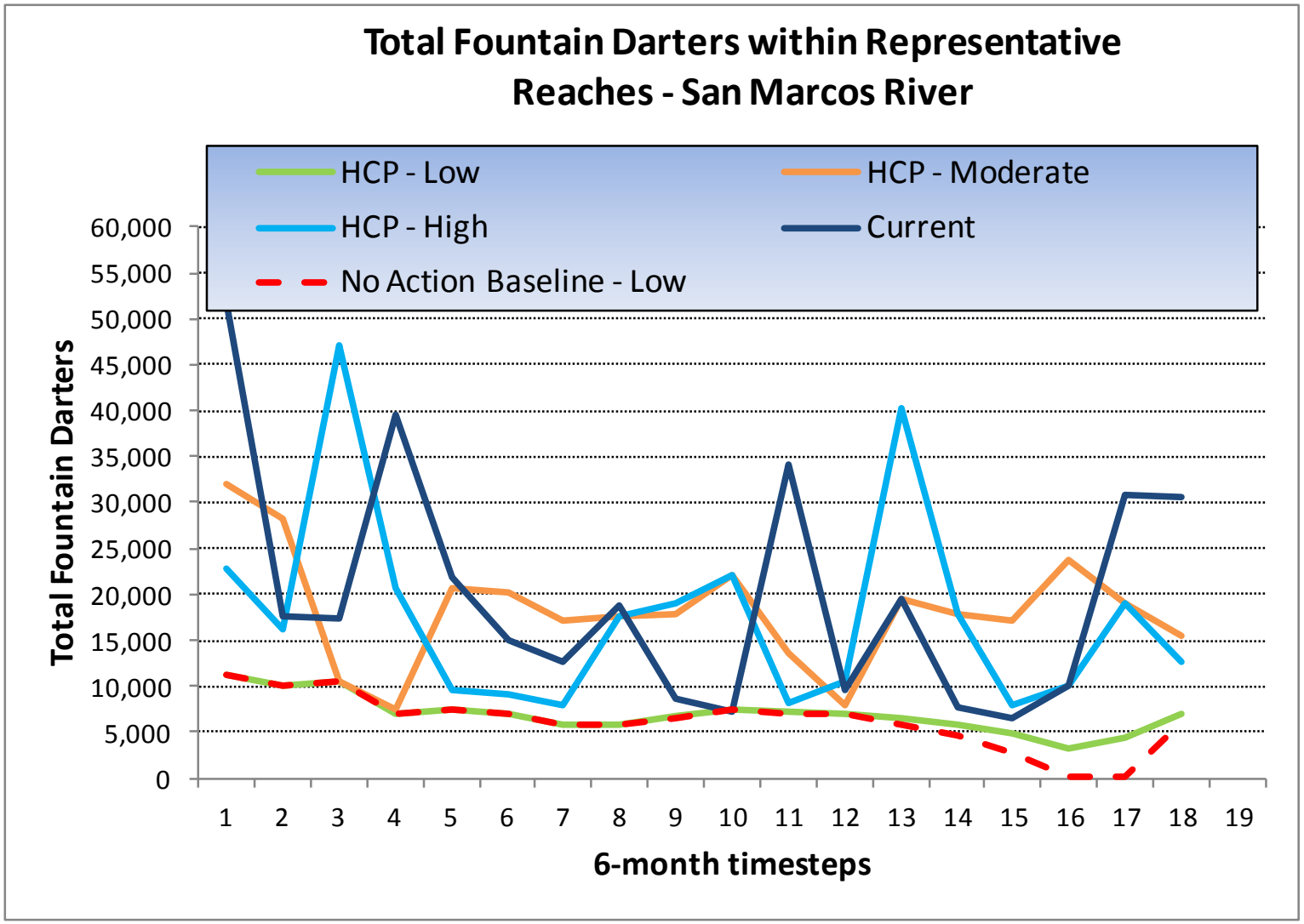


Figure 4-33. Total Fountain Darters within Representative Reaches for the HCP - Phase I package – San Marcos System: Habitat Quality Adjusted by Reach –Low, Moderate, and High represent 9-year model run periods generated for the HCP and Low for the No Action baseline; Current = 2002-2010 flows over 18 – 6 month time steps.

As a rough calculation, the aquatic vegetation mapped within the representative reaches in Fall 2009 (EAA Variable Flow Study) represented between 8 and 18 percent of the total aquatic vegetation mapped in the entire San Marcos System by Hardy (2010) during that same time period. Taking the average of 11 percent as a crude conversion factor for the total system and assuming a one to one relationship of aquatic vegetation and fountain darters, it is possible to use the total fountain darter numbers generated in Table 4-44 and divide those values by 0.11 to get a rough estimate of the total fountain darter population in the San Marcos River (excluding Spring Lake) at that snapshot in time.

Using this approach results in a calculation (with all the caveats of this analysis) that the number of total fountain darters in the San Marcos River (again excluding Spring Lake) from 2002 to 2010 ranged from approximately 58,000 to 470,000. Table 4-45 shows the calculations for system-wide darters converted from Table 4-44.

TABLE 4-45
TOTAL FOUNTAIN DARTERS IN THE SAN MARCOS RIVER (EXCLUDING SPRING LAKE) BASED ON A CONVERSION FACTOR OF 0.11 RELATIVE TO MODELED RESULTS FROM THE REPRESENTATIVE REACHES FOR THE PHASE I PACKAGE

Scenario	Range of Total Fountain Darters in the San Marcos River (excluding Spring Lake)		
	Minimum	Average	Maximum
CURRENT	58,562	181,478	471,315
HCP			
Low	29,046	62,965	102,343
Moderate	68,329	165,752	291,094
High	71,190	160,630	428,103

Effects of Action Added to the Environmental Baseline

Based on the fountain darter habitat and population model results, it is evident that the No Action Baseline and Existing Baseline will cause incidental take during average to above average springflow conditions, but likely within the range of variability experienced during the Current Conditions. More notably, modeling shows that the No Action Baseline and Existing Baseline might cause extirpation of the fountain darter during a repeat of conditions similar to the drought of record which could jeopardize the continued existence of the species. The word “might” for the fountain darter at San Marcos Springs versus “will” for the fountain darter at Comal Springs is used here because of the uncertainty surrounding fountain darter habitat within Spring Lake during those extreme conditions. Because almost all quantitative fountain darter data has been collected in the river over the years, all modeling activities for the take assessment were based on a fountain darter habitat in only the San Marcos River.

The Phase I package will similarly result in incidental take during periods of average to above average springflow conditions (again within the range of variability experienced during the

Current Condition), but is not projected to cause or even approach extirpation of the fountain darter at San Marcos Springs. It is evident that a large amount of incidental take (habitat and fountain darters) will be experienced in the river with the Phase I package relative to the Current Conditions under flow conditions similar to the drought of record. During extreme drought of record-like conditions, with all HCP conservation measures, there is the potential for a 50 to 94 percent reduction in fountain darters relative to the Current Conditions in the San Marcos River. Based on Current Conditions observed over the past nine years, this translates into the potential take of approximately 30,000 to 450,000 fountain darters from the San Marcos River, exclusive of Spring Lake, during a repeat of conditions similar to the drought of record, with the potential for approximately 30,000 fountain darters remaining in the San Marcos River. Although under this worst case modeled scenario only 30,000 fountain darters would remain in the river, a significant number of fountain darters are anticipated to survive within Spring Lake under the Phase I package.

At this time, it is impossible to predict the actual level of fountain darter take (in terms of habitat quantities or fountain darter numbers) over the 15-year term of the ITP as natural variability of the population of this species is large, but more importantly assumptions regarding: (1) use of existing water rights, (2) future hydrology, and (3) success of HCP conservation measures, etc. are impossible to predict. As such, a near worst case scenario based on the best available science was presented above. Should water rights not be fully utilized in the 15-year term of the ITP; hydrology remain fairly average; and the conservation measures be nominally successful, then the amount of take will be very low. Conversely, should full utilization of water rights start at the effective date of the ITP in 2013; followed by a 10-year drought similar in nature to the drought of record; in conjunction with the HCP conservation measures not having a chance to be fully tested or implemented, then the potential for take of 450,000 or more darters does exist. Additionally, some take would be anticipated to occur in Spring Lake during these extreme conditions, but it is not possible to quantify at this time with available data and existing modeling tools.

For this HCP, the Phase I package of minimization and mitigation measures results in a significant improvement from the No Action Baseline and Existing Baseline based on the springflow protection alone. This is highlighted in Figure 4-33 (green line [HCP] versus dashed red line [No Action Baseline]). To further emphasize this point, a detailed documentation of the improvements of the Phase I springflow protection package for the fountain darter at Comal Springs is presented in Section 4.2.2.2.3 with an example hydrograph. That exercise was not repeated here as it reaches the same conclusion, just on a smaller scale as the No Action Baseline springflows at San Marcos Springs are not nearly as low or extended as at Comal Springs.

In addition to springflow, on-going research and monitoring continues to confirm the importance of aquatic vegetation. (EARIP 2008 and 2009). Four checkpoint water temperature ranges have also been identified as critical to the fountain darter life cycle. The fountain darter habitat model developed for the take analysis examined the effects of the Phase I package springflow regime specifically on aquatic vegetation in the representative reaches as described above. Those habitat areas were then converted to population numbers to assess the ability of the regime to support a viable population of fountain darters in the San Marcos system. From that analysis, it is evident that during periods of extended low-flow, which is predicted with the Phase 1 package upon conditions similar to those experienced during the drought of record, critical habitat will be impacted and fountain darter populations reduced. However, this analysis shows that during periods of average and higher flows, very minimal impacts to fountain darter critical habitat are projected.

Further, as described in Chapter 5, the Applicants will implement significant minimization and mitigation measures that will restore and maintain habitat, remove exotic species, control non-native animal species, control recreation, and limit access points to the Spring system and river. In addition, specific HCP conservation measures will be implemented to protect aquifer water quality (addressing issues such as impervious cover, low impact development, minimizing the impacts of contaminated runoff, and increased monitoring) which will help mitigate the impacts of cumulative effects including development.

Thus, the Phase I measures should appreciably improve the likelihood of the survival and recovery of the fountain darter in the San Marcos system through a repeat of conditions similar to the drought of record during the initial phase of the ITP and contribute significantly towards attaining the long term biological goals.

San Marcos Salamander

Habitat Requirements and Current Conditions

As with the fountain darter, on-going research and monitoring continues to confirm the importance of suitable habitat to the San Marcos salamander. Suitable habitat for the San Marcos salamander is defined as silt-free rocks ranging in size from one to eight inches (2.5 to 20 cm) diameter with surrounding aquatic vegetation and floating mats of algae in the headwaters of the San Marcos River (primarily Spring Lake). (EARIP 2009). The quality and quantity of this habitat in the system are the most important factors determining the density of salamanders in the San Marcos Springs/River ecosystem. Detailed information on habitat requirements and Current Conditions can be found in EARIP (2009), EARIP (2010), and BIO-WEST (2002b-2011b).

Take Thresholds Relative to Springflow

Any reduction in the quantity and quality of suitable habitat would likely take place first in the downstream-most portion of the San Marcos salamander range: the spillways below Spring Lake Dam. Direct observations suggest that take directly associated with decline in discharge begins approximately when flows decline to a level of 80 cfs, as a daily average, discharge in the San Marcos River (BIO-WEST 2010b). At this flow, a small proportion of wetted area along the channel is lost. As flow in the San Marcos Springs/River ecosystem declines below 50 cfs, the potential for take increases.

Take Analysis Methodology (Assumptions, Model Development, Status)

San Marcos Salamander Specific Assumptions

Similar to the long-term biological goals (Table 4-25), the take assessment for the San Marcos salamander centers on a habitat-based approach within three main sample areas in the San Marcos system. The three sample areas include the Hotel area and Riverbed area both within Spring Lake, and the area of the eastern spillway below Spring Lake Dam (Figure 4-3).

In addition to the system-wide assumptions stated above, the following San Marcos specific assumptions apply to this approach:

- San Marcos salamander analysis does not include subsurface habitat area.
- San Marcos salamander recruitment is fully maintained when wetted surface area is available.

The former assumption is conservative as salamanders use subsurface habitats. However, without a mechanistic ecological model to describe all the complexities that subsurface movement and habitat usage presents, this assumption is in place to simplify a current unknown. The latter assumption regarding recruitment is thought to be true based on the empirical data at total springflows greater than 80 cfs, but is untested at lower springflow conditions. However, even if it is true that recruitment continues, recruitment rates will likely be adversely affected by changing habitat conditions and the duration of periods of altered springflow. At present time, there is not a modeling tool available to the HCP team to assess all the potential effects of the HCP alternative on San Marcos salamander recruitment.

The San Marcos salamander take analysis focuses on the following components:

- San Marcos salamander density variability with flow and time
- Habitat quantity adjustments (recreation in Eastern spillway) relative to flow
- Salamander habitat quality adjustments relative to flow

Physical habitat and water quality modeling (Hardy 2010), along with EAA Variable Flow Study actual observations (BIO-WEST 2002b–2011b), and professional judgment were used to quantify the levels of take relative to the Phase I package and HCP conservation measures. This was done by incorporating best available scientific information into the development of a San Marcos salamander model for the San Marcos system.

San Marcos Salamander Habitat and Population Model Development

A San Marcos salamander habitat model within each of the three sample areas described above was developed using Stella 9.1. (Figure 4-34). The model includes actual field collected data for San Marcos salamanders from 2002 to 2010. Both the spring and fall sampling periods over that nine year span were incorporated into the model. The model was set up on a six-month time step to be consistent with the fountain darter models developed for the take analysis.

The eastern spillway sample area was further evaluated to develop a wetted area to flow relationship (0 to 1.0 with 1.0 being the best). This exercise was based on Dr. Hardy's habitat model as well as professional experience from EAA Variable Flow Study observations over the past decade. For example, at springflows of 20 cfs or less as a daily average, wetted area of adequate salamander surface habitat within the eastern spillway is predicted to be scarce. Based on the habitat modeling noted above and professional judgment, total San Marcos springflows less than 20 cfs were deemed unsuitable (0, Figure 4-35). Flows above 120 cfs (Figure 4-35) were considered to provide the maximum quantity of wetted area for quality salamander habitat in the eastern spillway. For the two Spring Lake sample areas, because some level of springflow is provided by all scenarios evaluated, no wetted area to flow relationship was developed.

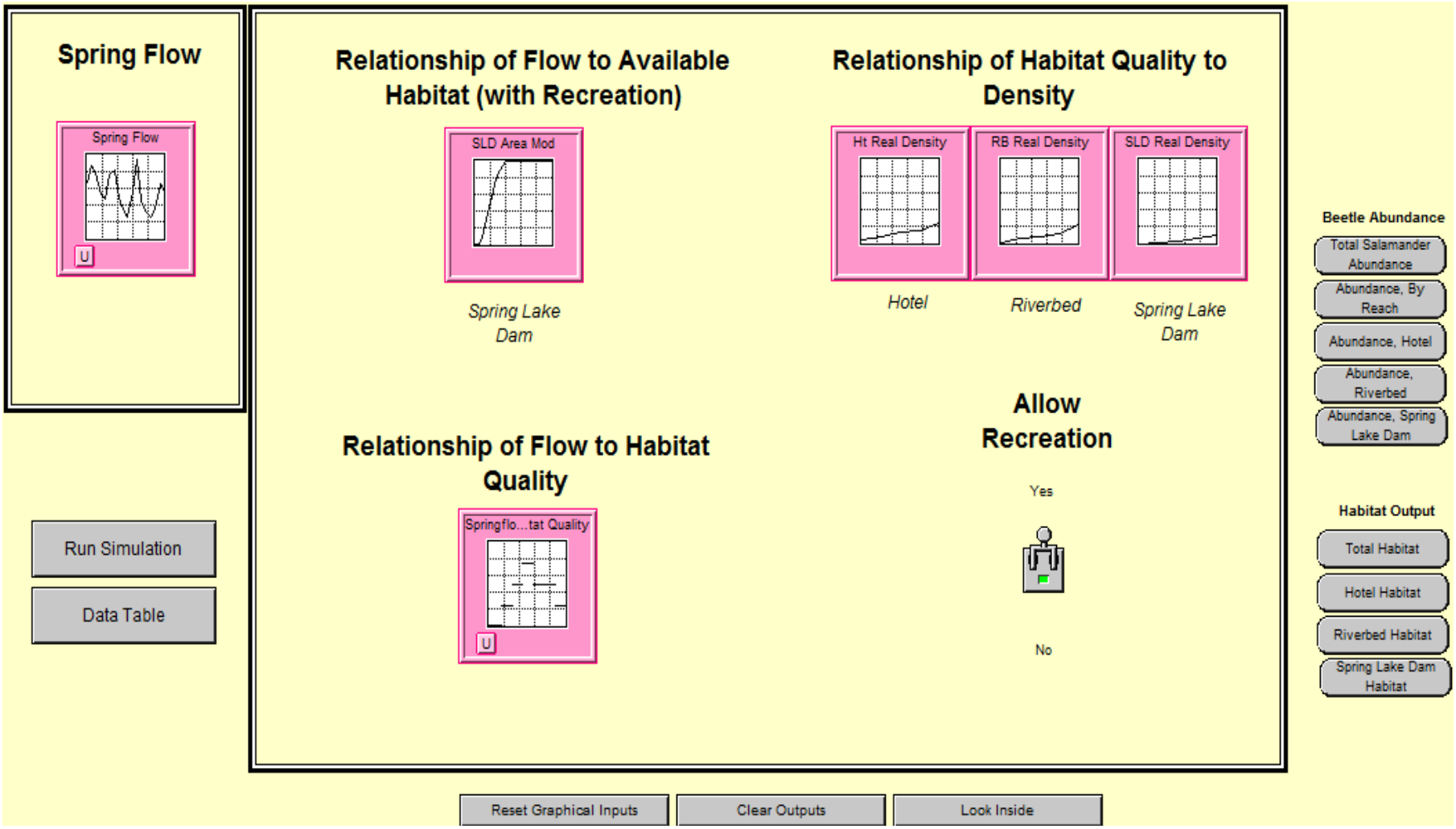


Figure 4-34. Stella Model Interface for San Marcos Salamander Habitat Model at San Marcos Springs.

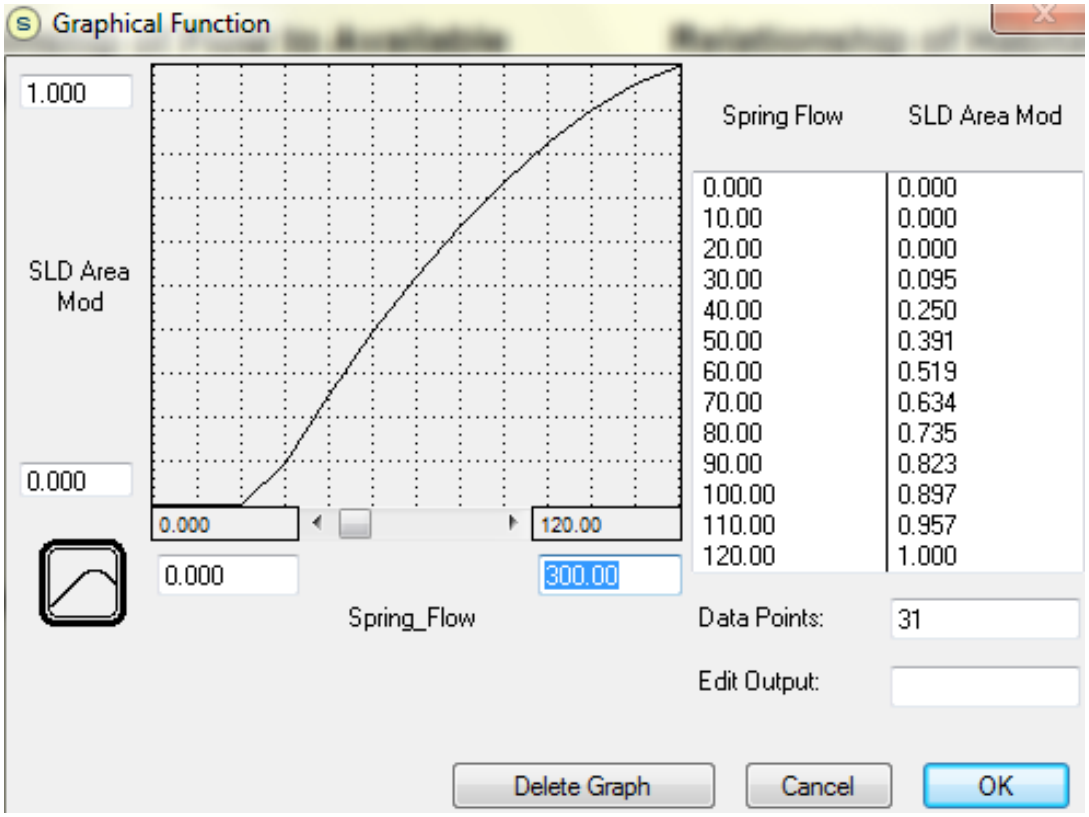


Figure 4-35. Wetted area to flow relationship for Eastern Spillway sample area.

The second component entered into the model is the San Marcos salamander density values recorded in the San Marcos system over the nine year sample period. Table 4-46 shows the minimum, 25th, median, 75th, and maximum densities recorded for San Marcos salamanders.

TABLE 4-46
SAN MARCOS SALAMANDER DENSITIES PER SAMPLE AREA IN THE SAN MARCOS SYSTEM OVER TIME (2002-2010)

	Hotel	Riverbed	Eastern Spillway
MIN	6.1	3.4	0.4
25th	9.9	8.3	2.3
MEDIAN	14.9	9.9	4.7
75th	17.5	13.2	7.2
MAX	25.2	23.5	12.1

A habitat quality ranking for San Marcos salamander density was then generated based on EAA Variable Flow Study data and from observations in the system. A ranking system (Table 4-47) was incorporated into the model as follows:

TABLE 4-47
HABITAT QUALITY RANKING FOR SAN MARCOS SALAMANDER DENSITIES

Description	Ranking Value for Model	Density Value from Table 4-45
Unsuitable	1	Minimum Density
Low quality	2	25th
Moderate quality	3	Median
High quality	4	75th

The habitat quality ranking per salamander density was then incorporated into the model for each sample area relative to the total San Marcos springflow condition (Figure 4-34 – lower left box labeled "Relationship of Flow to Habitat Quality"). For example, total San Marcos springflow below 50 cfs, as a daily average, received a habitat quality ranking of 1; 60-100 cfs and greater than 300 cfs received a 2; 110-140 cfs and 200-300 cfs received a 3; and 140-190 cfs received a 4. The peak range for habitat quality was set between 140 and 190 cfs. Higher total springflow rates are projected to cause declining surface habitat conditions because of the high velocities generated at these discharges below Spring Lake Dam and also the clearing of filamentous algae and bryophytes from the lake bottom sample areas when discharge is considerably greater than average. This does not imply that higher flows are not important, as they clearly are from an ecological standpoint. Again, as with each species evaluated, the take analysis for the San Marcos salamander and assumptions embedded within highlight the need for the applied research and mechanistic ecological modeling outlined in Section 6.3.

One additional factor, recreation in the Eastern Spillway, was included in the San Marcos salamander model. With recreation turned on, an adjustment factor to wetted area was applied for this sample area to reflect the adverse impact that recreation might have on habitat quality. Recreational Impacts in this area are typically caused by the physical manipulation of habitat (*e.g.*, moving large rocks around to form dams and swimming areas) and trampling from extensive wading. Including that function in the model also allows for future comparisons of the benefit potentially achieved should recreational impacts be removed from the eastern spillway area immediately below the dam.

San Marcos Salamander Species Status

To establish a representative baseline of what the approximate San Marcos salamander population has been within the sample reaches in the San Marcos system from 2002 through 2010, the actual hydrology from that time period (Figure 4-36) was incorporated into the model. Additionally, constant flows from 10 to 360 cfs (in 20 cfs increments) were modeled to evaluate the model response to total San Marcos springflow.

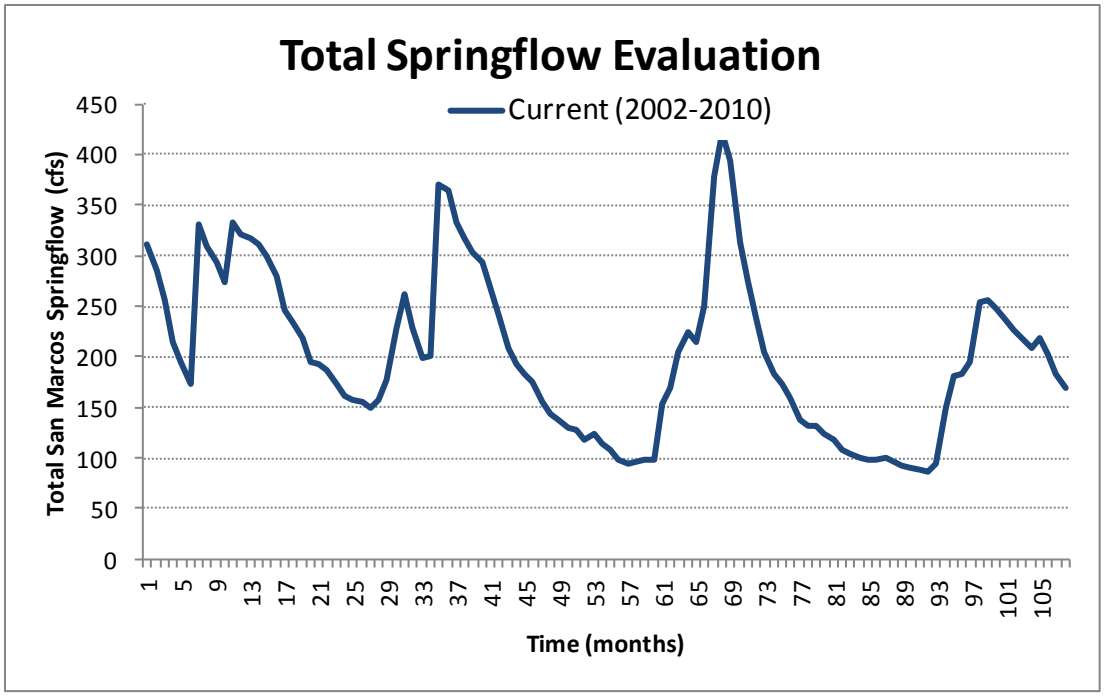


Figure 4-36. Total San Marcos Springflow (daily average) current scenario (2002-2010) evaluated in Stella.

Figure 4-37 shows the Stella model results for total San Marcos salamanders within the sample reaches. For all runs, the springflow dependent habitat quality adjustment was used. Additionally, the recreation toggle for the Eastern Spillway was activated.

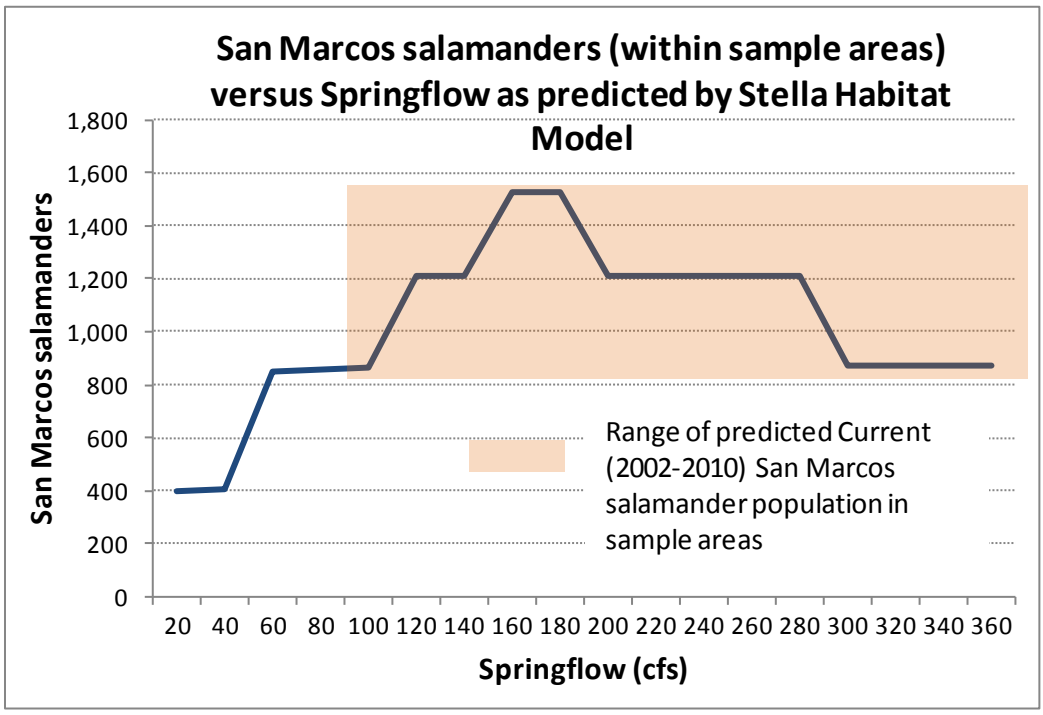


Figure 4-37. San Marcos salamander (within sample areas) predicted by Stella model (blue line). Shaded area is the predicted range of current (2002-2010) population within sample areas. Flows shown are daily average values.

The salamander model is similar to the riffle beetle habitat model in that it does not have a habitat (*e.g.*, aquatic vegetation) input that changes over time regardless of flow. As such, each independent flow level will produce one habitat estimate which in turn calculates one population number. Springflows observed during the existing period ranged from approximately 95 cfs to 400 cfs which, when modeled, translated to a population range of approximately 800 to 1,600 salamanders within the three sample areas. It must be emphasized that the population estimate is only for the sample areas and clearly an approximation based on the assumptions stated above. These assumptions add uncertainty regarding the actual number of San Marcos salamanders as projected by this modeling exercise. However, for this take analysis, this approach provides a level of consistency that allows for a meaningful comparison across different modeled flow scenarios.

Evaluation of Effects of Action and Environmental Baseline Versus Current Condition

To assess the Phase I package and No Action Baseline, the project team used the monthly flow data provided by HDR. Again, Figures 4-10a and 4-10b show that projected springflows resulting from the Existing Baseline are nearly identical to the No Action Baseline, and thus impacts would be very similar for either baseline as presented in this section. Figures 4-31 and 4-32 show the total San Marcos springflow for each of the respective nine-year periods for both the HCP and No Action Baseline.

For the take analysis, these three flow sequences were converted into six-month time steps and entered into the Stella San Marcos salamander model. Table 4-49 shows the model results for all three springflow conditions over the 18 – 6 month time steps. The most notable result is the reduction in salamanders for both the HCP Low and No Action Baseline Low scenarios. The second notable result is the similarity of the average and high flow scenarios between the HCP and No Action Baseline as the projected springflows are nearly identical. Figure 4-38 graphically depicts the differences between No Action Baseline and HCP during the low-flow period along with depicting the HCP moderate and high flow period and Current Conditions (2002 – 2010). The loss of salamanders during both low flow scenarios is visually evident. However, not evident in Table 4-48 or Figure 4-38 is individual sample area breakout. The model predicts the habitat and population estimates for each individual sample area. Those results are depicted in Table 4-49 showing the breakdown of San Marcos salamanders per sample area for the Current Conditions and the HCP Low, and No Action Baseline Low scenarios. From this breakout, it is evident that with the recreation function turned on in the model under the No Action Baseline low-flow scenario, salamanders are projected to be temporarily extirpated from the Eastern Spillway sample area. Again, the salamander model simply includes surface habitat within the sample area. As the model does not allow for subsurface movement, this is likely somewhat of a worst-case scenario, but highlights the potential for considerable reductions in salamander surface habitat and resulting populations within the sample areas under both the No Action baseline and HCP low-flow scenarios. Regardless if overly conservative or not, the point is to highlight the potential for impact and be consistent across analyses to allow the USFWS the ability to make a determination on the potential impacts on survival and recovery of the San Marcos salamander under the HCP.

Table 4-48. Total San Marcos salamanders within Sample Reaches for both the HCP and No Action Baseline – San Marcos System: Habitat Quality Adjusted by Sample Reach – Low, Moderate, High represent nine-year model run representative periods generated for each alternative.

Time step	HCP	No Action Baseline	HCP	No Action Baseline	HCP	No Action Baseline
	Low-Flow Representative Period		**Moderate-Flow Representative Period**		**High-Flow Representative Period**	
1	862	862	1,531	1,531	1,207	1,207
2	860	860	1,207	1,207	868	868
3	1,205	1,205	1,205	1,204	1,531	1,531
4	859	859	863	863	1,531	1,531
5	862	862	1,531	1,531	1,207	1,207
6	859	858	1,531	1,531	1,207	1,207
7	854	853	1,207	1,207	1,207	1,207
8	852	852	1,531	1,531	1,207	1,207
9	859	857	1,531	1,531	1,531	1,531
10	865	865	1,531	1,531	1,531	1,531
11	864	863	1,207	1,207	868	868
12	863	862	1,205	1,205	868	868
13	854	851	1,207	1,207	1,207	1,207
14	852	404	1,531	1,531	1,207	1,207
15	849	402	1,531	1,531	1,207	1,207
16	404	401	1,207	1,207	1,207	1,207
17	404	400	1,531	1,531	1,531	1,531
18	1,207	864	1,531	1,531	1,207	1,207
Min	404	400	863	863	868	868
Average	846	777	1,368	1,367	1,241	1,241
Max	1,207	1,205	1,531	1,531	1,531	1,531

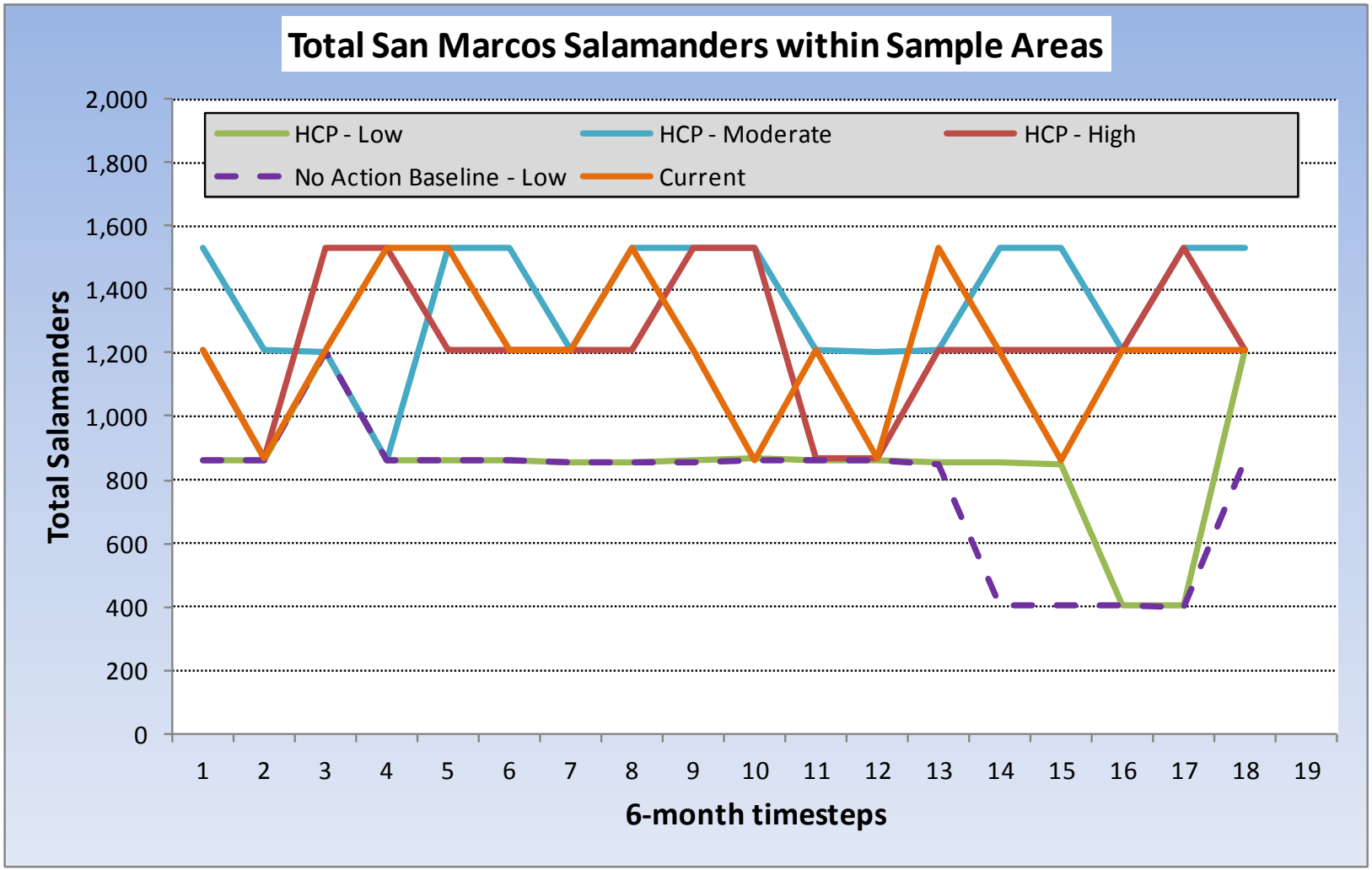


Figure 4-38. Total San Marcos salamanders for the HCP – San Marcos System: Habitat Quality Adjusted by area –Low, Moderate, and High represent nine-year model run periods generated for the HCP and Low for the No Action Baseline; Current = 2002-2010 flows over 18 – 6 month time steps.

Table 4-49. Total San Marcos salamanders within samples areas predicted for Current, HCP, and No Action Baseline scenarios.

Scenario	Range of San Marcos salamanders within sample areas		
	Minimum	Average	Maximum
Current (Total)	862	1,203	1,531
Hotel	312	453	549
Riverbed	512	662	845
Eastern Spillway	38	88	136
HCP (Total) : Low-Flow Representative Period	404	846	1,207
Hotel	190	316	471
Riverbed	210	494	648
Eastern Spillway	3	37	88
No Action Baseline (Total): Low-Flow Representative Period	404	846	1,207
Hotel	190	294	471
Riverbed	210	452	648
Eastern Spillway	0	30	86

Similar to the Comal Springs riffle beetle, there is not presently a way to translate the San Marcos salamander population estimates per sample area to the total San Marcos system. However, based on observations over the past decade, the Comal Springs riffle beetle sample areas constitute a large portion of the overall system habitat, whereas the San Marcos salamander areas represent only a small portion of the overall habitat available in Spring Lake. A focus of the Phase I bio-monitoring will be to better understand the system-wide, available salamander habitat and further describe the representative nature of the existing sample areas.

Effects of Action Added to the Environmental Baseline

Based on the San Marcos habitat and population model results, it is evident that the No Action Baseline, Existing Baseline, and HCP will cause incidental take during average to above average springflow conditions, but likely within the range of variability experienced during the Current Condition. More notably, modeling shows that the No Action Baseline, Existing Baseline, and Phase I package might cause extirpation of the San Marcos salamander in the Eastern Spillway during a repeat of conditions similar to the drought of record.

At this time, it is impossible to predict the actual level of San Marcos salamander take (in terms of habitat quantities or San Marcos salamander numbers) over the 15-year HCP period as natural variability of the population of this species is large, but more importantly assumptions regarding future flows and the success of HCP conservation measures, etc. are impossible to predict. As such, a near worst case scenario based on the best available science was presented above. Should flows remain fairly average; and the HCP conservation measures be nominally successful, then the amount of take will likely be very low. Conversely, should full utilization of water rights start at the effective date of the ITP in 2013; followed by a 10-year drought similar in nature to the drought of record; in conjunction with the HCP conservation measures not having a chance to be fully tested or implemented, then the potential for take of a considerable portion of the current population is possible.

In the case of the San Marcos salamander, when aggregated with the No Action Baseline, the Phase I package results in only a slight improvement based on springflow protection. Although springflows are improved, current information does not indicate a large improvement in physical habitat conditions for the San Marcos salamander. This is highlighted in Figure 4-38 (green line [HCP] versus purple line [No Action Baseline]). There should be considerable improvements based on water quality protection in the Phase I package but modeling tools to incorporate those parameters into the analysis are not available at this time. Whereas other species at Comal and San Marcos springs showed greater improvements with the HCP when compared to the No Action Baseline, the San Marcos salamander only showed slight improvements because conditions below the Dam were similar with extirpation or near extirpation in that area during extreme conditions. An assumption was made that a minimum number of salamanders would survive in Spring Lake as long as some springflow was provided. Siltation around spring openings will likely be the biggest detriment to the salamander population in Spring Lake at extremely low flows. It has been observed in Landa Lake (Comal system) that as upwelling springs in the Upper Spring Run area cease flowing, siltation ensues and salamanders retreat from those areas. Although observed at Comal Springs, flows have not reached a level over the past decade at San Marcos Springs to cause a similar condition in Spring Lake, and as such this assumption is currently unfounded. Similarly, establishing a cutoff point on habitat suitability within Spring Lake would be equally unfounded at this time. This again highlights the importance of the applied research and mechanistic ecological modeling to be developed for this species as part of the AMP.

Based on the habitat modeling conducted, during these extreme conditions, with all HCP conservation measures in place, there is the potential for a 90 percent reduction in salamanders located in the Eastern Spillway sample area, and approximately a 60 percent reduction in population at the Hotel and Riverbed sample areas in Spring Lake. However, even with these potential reductions considering this near worst-case scenario based on the best available scientific data, the remaining habitat provided by Spring Lake and the historical survival of the San Marcos salamander during the historical drought of record supports a determination that the HCP with all measures should be protective of the continued existence of the San Marcos salamander in the San Marcos System through a repeat of conditions similar to the drought of record.

Further, recreation below Spring Lake Dam plays a major role regarding impacts on salamander critical habitat, especially during low-flows. As such, recreational impacts are being addressed via HCP conservation measures including a State Scientific Area that includes the Eastern Spillway limiting impacts from recreation at low flows.

Texas Blind Salamander

The Texas blind salamander was first collected in 1895 from the NFHTC in San Marcos, Texas, when they were expelled from an artesian well drilled to supply the hatchery with water. (*See* Longley 1978).

Habitat Requirements and Current Conditions

Texas blind salamanders have been well documented from the subterranean waters of the San Marcos area of the Aquifer in Hays County. They have been observed, in caves with access to the water table, traveling along submerged ledges within the Aquifer and swimming small distances before spreading their legs and settling to the bottom. It is likely that they are sensitive to changes in water temperatures, preferring the thermally constant temperatures of the Aquifer, although more research is needed to determine critical thermal minima and maxima for their various life stages (Longley 1978; Berkhouse and Fries 1995).

Take Thresholds Relative to Springflow

An assumption throughout the HCP (and supported by EARIP 2008; EARIP 2009) is that as subterranean species, mechanisms exist for these species to retreat into the Edwards Aquifer should springflows cease at the spring outlets at San Marcos Springs. With that assumption, a conservative measure for take for the Texas blind salamander, which includes potential indirect habitat loss associated with springflow reductions, is that take begins when flows are reduced to 50 cfs, as a daily average, total discharge in the San Marcos River. As total flow for the San Marcos Springs/River ecosystem declines below 30 cfs, the potential risk increases.

Take Analysis Methodology (Assumptions, Model Development, Status)

The sparse amount of data for this species did not support the development of a Stella habitat or population model at this time. The limited existing data and inability to model this species led to a qualitative assessment of take with the focus on providing continuous springflow and protection of water quality. There is uncertainty regarding this qualitative analysis, which again highlights the necessity of applied research, expanded biological and water quality monitoring, and ecological modeling.

Evaluation of Effects of Action and Environmental Baseline Versus Current Condition

As a quantitative modeling approach was not employed, no attempt was made to quantitatively describe a known Current Condition against which to make comparisons. As for the Comal subterranean species, the details of the Aquifer food chain at San Marcos Springs are not well understood and additional concerns beyond the preservation of habitat related to springflow include the maintenance of a natural flow of carbon through the system. This carbon flow may be disrupted with combined drought and high levels of pumping.

Effects of Action Added to the Environmental Baseline

An informal qualitative take assessment was attempted but the sparse amount of data for this species limited that evaluation. The springflows projected for the No Action Baseline and Existing Baseline could result in the drying of surface habitat near spring orifices during extreme drought that might adversely impact the salamander. However, this is not the case for the HCP springflow protection as springflow is not projected to fall below 50 cfs on a monthly time step. As a subterranean species, the larger threat is likely contamination of aquifer water quality. As set out in Chapter 5, specific HCP conservation measures will be implemented to protect aquifer water quality and to expand the existing water quality monitoring network at San Marcos Springs.

As discussed for the other San Marcos species, when added to the No Action Baseline or Existing Baseline, the HCP results in an improvement for the Texas blind salamander based primarily on added springflow protection during the extreme drought conditions. Following the same rationale as described above for the listed Comal subterranean species, it is expected that the HCP conservation measures relative to protection of continuous springflow and aquifer water quality are sufficient to ensure that the San Marcos salamander will survive a repeat of the drought of record with an adequate potential for recovery.

Texas Wild-Rice

Texas wild-rice was first collected in the San Marcos River in 1892 and currently occurs in the upper 2.4 kilometers of the San Marcos River, above the confluence with the Blanco River (EARIP 2009).

Habitat Requirements and Current Conditions

A wealth of monitoring data exists for Texas wild-rice as TPWD has been monitoring this species annually since the early 1980's and the EAA Variable Flow study has collected data annually for the past 10 years with several additional monitoring periods following high flow and low flow events. Detailed information on habitat requirements and Current Conditions can be found in EARIP (2009), EARIP (2010), and BIO-WEST (2002b-2011b).

Adverse Impact Thresholds Relative to Springflow

As previously discussed, adverse impacts are an ongoing reality in the San Marcos River relative to recreation, in many cases regardless of springflow level. However, lower springflows have been documented to facilitate greater amounts of adverse impact by supporting wading access to more areas of the river. Over the past decade of EAA variable flow monitoring, as springflows decline below 120 cfs, as a daily average, adverse impact relative to springflow through loss of water depth or wetted area starts to occur. Low flows experienced in 2006 and 2009 provided additional insight on Texas wild-rice responses during drought and subsequent recovery. (EARIP 2009). Total discharge in the San Marcos dropped below 100 cfs during the summer of 2006 and for an extended period during 2009. Monitoring data collected during those periods clearly illustrates that as flows approach 100 cfs, as a daily average, total discharge, impacts to Texas wild-rice become more pronounced (EARIP 2009). The durational component experienced in 2009 must also be considered in an evaluation of adverse impact. In 2006, the lower flow conditions were only experienced for approximately three months, whereas in 2009 the low flow conditions were experienced for greater than one year, which resulted in a greater impact to the overall population of Texas wild-rice (EARIP 2009).

Saunders *et al*. (2001) shows that approximately 10 percent and 20 percent of weighted usable area would be lost when springflow drops from 140 cfs, as a daily average, to 80 cfs and 50 cfs, respectively. Using only high quality habitat (> 0.75 suitability) as an indicator, Hardy (2010) shows that over 90 percent of the maximum available area is sustained at a daily average flows of 80 cfs, over 75 percent of the maximum available area is maintained at 50 cfs; and over 55 percent of the maximum available area is preserved at 30 cfs total San Marcos discharge.

Impact Analysis Methodology (Assumptions, Model Development, Status)

Two main factors led the HCP team not to quantify potential reductions in areal coverage of Texas wild-rice from Phase I package covered activities. The first is that an aggressive Texas wild-rice restoration and enhancement program is included within the HCP conservation measures. Second is that TPWD intends to create State Scientific Areas to help protect at least 1000 m^2 of wild-rice from recreational impacts. These areas will provide for the exclusion of recreational activities for prime Texas wild-rice habitat during flows of 100 cfs or less.

Evaluation of Effects of Action and Environmental Baseline versus Current Conditions

As flows have not been observed at levels nearer to historical minimums, several modeling efforts have been conducted to evaluate the potential for impacts to Texas wild-rice at lower flow conditions (Saunders *et al*. 2001, Hardy 2009, Hardy 2010). A combination of existing data (TPWD unpublished and BIO-WEST 2002b-2011b), physical habitat modeling (Saunders *et al*. 2001; Hardy 2010), and professional judgment were used to assess the survival and recovery of Texas wild-rice at San Marcos Springs relative to the Phase I package. Additionally, although springflow is unquestionably important to Texas wild-rice, management of certain other potential impacts to Texas wild-rice can also prove beneficial to the species. For instance, the build-up of aquatic vegetation mats on Texas wild-rice and other vegetation creates sub-optimal conditions. Similarly, recreational activity in the immediate vicinity of plants that are in vulnerable (shallow)

areas can have negative impacts. Both of these impacts can be reduced by specific management activities. Therefore, mitigation measures will be implemented for both recreation control and vegetative mat removal during low flow periods.

Hardy (2010) also described the potential addition of Texas wild-rice habitat that might be achieved with the removal of non-native aquatic vegetation (*Hydrilla verticillata* and *Hygrophila polysperma*) within predicted optimum areas of occupied Texas wild-rice habitat and within a 2 m buffer around occupied optimal Texas wild-rice areas. Hardy (2010) shows that the removal of *H. verticillata* and *H. polysperma* within Texas wild-rice patches and including a 2 meter buffer around those patches would provide over 1,000 m^2 of additional optimum Texas wild-rice habitat area over the entire flow range (45 to 80 cfs) simulated. Hardy (2010) concludes that the simulated optimal habitat for Texas wild-rice over a range of discharges between 45 and 80 cfs, as a daily average, strongly suggests that proactive planting and conservative non-native vegetation removal has a high potential for increasing existing Texas wild-rice occupied area that would remain hydraulically suitable at these modeled flow levels. As such, Chapter 5 describes Texas wild-rice enhancement measures designed at accomplishing this objective.

Effects of Action Added to the Environmental Baseline

As discussed for the other San Marcos covered species, when added to the No Action Baseline or Existing Baseline, the HCP results in an improvement for Texas wild-rice based on springflow protection alone. The hydraulic and habitat modeling conducted by Dr. Hardy and subsequent analysis by the EARIP and HCP team shows that Texas wild-rice will be impacted by the HCP flow regime, but that flows of 50 cfs or more monthly average will be maintained during a repeat of the drought of record-like conditions.

Texas Troglobitic Water Slater

Habitat Requirements and Current Conditions

The Texas troglobitic water slater is known from two localities in Hays County, San Marcos Springs (Diversion Springs) and the Artesian Well that is located very close to San Marcos Springs. The species is not currently listed as threatened or endangered, but has some likelihood of being listed in the future due to a positive 90-day finding to a petition (USFWS 2009a and 2009b). The state of knowledge of this species is similar to that for the Edwards Aquifer diving beetle. There has not been any species-specific monitoring during the EAA Variable Flow Study.

Take Thresholds Relative to Springflow

The subterranean nature of this species suggests that it does not require substantial surface discharge from springs to survive and presumes that springflow (of sufficient water quality) that continually covers the spring orifice should prevent harm to the population related to habitat loss from dewatering. Given that assumption, at San Marcos Springs, a conservative measure for establishing when take occurs for this species is 50 cfs, as a daily average, total discharge from the San Marcos Spring system. As the flows decline below 30 cfs, the potential for risk increases.

Take Analysis Methodology (Assumptions, Model Development, Status)

The sparse amount of data for this species did not support the development of a Stella habitat or population model at this time. The limited existing data and inability to model this species led to a qualitative assessment of take with the focus on providing continuous springflow and protection of water quality.

Evaluation of Effects of Action and Environmental Baseline versus Current Condition

As there is insufficient data regarding the Texas troglobitic water slater to inform the analyses, no attempt was made to quantitatively describe known Current Conditions to compare against. As with the Comal Springs subterranean species, the details of the Aquifer food chain at San Marcos Springs are not well understood and additional concerns beyond the preservation of habitat related to springflow include the maintenance of a natural flow of carbon through the system. This carbon flow may be disrupted with combined drought and high levels of pumping.

Effects of Action Added to the Environmental Baseline

An informal qualitative take assessment was attempted but the sparse amount of data for this species limited that evaluation. As with the Texas blind salamander, take of this species is anticipated to occur with the drying of surface habitat near spring orifices during periods of extreme drought. Similar to the Texas blind salamander, the larger threat is likely contamination of aquifer water quality. As such, specific HCP conservation measures will be implemented to protect aquifer water quality and to expand the existing water quality monitoring network at San Marcos Springs.

As discussed for the Texas blind salamander, when aggregated with the No Action Baseline or Existing Baseline, the HCP results in an immediate improvement for the Texas troglobitic water slater based on springflow protection alone. Following the same rationale as described above for the Texas blind salamander, it is expected that the HCP conservation measures relative to protection of continuous springflow and aquifer water quality are sufficient to avoid reducing appreciably the likelihood of survival and recovery of this species during the ITP.

4.2.2.3 Downstream and Other Spring Systems

Two Edwards Aquifer springs other than Comal and San Marcos Springs in the area provide aquatic habitats for Covered Species. Hueco Springs, located approximately 4 kilometers north of Comal Springs near the Guadalupe River in Comal County, is a group of smaller springs known as habitat for the Peck's Cave amphipod, also found in Comal Springs. Fern Bank Springs is located in Hays County along the bank of the Blanco River, approximately 13 miles north-northwest of San Marcos Springs, and serves as habitat for the Comal Springs dryopid beetle, which also is found in Comal Springs (Figure 4-39).

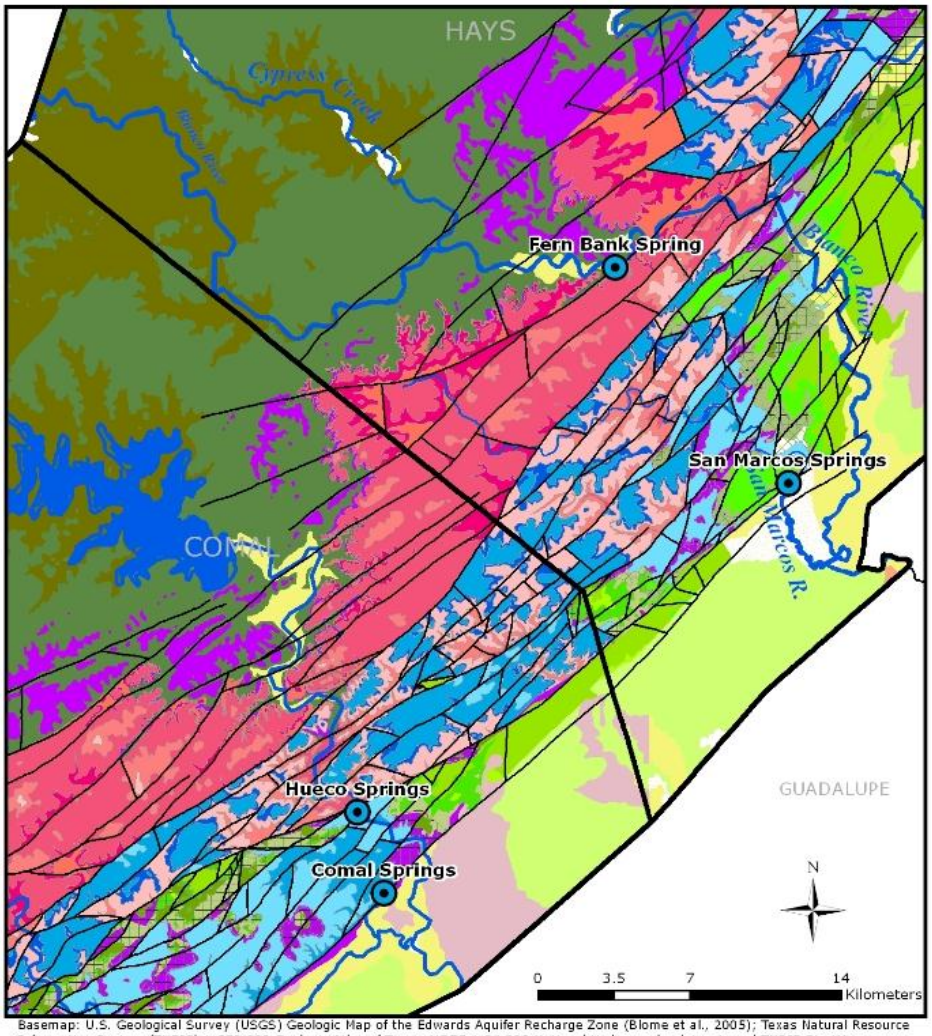
The Peck's cave amphipod at Hueco Springs will likely benefit from the minimization and mitigation measures in the HCP because of the hydrogeologic setting of the springs is similar to that of Comal Springs. The springs have been identified within part of the central Comal flowpath by Otero (2007), which also feeds Comal Springs. This flowpath is characterized to lie within a set of fault blocks bounded on the northwest by the Hueco Springs fault and to the southeast by the Comal Springs fault.

The hydrographs of Hueco and Comal Springs are compared in Figures 4-40 and 4-41. The general flow trends display similar patterns to Comal Springs as comparison of hydrographs from the two springs shows. The flow at Hueco Springs is on average an order of magnitude lower than Comal Springs (Figure 3-21). Hueco Springs tends to drop more rapidly from higher flow rates (> 50 cfs) as dry conditions persist, as in the 2006 and 2008 droughts. As Comal Springs approaches lower discharge values of 200 cfs and below, the flow at Hueco Springs nears zero.

Hueco Springs have been documented to cease flowing several times in the past 90 years, and the amphipod has re-emerged from the Aquifer following these periods of drought. Accordingly,

the measures implemented to maintain sufficient springflow and water quality at Comal Springs should maintain adequate habitat associated with Hueco Springs.

Fern Bank Springs, Critical Habitat for the Comal Springs riffle beetle, Comal Springs dryopid beetle, and Peck's cave amphipod (72 FR 39,247 (July 17, 2007), flows from a significantly different hydrogeologic setting than that of Comal and San Marcos Springs. The elevation of Fern Bank Springs is significantly higher than the other two springs, and it drains a relatively thin portion of the lower members of the Kainer Formation under unconfined conditions. Recent dye traces to Fern Bank Springs confirm that groundwater recharged south of the Blanco River in the Kainer Formation feeds the spring (EAA 2010a). The significant topographic high south of the springs likely produces a local groundwater divide from water feeding San Marcos Springs to the southeast. Although Covered Activities of the HCP will not negatively impact quantity and quality of water flowing from Fern Bank Springs, it is unlikely that conservation measures included in the HCP to protect conditions at Comal and San Marcos Springs will guarantee water will continue to flow at Fern Bank Springs. Localized pumping increases near Fern Bank Springs, which would not be protected as Covered Activities, that would have little effect on Comal or San Marcos Springs could potentially intercept and stop water from emerging from the spring. Since water flows through a stream passage cave in vadose/water table conditions, and this is the habitat for the Comal Springs dryopid beetle at Fern Bank Springs, such localized pumping could produce detrimental conditions to the beetle population here.



Basemap: U.S. Geological Survey (USGS) Geologic Map of the Edwards Aquifer Recharge Zone (Blome et al., 2005); Texas Natural Resource Information System (TNRIS) 1:250,000 Geologic Atlas of Texas; USGS 1:24,000 National Hydrography dataset; and TNRIS StratMap county boundaries dataset.

Legend

USGS Edwards Recharge Zone Geology
- Fault-certain
- Austin Group
- Eagle Ford Group
- Buda Limestone
- Del Rio Clay
- Georgetown Formation
- Cyclic and marine member of Person Formation
- Leached and collapsed member of Person Formation
- Regional dense member of Person Formation
- Grainstone member of Kainer Formation
- Kirschberg evaporite member of Kainer Formation
- Dolomitic member of Kainer Formation
- Basal nodular member of Kainer Formation
- Upper member of Glen Rose Limestone

TNRIS Non-Edwards Geology
- Fault

TNRIS Non-Edwards Geology
- <all other values>
- Q - Alluvium
- Qt
- Q - High Gravel Deposits
- Q - Leona Formation
- Q - Onion Creek Marl
- K - Navarro Group
- K - Pecan Gap Chalk
- K - Austin Chalk
- K - Eagle Ford Fm
- K - Eagle Ford / Buda undivided
- K - Buda Limestone
- K - Del Rio Clay
- K - Del Rio Clay / Georgetown Ls undivided
- K - Edwards undivided
- K - Fredricksburg Group undivided
- K - Fort Terrett Ls
- K - Glen Rose undivided
- K - Upper Glen Rose; Kgru
- K - Lower Glen Rose; Kgrl
- K - Cow Creek Ls / Hammett Shale
- K - Hensell Sand
- Ko

Figure 4-39. Location and geology surrounding springs

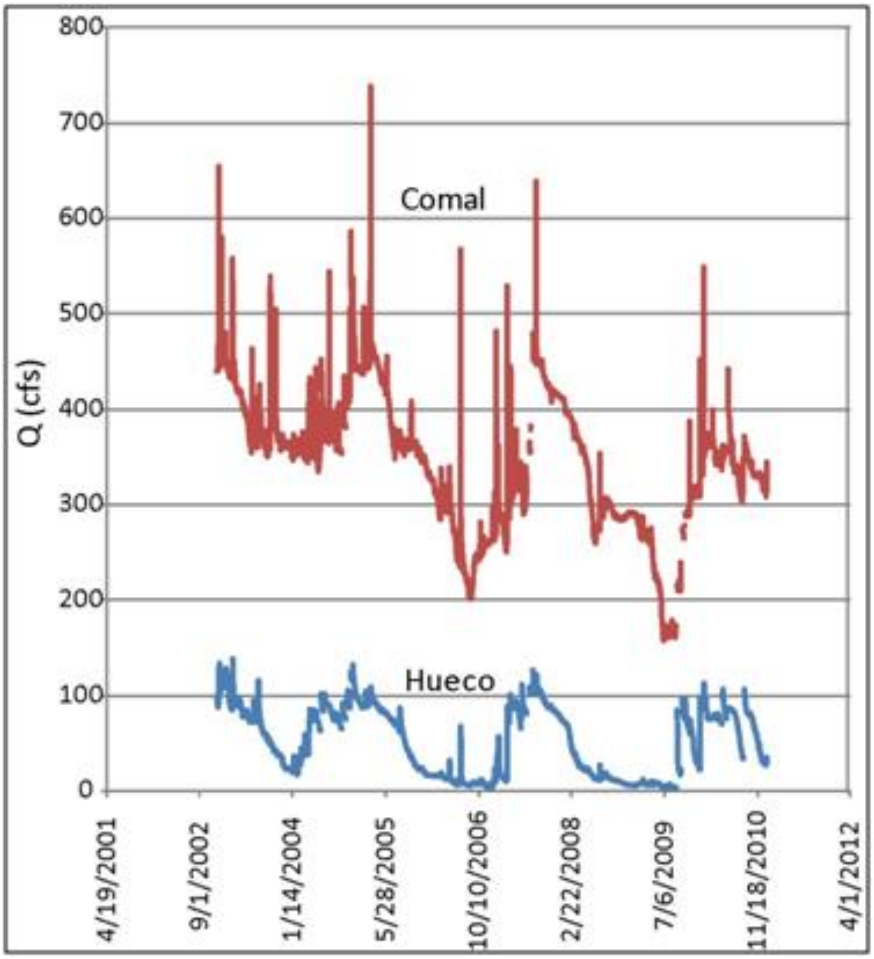


Figure 4-40. Hydrographs of Comal and Hueco Springs, 2002 to 2010

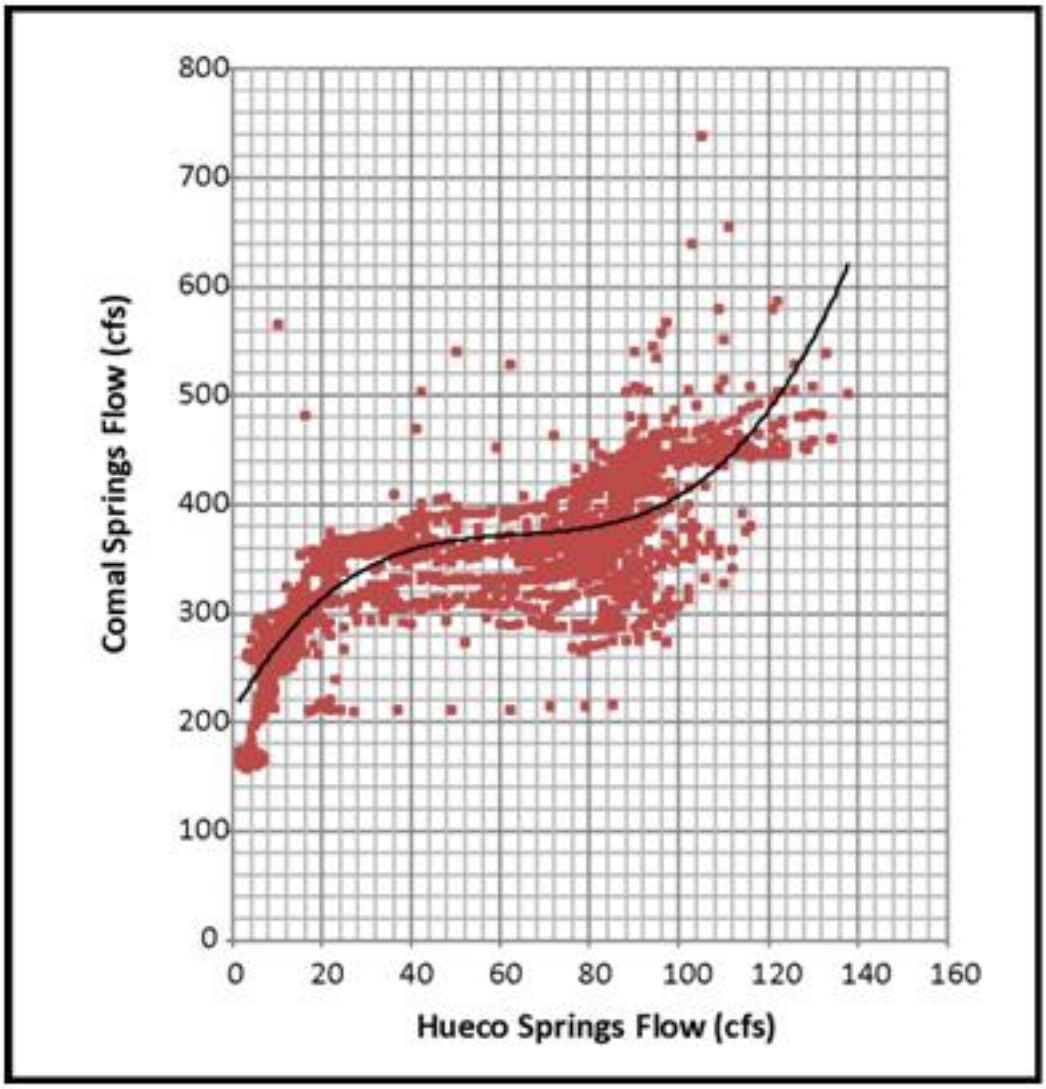


Figure 4-41. Crossplot of Comal and Hueco springflows

Chapter 5 Minimization and Mitigation Measures; Measures Specifically Intended to Contribute to Recovery

The ESA requires the HCP to specify what steps the applicants will take to minimize and mitigate the impacts which will likely result from the anticipated incidental take associated with the Covered Activities. (16 U.S.C. § 1539(a)(2)(A)). In order to issue an incidental take permit, USFWS must find that the applicants "will, to the maximum extent practicable, minimize and mitigate the impacts of such taking." (*Id.* at § 1539(a)(2)(A)(B)(ii)).

This chapter describes the measures that the Applicants commit to carry out to minimize and mitigate the incidental take resulting from the Covered Activities to the maximum extent practicable. Additionally, some measures identified in the Sections below go beyond the "minimize and mitigate" standard and actually contribute to the recovery of the Covered Species. This chapter identifies the impact of the anticipated incidental take to be addressed by each measure and how that measure positively addresses that impact. The overall management of the implementation of these measures is set out in Chapter 9.

5.0 Approach to the Implementation of the Minimization and Mitigation Measures

The HCP will be implemented in two phases. In the first phase of the HCP, habitat minimization and mitigation measures and measures to maintain continuous minimum springflow during a repeat of the drought of record (*see* Table 5-1) will be put into place promptly on issuance of the ITP. This Phase I package will be implemented throughout the permit term unless modified by the AMP. Other components of Phase I will include implementation of measures designed to contribute to recovery of the species, and a robust AMP. Information developed in the AMP during Phase I will inform decisions regarding whether it is necessary to implement any flow protection measures during Phase II of the HCP beyond those implemented in Phase I.

TABLE 5-1
SUMMARY OF MINIMIZATION AND MITIGATION MEASURES INCLUDED IN THE PHASE I PACKAGE

Flow Protection Measures	Emergency Stage V Critical Period Management Reductions
	SAWS ASR Trade Off
	Regional Water Conservation Program
	Voluntary Irrigation Suspension Program Option
Habitat Protection Measures	Measures to Reduce the Impacts of Drought and Enhance the Viability of the Listed Species at San Marcos Springs
	Measures to Reduce the Impacts of Drought and Enhance the Viability of the Listed Species at Comal Springs
	Environmental Restoration and Protection Area at Comal Springs
	Gill Parasite Control
	Wild Rice Restoration and Maintenance at San Marcos Springs
Other Measures	Riparian Habitat Restoration
	Household Hazardous Waste Programs
	Water Quality Protection and Monitoring
	NFHTC Refugia

ASR = Aquifer Storage and Recovery
SAWS = San Antonio Water System
NFHTC = National Fish Hatchery and Technology Center
LID = Low Impact Development

In Phase II, the Applicants will implement the specified additional measures (see Section 5.5.2) if needed to ensure the springflows necessary to foster achievement of the biological goals and objectives as well as implementing any further adjustments to improve the effectiveness of the measures implemented in Phase I.

The decision as to the Phase II actions and any ongoing necessary adjustments will be made through the AMP as set out in Chapter 6 and, more specifically, in Article 7 of the FMA. Until the AMP decision-making process is complete, it is not known whether additional flow protection measures are required. To address the ability and commitment to achieve the existing flow objectives, while recognizing the uncertainty associated with those objectives, Applicants commit to implement a “presumptive” measure that is adequate to achieve the flow-related objectives for attaining the biological goals. If needed, the use of the expanded capacity of the SAWS ASR will be the “presumptive” additional measure to meet the biological objectives with critical period reductions in Stage V beyond those in Phase I, if necessary. (*See* Section 5.5.2).

Applicants will include in the Annual Report a description of the status of implementation of the minimization and mitigation measures and an evaluation of the effectiveness of those measures.

5.1 Edwards Aquifer Authority

5.1.1 San Marcos National Fish Hatchery and Technology Center, Uvalde National Fish Hatchery, and Inks Dam National Fish Hatchery – Refugia

The EAA will support and coordinate with the USFWS on the work relating to the San Marcos NFHTC's operation and maintenance of a series of off-site refugia at USFWS's San Marcos, Uvalde, and Inks Dam facilities. (*See* Section 6.4). The limited geographic distribution of these species leaves the populations vulnerable to extirpation throughout all or a significant part of their range. A series of refugia, with back-up populations at other facilities, will preserve the capacity for these species to be re-established in the event of the loss of population due to a catastrophic event such as the unexpected loss of springflow or a chemical spill.

The support of the refugia will augment the existing financial and physical resources of these facilities, and provide supplementary resources for appropriate research activities, as necessary, to house and protect adequate populations of Covered Species and expanded knowledge of their biology, life histories, and effective reintroduction techniques. The use of this support will be limited to the Covered Species in this HCP.

5.1.2 Voluntary Irrigation Suspension Program Option

The EAA will administer the Voluntary Irrigation Suspension Program Option (VISPO) program. As discussed below in Section 5.8, VISPO is intended to minimize and mitigate the impacts of incidental take from low springflows by suspending the use of Aquifer water for irrigation purposes during drought.

The use of Aquifer water for irrigation accounts for over 30 percent of the annual pumping. This use typically occurs between January and July. The concentrated use of the Aquifer can contribute to substantial drawdown in Aquifer levels. This measure will require EAA irrigation permit-holders who voluntarily participate in the program to suspend the use of Aquifer water for irrigation purposes during drought to maintain springflow.

5.1.2.1 Target Volume, Distribution & Eligible Permits

The volume goal for the VISPO program is 40,000 ac-ft/yr. Irrigation permit-holders in Atascosa, Bexar, Comal, and Hays counties will be approached for enrollment in the program first because these counties are closest to the springs where temporarily suspending pumping is likely to be most effective. It is hoped that at least 10,000 ac-ft can be enrolled in these counties. Assuming that this goal can be obtained, the goal is to enroll 15,000 ac-ft/yr each in Medina and Uvalde counties.

The EAA anticipates that base irrigation groundwater permits will be the primary permits enrolled; however, all permitted irrigation water rights (base and unrestricted) will be accepted in the program. If an irrigation permit-holder desires to enroll less than its full permitted volume, their withdrawals will be monitored by real time automated meters installed by the EAA.

5.1.2.2 Program Trigger

The suspension of pumping by the participants in the program will be triggered if the J-17 index well in Bexar County is at or below 635 ft-MSL on the annual trigger date of October 1. This date provides irrigators, and businesses affected by the decisions made by irrigators, ample time to make crop planting and other business decisions. Announcing implementation of the program on that date will result in a complete suspension of withdrawals of the enrolled water for each program participant for the following calendar year beginning on January 1.

5.1.2.3 Program Term

Irrigators will be offered the option of committing to the program for either five- or ten-year programs. The payment structure is designed to encourage the longer commitment.

Five-year program:

- A standby fee of $50/acre-foot that increases 1.5 percent per year will be paid to the enrollee every year of the term, regardless of Aquifer conditions; and
- A fee of $150/acre-foot that increases 1.5 percent per year will be paid for each year when temporary pumping suspensions are required.

Ten-year program:

- A standby fee of $57.50/acre-foot for years 1-5 and $70.20/acre-foot for years 6-10 will be paid to the enrollee every year of the term, regardless of Aquifer conditions; and
- A fee of $172.50/acre-foot for years 1-5 and $210.60 for years 6-10 will be paid for each year when temporary pumping suspensions are required.

5.1.2.4 Full Subscription to VISPO Program Is Reasonably Certain to Occur

The VISPO Work Group sent letters to all EAA irrigators in November 2010 explaining the VISPO and inviting them to informational meetings to learn more. Two informational meetings were held, one in Uvalde, Texas, on December 6, 2010, and one in Castroville, Texas, on December 7, 2010. Approximately 150 persons attended the meetings (approximately 35 in Uvalde and approximately 115 in Castroville).

Following the meetings, all irrigators were contacted again in January 2011 with a letter of inquiry, a list of Frequently Asked Questions and a schedule of payments for the five- and ten-year program options. (Attachment O) Irrigators were asked to indicate whether they were interested in participating in the VISPO program and, if so, whether they were likely to opt for the 5- or 10-year program.

The EARIP received positive written expressions of interest from irrigators in enrolling 17,226 ac-ft of water as indicated in Table 5-2. This level of response is higher than what has been received for similar surveys, particularly when the responses were solicited so far in advance of a commitment to go forward with the VISPO. Additionally, other irrigators contacted the EAA

after the requested response deadline to express interest in the program. The positive responses indicate a reasonable likelihood of enrolling the full volume of permits once funding is available and contracted enrollment begins.

TABLE 5-2
ACRE-FEET OF INTEREST IN VISPO BY COUNTY

	Atascosa County	Comal County	Bexar County	Medina County	Uvalde County	Total
			Acre-feet of interest			
5-Yr. Base	200	242	1,186	933	6,258	8,819
5-Yr. Unrestricted	400		527	535	1,664	3,126
						0
10-Yr. Base		40	353	3,354	693	4,440
10-Yr. Unrestricted			266	376	200	842
TOTAL	600	282	2,332	5,197	8,815	17,226

Based on the responses and public input and the financial incentives offered to enrollees, the Applicants believe that: (1) the 40,000 ac-ft will be fully subscribed; and (2) the irrigators who initially opt for the five-year option will continue their participation in the program and that the full 40,000 feet will be subscribed over the requested 15-year term of the ITP. To the extent that the program is not fully subscribed, the Adaptive Management Process will be used to identify alternative measures, perhaps additional pumping cuts, achieve the full springflow protection anticipated from the VISPO program and those measures will be implemented.

5.1.3 Regional Water Conservation Program

Some communities and industries in the Edwards Aquifer region have demonstrated a commitment to water conservation. However, water conservation programs have not been implemented across the region or developed to target exempt domestic wells. The Regional Water Conservation Program will minimize and mitigate the impacts of pumping from the Aquifer by building on the expertise of the successful programs to realize savings throughout the Edwards Aquifer region.

The goal of the Regional Water Conservation Program is to conserve 20,000 ac-ft/yr of permitted or exempt Edwards Aquifer withdrawals. In exchange for technical assistance and incentives for implementing the various measures, one-half of the conserved water (10,000 ac-ft) will be committed to remain in the Aquifer unpumped, but still owned by participating permit-holders, for 15 years to benefit springflow levels and contribute to species protection. The other one-half of the conserved water will remain available to the participating entity.

To ensure that the benefit from this program is reasonably certain to be realized, SAWS and certain municipal purveyors will initially commit not to use an amount equal to 10,000 ac-ft/yr of permitted Edwards Aquifer water for municipal use immediately upon implementation of this measure, which will not be utilized, but will still be owned and controlled by the purveyor.

5.1.3.1 Administration

The EAA will administer the Regional Water Conservation Program targeting municipal water users and owners of exempt domestic wells. In this role, the EAA will seek out local program

implementation entities, such as water purveyors and other governing or civic groups, to deliver the anticipated services (*see* Section 5.1.3.2) to Edwards Aquifer municipal permit-holders and domestic well-owners. The EAA, county governments, or a contractor may take responsibility for program delivery in areas where a water purveyor does not have a presence or otherwise chooses not to operate the program itself. The EAA will keep a record of committed water amounts and monitor water use by the implementing entity to ensure compliance.

The EAA will develop a set of forms and procedures for use by the local implementing entity. Technical assistance will also be provided or coordinated by the EAA. The EAA will recruit water purveyors and other entities to implement the Regional Water Conservation Program in their jurisdiction. Contracts will be negotiated and completed between the EAA as the coordinating entity and the local implementing agencies or groups.

The EAA will organize a Regional Conservation Monitoring Committee to be initially comprised of one representative knowledgeable in water conservation from SAWS, the City of San Marcos, the City of New Braunfels, the Bexar Metropolitan Water District, or its successor if that successor entity is not already represented on the Committee, and a small water purveyor which utilizes the Edwards Aquifer. The Regional Conservation Monitoring Committee will provide technical input and expertise, and seek any additional funding from other funding sources such as foundations, state agencies and private sector firms as opportunities arise.

The Regional Conservation Monitoring Committee will also:

- Rank proposed activities in order of efficiency based on water saved/cost;
- Comment on the potential of each activity to achieve its goal for the term of the HCP;
- Make specific recommendations on adjustments that should be made to each proposed activity with the expected result; and
- Prepare periodic statements to demonstrate that the program goals – 20,000 ac-ft saved and 10,000 ac-ft committed to the Aquifer for 15 years – will be achieved by the 10th year of operation.

5.1.3.2 Services, Techniques, Measures, and Technical Assistance

The Regional Water Conservation Program will focus on implementation of incentive programs encouraging: (1) reduction of “lost water” through leak detection; (2) installation of high-efficiency plumbing fixtures and high-efficiency toilets; (3) large-scale commercial/industrial retrofit rebate; and (4) water reclamation for efficient water use.

5.1.3.2.1 Lost Water & Leak Detection

Many municipal water purveyors in the Edwards Aquifer region provide water services to expansive suburban or rural service areas, resulting in extensive lengths of pipe and other transmission and distribution infrastructure systems in areas that are not frequently visited, leaving many water leaks undetected. Even if detected, many smaller purveyors lack the financial means or technical expertise to address the issue in a pro-active manner. The lost water technical assistance program is meant to help identify the sources of water lost from the distribution systems of these purveyors and marshal resources to assist in repair.

Where a water purveyor has estimated a total volume or percentage of water produced that is lost in transmission and identified where the loss is most likely occurring, the purveyor may submit an application to the EAA with a plan to reduce the lost water and a request for technical assistance. If the purveyor agrees to commit half of the saved water to remain unutilized for 15 years, then a one-time assistance of $500 for each ac-ft saved will be provided. The EAA will also seek to identify funding sources available to small water purveyors to help enhance or supplant any financial assistance provided by the EAA under this measure, or to organize other funding.

Where purveyors have the capability to identify or estimate water lost in the distribution system, the EAA will enter into contracts with SAWS, the City of San Marcos, the City of New Braunfels, or other interested parties or contractors to provide assistance with a distribution system leak detection and lost water survey for the participating purveyor. The EAA, recipient purveyor, and appropriate expert staff from the surveying entity, as appropriate, will use the gathered data to prepare a lost water analysis and improvement plan for the targeted purveyors. These purveyors would then request assistance from the EAA with this plan to reduce water lost during transmission.

5.1.3.2.2 High-Efficiency Plumbing Fixtures & Toilet Distribution Program

Many new homes and businesses have been built in the Edwards Aquifer region since 1992, when enhanced requirements for high-efficiency toilet and other fixtures became effective. However, many structures remain from prior to 1992 that still utilize older, high-flow toilets and plumbing fixtures. These relatively simple replacements rapidly conserve water – each old toilet replaced conserves 12,500 gallons per year, while a typical household that replaces plumbing fixtures saves 10,500 gallons per year. Even more water is saved when old toilets and fixtures in commercial and institutional settings are replaced.

Some water purveyors may decide to lead the initiative to recruit its customers in the replacement of older high-flow toilets with a new Caroma, two-volume, high-efficiency toilet (or another high-efficiency toilet). During this effort, high-efficiency faucets and shower-heads may also be provided. The purveyor then organizes the distribution of the toilets to customers who are interested in participating. The old toilet is collected to verify that the new toilet is installed. Partnerships with area plumbers, non-profits, and civic groups have proven to be effective means of ensuring the new fixtures and high-efficiency toilets are distributed and installed.

In other instances, the EAA or subcontractor, such as a county government, will make the toilets and high efficiency plumbing fixtures available to Edwards' pumpers with exempt wells. The toilets will be distributed in the same manner as water-purveyor-led initiatives, or a central depot can be established that is staffed at specified times.

The EAA or the subcontractor will obtain the commitment in the form of a contract with the recipient to replace a high flow toilet using Aquifer water. It would also require a commitment to proper maintenance in the contract. Plumbers and/or non-profits may be utilized for this task as well.

5.1.3.2.3 Commercial/Industrial Retrofit Rebate

Commercial and industrial processes are often large users of water. Many processes which use water as an input or as part of the production practice in the past have alternative water-saving means available today. The type of business or industrial activity that may be updated with

water-saving equipment or process varies widely, and each interested participant will require unique consideration of the individual circumstance, goal, and capacity.

The EAA will provide a full or part-time staff person to make the contacts and complete the planning and process implementation. Invoices from the participating commercial or industrial concern are to be sent to the EAA. For example, a comparable SAWS program pays for 50 percent of the cost of the technological change or $400 per ac-ft of water saved over 10 years, whichever is less. The Regional Water Conservation Program will be modeled on this SAWS program. SAWS staff will provide training and perhaps ongoing technical assistance for the EAA staff as needed. One of every two ac-ft saved will have to be left unutilized by the sponsoring entity for the duration of the ITP.

5.1.3.2.4 Water Reclamation for Efficient Water Use

This portion of the Regional Water Conservation Program will be operated by the EAA and target exempt well owners.

Staff person(s) involved will be technically proficient in a number of related technologies including condensate collection, gray water use, rainwater collection, xeriscaping, self-contained water systems, and drip irrigation. Her/his goal would be to identify rural residents that were willing to implement these technologies with a small subsidy from the sponsoring entity. The subsidy of $300 or $400 per ac-ft saved is the same as that for the other conservation programs but is unlikely to cover a significant portion of the total cost of the technology. Nevertheless, people regularly approach various water conservation information events throughout the region inquiring about these practices. A participant will have to commit to leaving 50 percent of the water savings in the Aquifer for 15 years.

In an urban setting, opportunities for this activity are mostly confined to new construction or large scale rehabilitations or conversions. In such a setting, the EAA will require a commitment by the appropriate water purveyor to leave one-half of the savings unutilized for the permit term.

5.1.3.3 Initial Commitment

Municipal water purveyors which utilize the Aquifer and have had success at implementing water conservation measures will initially commit an amount approximating 10,000 ac-ft/yr of permitted Aquifer water for municipal use immediately upon implementation of this measure, which will not be utilized, but will still be owned and controlled by the purveyor, as follows:

- San Antonio Water System: 8,000 ac-ft/yr
- TBD: 2,000 ac-ft/yr

As participating water purveyors and exempt well-owners achieve new water savings, the volume of conserved water committed by the new participants will be off-set against the initial commitment, allowing the initial commitment to revert to the control of the original permit-holder proportionally until the Regional Water Conservation Program achieves 20,000 ac-ft of savings, 10,000 ac-ft of which would remain unutilized by the new participating entities during the term of the HCP.

5.1.4 Critical Period Management – Stage V

5.1.4.1 Stage V Emergency Withdrawal Reductions

By December 31, 2012, EAA will amend its Critical Period Management Program to add a new emergency Stage V reduction of 44 percent applicable in both the San Antonio and Uvalde pools. Stage V is designed to be triggered only when other measures have not proven sufficiently effective in maintaining springflow during drought conditions. For the San Antonio Pool, Stage V would be triggered by a combination of monthly average J-17 levels below 625 feet or springflows of either 45 cfs based on a ten-day rolling average at Comal Springs or 40 cfs based on a three-day rolling average. The Uvalde Pool would trigger Stage V using the Uvalde County Index Well (J-27) water level of 840 ft-MSL.[1]

5.1.4.2 Stage V Emergency Water Supply

It is anticipated that during Stage V, all outdoor use of groundwater withdrawn from the Aquifer will be prohibited, except for limited circumstances, such as foundation watering, watering from a hand held hose, and emergency uses such as firefighting. It is possible that some of the smaller municipal water providers who are entirely dependent on the Aquifer may not have sufficient water supplies to meet public health and safety needs with Stage V critical period reductions. In such cases, municipal water providers will not be denied the use of groundwater from the Aquifer to meet public health and safety needs, but they will incur substantial fines and penalties as determined by the EAA pursuant to its enforcement rules and policies if they do not achieve the reductions. With such fines or penalties for overuse, it is anticipated that it would be more cost effective for small municipal providers who are entirely dependent to ensure that they have sufficient supplies available through lease arrangements than to pay the penalties for overuse during Stage V reductions.

To facilitate the leasing of water under these types of emergency situations, the Applicants may, with the support of the EARIP, seek a legislative amendment of § 1.34 of the EAA Act to allow irrigation permit holders to lease “Base Irrigation Groundwater” to municipal and irrigation users within the same county as the place of use for the irrigation permit during severe drought conditions.

5.2 City of New Braunfels

5.2.1 Flow-Split Management in the Old and New Channel

Presently, the culverts governing flow from Landa Lake into the Old Channel are inoperable. As a result, a constant level of springflow proceeds through the culverts and into the Old Channel. Over time, this has led to the scouring of preferred native vegetation types for fountain darters, and the establishment and eventual dominance by non-native non-preferred aquatic vegetation. Flow-split management is intended to complement the ecological restoration of aquatic vegetation in the Old Channel, by reducing long-duration high flows and allowing for more seasonal variability to be maintained, mimicking a more natural flow pattern.

To minimize and mitigate the impacts of low flows, the City of New Braunfels staff will manipulate at least once monthly the valves and culverts to the Old Channel and New Channel of the Comal River for the protection of existing and restored native aquatic vegetation in the

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[1] *See also* Section 5.5.2.

river, based on EAA's real-time flow gauges in these channels and as often as appropriate for the maintenance of a beneficial hydrologic condition of the Old Channel habitat. Prior to this, the City of New Braunfels will replace and repair existing gates and control mechanisms to restore the operability of all four water paths to the Old Channel from Landa Lake: the two small culverts, the one large culvert, and the Springfed Pool inlet. This repair will allow for the manipulation of water flow per the flow split strategy in Table 5-3 and the prevention of sustained high flows in the Old Channel that resulted in scouring.

A second objective is to maximize the quality of habitat in the Old Channel. This will be accomplished by: (1) providing an appropriate level of flow variability during average to high flow conditions; and (2) allowing proportionally more water to flow through the Old Channel versus the New Channel during periods of critically low-flow with the ultimate goal of preserving high quality fountain darter habitat within the Old Channel as long as possible.

A detailed description of flow-split management is described in BIO-WEST (2011c). Based on the analysis conducted to date, the desired goal for maximizing fountain darter habitat in upper portions of the Old Channel at all times is to maintain 40–80 cfs. Extremely uniform suitable habitat is present in the New Channel under modeled (10–300 cfs) flows (Hardy 2011). Table 5-3 describes the flow-split for total Comal springflow conditions. During average to high flow conditions the focus is on a seasonal flow split in order to optimize habitat conditions in the Old Channel over time. Slightly higher flows during the fall and winter will provide some channel maintenance benefit while not hindering overall fountain darter habitat. Optimal habitat conditions are proposed for spring and summer to provide the best opportunity for fountain darter recruitment.

TABLE 5-3
FLOW-SPLIT MANAGEMENT FOR OLD AND NEW CHANNELS

Total Comal	Old Channel (cfs)		New Channel (cfs)	
Springflow (cfs)	Fall, Winter	Spring, Summer	Fall, Winter	Spring, Summer
350+	80	60	270+	290+
300	80	60	220	240
250	80	60	170	190
200	70	60	130	140
150	60		90	
100	60		40	
80	50		30	
70	50		20	
60	40		20	
50	40		10	
40	30		10	
30	20		10	

When total Comal springflow flows drop to 150 cfs, the flow split will be shifted to protecting the maximum amount of habitat within the Old Channel year-round, while continuing to provide flow in the New Channel at all times (*see* Table 5-3). Additionally, when total Comal springflow drops below 100 cfs, if necessary, the City of New Braunfels staff will manipulate the valves and culverts more frequently to maintain the flow split ratio as detailed in Table 5-3.

As discussed in Hardy (2011), 20 cfs in the Old Channel will provide approximately 75 percent of the maximum available fountain darter habitat in the Old Channel from a physical habitat perspective. In addition to physical habitat, four checkpoint temperature ranges have been

identified as critical to the fountain darter life cycle: at and above 77 to 79°F there is reduction in fountain darter larval production; between 79°F and 82°F and above there is a reduction in egg production, and at approximately 91°F and 94°F larval and adult thermal death can be expected based on laboratory studies (Brandt *et al*. 1993, Bonner *et al*. 1998, McDonald *et al*. 2007). At 20 cfs, under the extreme ambient temperature conditions modeled in Hardy (2011), the Old Channel area between Landa Lake and Golf Course Road [Model Segment 18; Hardy 2011]) is projected to maintain water temperature below three of the four temperature threshold ranges at all times. Reduced larval production (up to 63 percent) has the potential to occur for portions of the day based on laboratory results from McDonald *et al*. (2007). Hardy (2011) shows that the lower portion of the next modeled segment downstream (Reach 19 – Old Channel above Elizabeth Street) is projected to have water temperatures high enough during portions of the day to cause reduction in egg production as well. All subsequent downstream Old Channel segments also are projected to have temperatures at least as high for short periods of time. However, it should be reiterated that even at 20 cfs, nowhere in the Old Channel during the extreme conditions modeled, are water temperatures projected to exceed levels necessary for adult or juvenile survival. (Hardy 2011).

Additionally, it should be noted that the City of New Braunfels is in the process of restoring the functionality of the Landa Lake Spillway and Landa Lake Dam. This repair and restoration project will protect the Old Channel from scouring in less severe rainfall events and reduce sedimentation effects in the Old Channel. This repair is contingent upon receiving permits from the Army Corp of Engineers and the USFWS.

5.2.2 Native Aquatic Vegetation Restoration and Maintenance

It has been documented over the past decade (BIO-WEST 2002a–2011a) that native aquatic vegetation plays a key role in supporting the native fish assemblages, including the fountain darter. To minimize and mitigate the impacts of incidental take from low-flow events by providing better habitat conditions for the ecological community, the City of New Braunfels will undertake a program of native aquatic vegetation restoration within key, sustainable reaches of the Comal River by planting native vegetation in unoccupied areas and in areas previously occupied by non-native aquatic vegetation, with the latter preceded by non-native vegetation removal.

The amounts and types of vegetation removed and restored in this program will be established by Table 4-5 and 4-6 respectively. Two-dimensional hydraulic models will be used to evaluate the potential for success of the native vegetation restoration. This evaluation will consider the depth, velocity, and substrate conditions present in the proposed areas along with what non-native vegetation is thriving in these areas. In areas that are bare of vegetation, the reason vegetation is absent (*e.g.*, recent flood scour, or unsuitable depth, velocity or substrate conditions) will be evaluated prior to restoration. Following an evaluation of the physical habitat model, an evaluation of water quality conditions will also be conducted. In particular, the CO_2 need of the native aquatic plant being considered for establishment and the CO_2 concentrations in the water column under varying flow conditions at the proposed restoration locations will be evaluated.

Additionally, restoration will involve acquiring local, disease- and pathogen-free plant material. The material will be removed from adjacent habitat, propagated off-site (*e.g.*, at the NFHTC) using plant material removed from the Comal system. Alternatively, it may be purchased from vendors who meet locality and disease free criteria. When non-native species are removed, they will be disposed of properly.

The focus of native vegetation restoration will be on Landa Lake downstream of Spring Run 3 but above the New Channel USGS weir and on the portions of the Old Channel bordered on both sides by City of New Braunfels' property, including the Old Channel ERPA. Restoration efforts will also include establishing additional *Cabomba* along the eastern shoreline of Landa Lake and along the New Braunfels' golf course property to create valuable fountain darter habitat.

5.2.2.1 Old Channel Environmental Restoration and Protection Area (Old Channel ERPA)

To minimize and mitigate the impacts of recreation and pumping during periods of low flow, the City of New Braunfels will remove problematic non-native vegetation, restore native habitat (per Table 4-6), undertake limited channel modification to enhance fountain darter habitat, and remove a small sediment island. The Old Channel Environmental Restoration and Protection Area (ERPA) includes the EAA Variable Flow Study reach below Elizabeth Street upstream to the culverts feeding the Old Channel from Landa Lake where the preferred native aquatic vegetation of the fountain darter has been scoured and replaced over time with less-preferred non-native aquatic vegetation.

This measure does not include an experimental channel or recirculation in Landa Park. As additional research is conducted and new data established, the City of New Braunfels will consider additional measures to protect habitat in this stretch of the Old Channel, *see* BIO-WEST (2011c), based on the protocols set forth in the FMA for determination of AMP measures and their implementation.

One specific area of targeted sediment removal is a small island that has formed just behind the Springfed Pool and immediately downstream of Landa Lake. This sediment island continues to grow, has established destructive non-native cane, and has displaced/destroyed fountain darter habitat.

5.2.2.2 Comal River Restoration

Upon final determination of locations suitable fountain darter habitat for restoration in the Comal River proper (below the USGS gauging weir, aka Stinky Falls), the City of New Braunfels will conduct native vegetation restoration and yearly maintenance to establish additional fountain darter habitat. Areas for targeted restoration preferred by the City of New Braunfels include the portion of the Comal River between Last Tubers Exit and the confluence of the Guadalupe River and portions of the Comal River that allow for protection on one side of the river and safe passage of recreators on the other side of the river. Once the habitat has been established, TPWD will pursue creation of State Scientific Areas to protect fountain darter habitat.

5.2.2.3 Native Aquatic Vegetation Maintenance

Restoring native vegetation within the Comal system will benefit the Covered Species, but will be unsuccessful or likely very limited in success if it is not monitored and protected over time. One-time restoration contradicts the purpose for these activities which is to provide better habitat conditions for the ecological community over time and in particular, upon entering into critical low-flow periods. To sustain these conditions prior to entering into low-flow periods, the City of New Braunfels will conduct yearly maintenance of native aquatic vegetation restoration sites in Landa Lake and the Old Channel, and the flow-split management discussed above in Section 5.2.1.

Native aquatic vegetation maintenance consists of actively monitoring and maintaining planted stands of native vegetation. Temporal monitoring will incorporate some form of quantitative measurement system to assess whether plantings are increasing, decreasing, or remaining stable. Additionally, intensive non-native vegetation control in the adjacent areas will be implemented until the native vegetation is well-established. It will include additional activities following natural disturbances such as floods, periods of limited recharge, and/or herbivory, as well as anthropogenic disturbances such as recreation or vandalism. Anytime a disturbance is observed, the monitoring/maintenance schedule will be modified temporarily in order to provide the stability for the native vegetation re-establishment.

5.2.3 Management of Public Recreational Use of Comal Springs and River Ecosystems

To minimize and mitigate the impacts of recreation, the City of New Braunfels will manage recreational use of the Comal Springs and Comal River Ecosystem through two methods:

1) The City of New Braunfels will not reduce current protections provided by City Ordinance or Policy and will continue to enforce these regulations, including:

a. Limiting recreation on Landa Lake to Paddle Boats

b. Prohibiting recreational access to the Spring Runs in Landa Park to the Wading Pool in Spring Run 2.

c. Prohibiting water recreation on the Old Channel; with the exception of Schlitterbahn operations within its present location.

2) Pursuant to Section 9.2 of the IA, the City of New Braunfels will issue Certificates of Inclusion (COIs) to those commercial outfitting businesses that facilitate recreational activities on the Comal River (Outfitters) that comply with the requirements of the COI program established in this section. Outfitters that opt into the COI program and receive a COI will receive incidental take coverage during the term of the COI, which shall not extend beyond the Permit term. The City of New Braunfels is not required to regulate the recreational activities of those Outfitters that choose not to participate through the COI process beyond the minimization and mitigation activities the City of New Braunfels has committed to undertake in this HCP.

Outfitters can apply for a COI when the ITP is issued and every two years thereafter. For those Outfitters that voluntarily participate in order to obtain incidental take coverage for their recreational activities, the COI will contractually require those Outfitters to comply with and implement listed minimum standards set out below. The City of New Braunfels will not reduce or eliminate any of the listed minimum standards during the 15-year ITP term but reserves the right to add additional standards in the future. COIs from the City of New Braunfels will be issued for a two-year term; so that every two years conditions of the COI may be re-evaluated and increased if necessary to further promote mitigation activities, reflect changes in New Braunfels policy or ordinance as related to protection of habitat or address new information established through the best science available as related to the species. The City will provide each year to the Program Manager for incorporation into the Annual Report a copy of all COIs issued during that year and information regarding the Outfitters compliance with the minimum standards.

Minimum COI Outfitter Standards

a. Provide litter bags to all customers

b. Sponsor one Comal River Cleanup annually. Outfitters may sponsor an existing river cleanup or may organize their own. Services and resources provided as a sponsor must exceed $1,000 in direct payment or in-kind service.

c. Provide at point of purchase at place of business, educational signage about the endangered species, their Critical Habitat, and efforts to promote the Covered Species (largely HCP initiatives and Critical Period Management information). Design and artwork will be produced and supplied by the City of New Braunfels. Signage must be at a minimum 3'x 6'.

d. Require all businesses, at their respective business locations, to support and assist the City of New Braunfels' enforcement of laws that relate to the Covered Species and their habitat. Specifically, this applies to, but is not limited to, litter prevention and habitat protection.

e. Outfitters must submit a yearly report to the City of New Braunfels by January 1 of each year, detailing activities related to the COI for the previous year.

f. If established, Outfitters shall provide at point of purchase at place of business, a map and educational sign about the State Scientific Areas. Design and artwork will be produced and supplied by the City of New Braunfels. Combined map and sign must be at a minimum 3'x 6'.

g. Assist the City of New Braunfels with implementation of additional recreational management measures and controls at flows below 100 cfs to reduce habitat effects, water quality degradation, and other determined negative effects.

h. Stencil all outfitter rented recreational equipment with an anti-litter message. The City of New Braunfels will design and supply the stencil to be used.

If an Outfitter is in violation of any standard, the City of New Braunfels may suspend or revoke the Outfitter's COI after providing notice, an opportunity to come into full compliance, and a hearing.

5.2.4 Decaying Vegetation Removal and Dissolved Oxygen Management

The largest uncertainty noted in the Hardy (2011) report is the potential effect of extended low-flow periods on aquatic vegetation dynamics within the Comal system as neither the hydraulic and habitat modeling, nor water quality modeling conducted addresses this issue. The main concern is that under extremely low-flow conditions, aquatic vegetation may start to die, and subsequently decay, consuming a large amount of dissolved oxygen (DO) during the decay process. This in turn could cause large swings in the DO concentration within Landa Lake, which depending on the severity, could affect the biological community including the fountain darter. The concern is probably limited to the lake portions of the system as the culverts and weirs present at the uppermost portions of the Old and New Channels would likely provide

sufficient re-aeration to compensate for most events. However, within the lake environment, problems could occur.

To minimize and mitigate the impact of incidental take from low-flow events, upon receipt of DO data indicating a water quality concern created by decaying vegetation and the total Comal springflow drops below 80 cfs, the City of New Braunfels will implement a dissolved oxygen management program. The program will be focused on ensuring adequate DO levels for the ecosystem. Techniques to accomplish this objective may include artificial aeration of areas of Landa Lake or other solutions. If appropriate, the program may include removal of decaying vegetation. Removal techniques for decaying vegetation, if necessary, may include using rakes/pitch forks and a jon boat to transfer material to the banks for subsequent disposal. In this way, greater dissolved oxygen will remain available for the living aquatic ecology, rather than be consumed in the decay process.

5.2.5 Control of Harmful Non-Native Animal Species

To minimize and mitigate the impacts of low flows, the City of New Braunfels will conduct non-native animal species control on an annual basis. Initial control efforts will be intense and take place during the winter's first freeze, with continued control every winter. Control of non-natives will include annual maintenance and monitoring and non-natives will be disposed of out of the floodplain. The non-native animal species that will be addressed include the suckermouth catfish, tilapia, nutria, and ramshorn snail. Potential control methods are discussed below.

Studies have shown that many fishes (especially small fish) have very similar food habitats (Hubbs *et al*. 1978). If non-native species are added to the aquatic ecosystems, greater competition or overlap among species is possible as these non-native species may be able to acquire resources with greater efficiency than native species (USFWS 1984). Suckermouth catfishes (*Loricariidae*) are a non-native fish species that has become established in the waters of Texas including the Comal River. (Howells 2005). Suckermouth catfishes prefer to feed on periphyton and algae (Hoover *et al.* 2004). The fountain darter lays eggs on algae and loss of spawning habitat and possibly egg predation are potential threats from suckermouth catfish (SSC 2009). There is some concern that excessive numbers of suckermouth catfishes could cause direct (potential displacement) and indirect effects (disruption of food supply) to the fountain darter in the Comal River (SSC 2009). Suckermouth catfishes also burrow into the river banks, destabilizing them and causing the introduction of additional sediment load into the habitat.

Tilapia is another non-native fish species that can impact fountain darter habitat. Tilapia destroys vegetation by making bare ground nests. During times of low flow and drought this could further reduce already limited habitat for the fountain darter. Tilapia is a tropical species that will congregate in winter near spring openings and other warm water sources. When tilapia congregate this creates the opportunity to use seines, gill nets, cast nets, or other methods to remove large quantities with minimal impact to the habitat. Artificial heating could be one method used to congregate fish in areas away from springs and endangered species to minimize the impacts from collection efforts.

Similarly, tilapia tend to congregate in backwater pools during summer months. This may afford another opportunity for effective removal of the fish.

A non-native gastropod (giant ramshorn snail [*Marisa cornuarietis*]) also poses a threat to the Comal Springs ecosystem. The giant ramshorn snail, a species in the aquarium trade, was first discovered in Landa Lake in 1984. (McKinney and Sharp 1995). This snail grazes on aquatic

plants and in the 1990s played a major role in reducing plant biomass in Landa Lake. This snail prefers clear streams and pools with temperatures of at least 66°F (19°C). When exposed to lower temperatures, the snails withdraw into their shells and only survive for short periods. The warmest temperature that the giant ramshorn snail can withstand is 102°F (39°C). Although the population has diminished since the mid-1990s, the potential for future alteration of plant communities by the Ramshorn in the Comal ecosystems remains. (McKinney and Sharp 1995; BIO-WEST 2007c). The strong preference of fountain darters for aquatic vegetation highlights the concern posed by the grazing activities of the giant ramshorn snail (BIO-WEST 2004a). This species will be monitored closely to assure that it does not significantly reduce the available fountain darter habitat.

5.2.6 Monitoring and Reduction of Gill Parasites

A major concern in the Comal Springs ecosystem is the continued presence of an Asian trematode, *Centrocestus formosanus*. This parasite was first discovered on fountain darters in the Comal River during October 1996. The parasite attaches to the fish's gill filaments causing extensive gill tissue proliferation and damage (Mitchell *et al.* 2000) with mortality in the wild being reported following the discovery in 1996 (Tom Brandt, personal communication).

A non-native snail, *Melanoides tuberculatus*, that has been in central Texas since 1964 (Mitchell *et al.* 2005) has been confirmed as *C. formosanus*' central Texas first intermediate host (Mitchell *et al*. 2000). Parasite monitoring via examination of presence on fountain darter gills to determine *C. formosanus* levels in the Comal River has been ongoing since the late 1990s by the USFWS, Texas State University, and BIO-WEST (EAA Variable Flow Study).

In 2010, USFWS and BIO-WEST conducted a pilot study for the EARIP to determine the effectiveness of *Melanoides tuberculatus* removal on lowering drifting gill parasite numbers in the Comal River. (USFWS NFHTC and BIO-WEST 2011). The study confirmed that removing *M. tuberculatus* from the Comal River will result in a decrease in *C. formosanus cercariae* in the water column. It also recommended adaptive management studies to better determine the magnitude and duration of the benefits from snail removal.

To minimize and mitigate for the impact of low flows, the City of New Braunfels will retain and oversee the work of a contractor to establish a gill parasite monitoring and reduction program. The program may consist of non-native snail removal based on the pilot study conducted by USFWS and BIO-WEST (*Id.*). However, additional research on the most effective means of gill parasite removal will be conducted as part of the AMP as discussed in Section 6.3.6 to determine the method of gill parasite control that will actually be implemented.

5.2.7 Prohibition of Hazardous Materials Transport Across the Comal River and Its Tributaries

Hazardous materials transported by vehicles across the watershed of the Comal River and its tributaries present the possibility of accidental spills or releases into the environment. The limited geographic distribution of the Covered Species at Comal Springs could cause the species to be highly impacted by such a spill. The City of New Braunfels will coordinate with the Texas Department of Transportation (TDOT) to prohibit transportation of hazardous materials on routes that cross the Comal River and its tributaries. This effort may include legislation, City of New Braunfels ordinances, additional signage, and TDOT approval.

5.2.8 Native Riparian Habitat Restoration

To minimize and mitigate the impacts of low flow, the City of New Braunfels will restore native riparian zones, where appropriate, to benefit the Comal Springs riffle beetle by increasing the amount of usable habitat and food sources (*i.e.*, root structures and associated biofilms). The method of riparian zone establishment will include the removal of non-natives and replanting of native vegetation representative of a healthy, functioning riparian zone. Trees and plants with extensive root systems will be given preference to create the maximum beetle habitat. Fine sediment covering exposed roots and springs will also be removed. The riparian zone will be monitored (at least annually) for continued success and removal of reestablished non-natives. Riparian zones will be protected until the preferred riparian zone is established. Riparian habitat zones will be created along both sides of Spring Run 3 and along the portion of the western shoreline that is owned by City of New Braunfels.

In addition, riparian restoration also benefits the system through bank stabilization and nutrient and sediment processes. The City of New Braunfels will develop a program to incentivize private landowners on the Comal River and its tributaries to establish riparian zones along the western shoreline.

5.2.9 Reduction of Non-Native Species Introduction and Live Bait Prohibition

Introducing non-native species into the Comal Springs and River results in predators and competitors for the Covered Species in the ecosystem. To mitigate the impacts of recreation and pumping from the Aquifer during drought, the City of New Braunfels will undertake measures to stop or substantially reduce the introduction of non-native species from aquarium dumps and prohibit the use of live bait species.

The City of New Braunfels will prohibit by Ordinance introductions of domestic and non-native aquatic organisms, targeting specifically bait species and aquarium trade species into the Comal system. This action will include signage at key entrance points to parks on Landa Lake and the Comal River.

5.2.10 Litter Collection and Floating Vegetation Management

To minimize and mitigate the impacts of recreation and pumping during low flow periods, the City of New Braunfels will clean litter and debris from and manage floating vegetation in the Comal Springs, Landa Lake, and Old and New Channels of the Comal River. Litter and debris collection both flood-related and routine, will utilize self-contained underwater breathing apparatus (SCUBA). Debris removal also includes the removal of litter from floating vegetation mats before dislodging the vegetation mat and allowing it to continue downstream. Vegetation mats shade out native vegetation and create die off of vegetation if the mats are allowed to collect and grow in size. By dislodging the floating vegetation mats, fountain darter habitat is maintained and protected.

5.2.11 Management of Golf Course Diversions and Operations

Historically, the City of New Braunfels Golf Course has not used its full permitted surface water rights for irrigating the Golf Course. From 2006 through 2010, an average of 115.4 ac-ft/yr of

water was diverted under both permits for golf course irrigation compared to the full permitted amount of 300 ac-ft/yr. To reduce use of Comal River water further, the City of New Braunfels is working with New Braunfels Utilities under a grant received by the Texas Water Development Board to develop and implement a reuse water system that will be used to maintain the golf course by supplementing or, to the extent feasible, replacing the surface diversions used for irrigation purposes. The design process has been started for the reuse system.

The City of New Braunfels will develop a golf course management plan that will document current practices and include an Integrated Pest Management Plan (IPMP). The golf course management plan and IPMP will incorporate environmentally sensitive techniques to minimize chemical application, improve water quality, and reduce negative effects to the Covered Species. Any chemicals used will be applied by a licensed applicator in a manner consistent with the label directions. Expanded water quality sampling targeted at Golf Course operations will be conducted per Section of 5.7.2 of the HCP. Changes in golf course management will be addressed through the AMP as set out in Article 7 of the FMA.

5.3 City of San Marcos[2]

5.3.1 Texas Wild-Rice Enhancement and Restoration

Hardy (2011) describes the potential addition of Texas wild-rice habitat that might be achieved with the removal of non-native aquatic vegetation (*Hydrilla verticillata* and *Hygrophila polysperma*). Hardy (2011) shows that the removal of *H. verticillata* and *H. polysperma* within Texas wild-rice patches and including a 2-meter buffer around those patches could potentially provide over 1,000 m^2 of additional optimum Texas wild-rice habitat area over the entire simulated flow range (45 to 80 cfs). Proactive planting and conservative non-native vegetation removal has a high potential for increasing existing Texas wild-rice occupied area that would remain hydraulically suitable at these modeled flow levels. (Hardy (2011).

Based on BIO-WEST and TPWD monitoring data collected over the past decade and Hardy (2011) model results, the City of San Marcos, in partnership with Texas State University, will implement a Texas wild-rice enhancement and restoration program. Model results will be used to identify restoration/enhancement areas for Texas wild-rice that have a high probability of success (*i.e.*, optimal habitat). In mixed (Texas wild-rice and non-native vegetation) stand areas, the non-natives will be removed and the original Texas wild-rice stand monitored for expansion. Similarly, for Texas wild-rice occupied optimal areas with adjacent non-native vegetation, the non-native plants will be removed and the Texas wild-rice stand monitored for expansion. Finally, in optimal areas for Texas wild-rice that are unoccupied by Texas wild-rice, non-native vegetation will removed and Texas wild-rice plants planted and monitored to assess the potential success of transplants. As described in Hardy (2011), the specific areas chosen for field trials will first consider only optimal habitat areas that remain suitable over the full range of discharges between the long-term average and lower flows. Initial field experiments associated with Texas wild-rice enhancement will be initiated early in the first phase of the AMP.

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[2] Figure 5-1 displays the areas where minimization and mitigation measures will be implemented by the City of San Marcos.

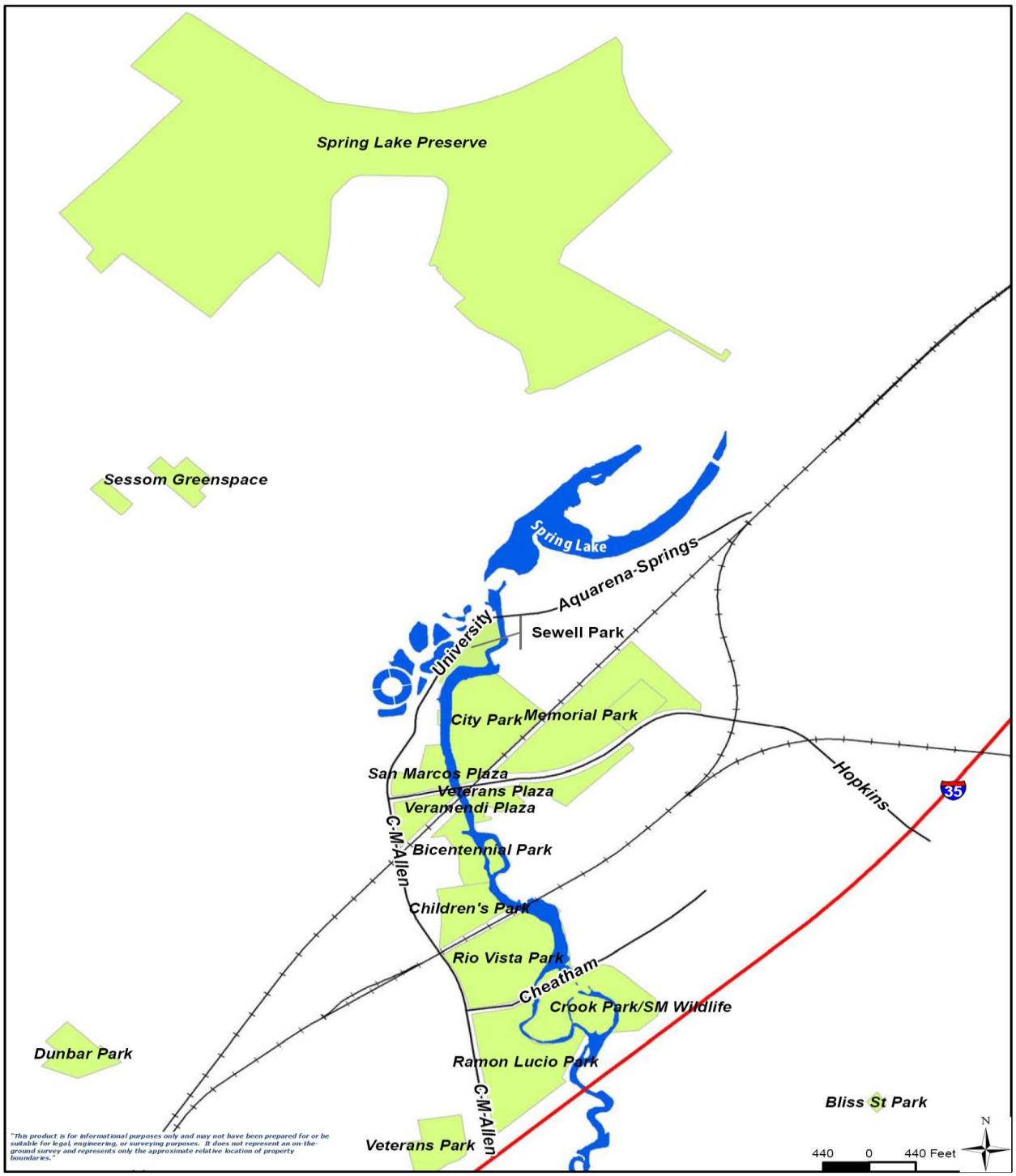


Figure 5-1. Areas where the City of San Marcos will implement Minimization and Mitigation Measures

5.3.2 Management of Recreation in Key Areas

Recreation plays an integral part in what makes the San Marcos River such an attractive resource. San Marcos is expected to double in population to over 94,000 people by 2030 with the Austin-San Antonio corridor increasing at the same rate. This is expected to lead to increased recreation, especially as the San Marcos River is reaching its capacity. The most prominent recreation feature of the river downstream of Sewell Park is the Noon Day Lion's Club "Toob" Rental which is housed in the City's recreation hall in City Park. Tubes are rented for a fee with proceeds gifted back to the community through the Lion's Club. There are several other small businesses which rent tubes but these are minor contributors to the overall number of rentals.

Parking around the river is limited to City Park and at Rio Vista Park. No new parking is planned.

A major concern regarding Texas wild-rice is recreational activity in high-quality habitat areas of the San Marcos River. Several types of recreation occur traditionally on the San Marcos River, including swimming, snorkeling, scuba, non-motorized boating, tubing, wading, fishing, and recreating with dogs. All these activities impact Covered Species and their habitat, some to a greater degree than others. While exact impacts are unknown, as discharge decreases, a greater percentage of plants are exposed to potential negative consequences. Damage to wild-rice stands by recreationists, particularly dogs, through direct contact was documented by Breslin (1997). Wild-rice is further impacted through fragmentation of other vegetation which then floats downstream eventually collecting on wild-rice stands. Fountain darters are potentially impacted through increased turbidity and accidental contact. While there are hardscaped access points throughout City parks, numerous desire trails exist and contribute to bank erosion where recreationists enter and exit at whim.

Recreation control is not meant to curtail recreation for large stretches of the river, but simply within key high quality habitat areas for Texas wild-rice to limit unnecessary impacts during low-flow conditions. To minimize the impacts from recreation, the City of San Marcos will establish permanent river access points. Permanent access will be located at Dog Beach, Lion's Club Tube Rental, Bicentennial Park, Rio Vista Park, the Wildlife Annex, and potentially other areas (as determined through the AMP). Areas between access points will be densely planted with vegetation that discourages streamside access.

Additionally, TPWD will pursue the creation of State Scientific Areas by limiting recreation in these specified areas during low flow conditions. With the exception of the eastern spillway immediately below Spring Lake dam, none of the protected areas would extend across the entire river channel in order to allow longitudinal connectivity for reasonable recreation throughout the river. The City of San Marcos will install kiosks showing access points, exclusion zones, and associated educational components at key locations.

5.3.2.1 Management of Public Recreational Use of San Marcos Springs and River Ecosystem

Public recreational use of the San Marcos Spring and River ecosystems include, but are not limited to swimming, wading, tubing, boating, canoeing, kayaking, golfing, scuba diving, snorkeling, and fishing. To minimize the impacts of incidental take resulting from recreation, the City of San Marcos will implement the Recreation Mitigation Measures adopted by the San Marcos City Council on February 1, 2011 (Resolution 2011-21) (Appendix N) Some of the measures adopted by the City Council are described elsewhere in this Section. Those not described elsewhere include:

1. Trespassing Enforcement. The public is accessing the river via private property without the permission of the property owners. Private property owners have requested City assistance through signage to enforce trespassing laws.
2. Buffer zones. Create an appropriate buffer zone by location to keep picnic tables, pop-up tents, shelters, and portable grills away from the river. Pushing these amenities farther away from the river will reduce litter getting into the river and decrease bank compaction/erosion.
3. Education of the river user and the community. Suggestions include:
   a. Signage. Post signage at the City Park tube rental facility, Rio Vista Falls and at proposed hard access points along the river. Signage will be simple, natural, and when possible the existing sign locations will be used (trying to avoid too many signs). Signs will have the same template and coloration so they are recognized up and down the river. Signs will cover the rules of the river and educate the public on the importance of the resource. All signs will be bilingual.
   b. Video Loop at City Park offering information about the river and safety rules while people are waiting for shuttle or tubes. Possibly also at Rio Vista Falls.
   c. Posted maps showing trail, access points, fishing access and other amenities. Include a map at Stokes Park to help inform about the San Marcos River/Blanco confluence.
   d. Recreation information at hotels/restaurants, bed and breakfast facilities, Chamber of Commerce, Visitor's Center, City of San Marcos internet site, etc. could include information on restrictions so river users are prepared prior to entering the river.
   e. Park Rangers. Include a section on river biology in the training of the park rangers so they can help disseminate the information.
   f. School Outreach. Implement an outreach program for San Marcos Consolidated Independent School District (SMCISD) so this information can be relayed to youth in San Marcos and indirectly to the parents.
   g. Overall Interpretation Plan. This would pull all the informational ideas together for conformity, continuity, and implementation.
   h. Lecture series at Texas State University.
   i. Stencils on rented tubes.
4. Reduce turbidity and sedimentation through the establishment of watershed management strategies. This will decrease erosion and subsequent sedimentation and filter runoff to enhance water quality. Remove silt and accumulated sediment from designated areas within the river to more closely match historical conditions.
5. The development of a partnership between the City and the University to enforce suggested measures and educate river users, and the use of officers dedicated to enforcing environmental regulations working both in and along the river.

Pursuant to Section 9.2 of the IA, the City of San Marcos will issue Certificates of Inclusion (COIs) to those commercial outfitting businesses (businesses and nonprofit entities that rent tubes, canoes, kayaks, or similar equipment to facilitate recreational activities on the San Marcos River) (Outfitters) that comply with the requirements of the COI program established in this section. Outfitters that opt into the COI program and

receive a COI will receive incidental take coverage during the term of the COI, which shall not extend beyond the Permit term. The City is not required to regulate the recreational activities of those Outfitters that choose not to participate through the COI process beyond the minimization and mitigation activities the City of San Marcos has committed to undertake in this HCP.

Outfitters can apply for a COI when the ITP is issued and every two years thereafter. For those Outfitters that voluntarily participate in order to obtain incidental take coverage for their recreational activities, the COI will contractually require those Outfitters to comply with and implement listed minimum standards set out below. The City of San Marcos will not reduce or eliminate any of the listed minimum standards during the 15-year ITP term but reserves the right to add additional standards in the future. COIs from the City will be issued based on a two-year term; so that every two years conditions of the COI may be increased if necessary to further promote mitigation activities, San Marcos policy or ordinance as related to protection of habitat or address new information established through the best science available as related to the species. The City will provide each year to the Program Manager for incorporation into the Annual Report a copy of all COIs issued during that year and information regarding the Outfitters compliance with the minimum standards.

COI Outfitter Standards

1) Provide litter bags to all customers

2) Sponsor at least one San Marcos River Cleanup annually. An Outfitter may sponsor an existing river cleanup or may organize its own. Services and resources provided as a sponsor must exceed $1,000 in direct payments or in-kind services.

3) Provide at point of purchase at each place of business of the Outfitter, educational signage about the Covered Species, their Critical Habitat, and efforts to protect the Covered Species (largely Applicant initiatives and CPM information). Design and artwork will be produced and supplied by the City. Signage must be at a minimum 3’x 6’.

4) Require each Outfitter, at each of its business locations, to support and assist the City’s enforcement of laws that relate to the Covered Species and their habitat. Specifically, this applies to, but is not limited to, litter prevention and habitat protection.

5) If one or more State Scientific Areas are established in the City, each Outfitter must provide at point of purchase at each place of business, a map and educational sign about the areas. Design and artwork will be produced and supplied by the City. Combined map and sign must be at a minimum 3’x 6’.

6) Assist the City with implementation of additional recreational management measures and controls at flows below 100 cfs to reduce habitat effects, water quality degradation, and other negative effects.

7) Stencil all Outfitter-rented recreational equipment with an anti-litter message. The City will design and supply the stencils to be used.

Each Outfitter must submit a report to the City by January 31st of each year, detailing its activities related to the COI for the previous year. If an Outfitter is in violation of any standard, the City of San Marcos may suspend or revoke the Outfitter's COI after providing notice, an opportunity to come fully into compliance, and a hearing.

5.3.3 Management of Aquatic Vegetation and Litter below Sewell Park

The San Marcos River is heavily used for recreation from Sewell Park to IH-35. To minimize the impacts of recreation on Texas wild-rice and other Covered Species, the City of San Marcos will perform activities to manage floating vegetation and litter to enhance habitats for Covered Species. Management activities will include removal of vegetation mats that form on top of the water surface as well as on top of Texas wild-rice plants, particularly during low flows, and removal of litter.

Vegetation mats interfere with Texas wild-rice by impeding flowering and reproduction, blocking sunlight, interfering with photosynthesis, and slowing current velocity (Power 1996). The City of San Marcos will push floating vegetation downstream of any Texas wild-rice stands. The City will monitor downstream Texas wild-rice stands to keep the stands clear of drifting vegetation.

Inorganic litter will be removed from the San Marcos River from City Park to IH-35 during the recreational season (May through September) and less often during offseason. Litter in or around Texas wild-rice stands will not be removed.

5.3.4 Prohibition of Hazardous Materials Transport Across the San Marcos River and Its Tributaries

Hazardous materials transported by truck across the watershed of the San Marcos River and its tributaries presents the possibility of accidental spills or releases into the environment. The limited geographic distribution of the endangered species at San Marcos Springs could cause the species to be highly impacted by such a spill.

The City of San Marcos will coordinate with the Texas Department of Transportation to designate hazardous materials routes which minimize the potential for spills entering the San Marcos River. This effort will include legislation, if necessary, and additional signage.

5.3.5 Reduction of Non-Native Species Introduction

Introducing non-native species into the San Marcos Springs and River results in predators and competitors for the listed species in the ecosystem. To mitigate the impacts of recreation and pumping from the aquifer during drought, the City of San Marcos will stop or substantially reduce the introduction of non-native species from aquarium dumps.

Dumping aquariums into the San Marcos River and its tributaries will be minimized through education, including signage and brochures, and offering alternative disposal to citizens wanting to get rid of unwanted aquatic pets. The City of San Marcos will partner with the River Systems Institute, Texas State University, and local citizen groups to help distribute educational materials. Partnerships with the school districts will also be considered. Educational materials will also be provided to local pet shops.

5.3.6 Sediment Removal below Sewell Park

The City of San Marcos will remove sediment from the river bottom at various locations from City Park to IH-35. These areas include but are not limited to reaches of the river in City Park,

Veramendi Park, Bicentennial Park, Rio Vista Park, and Ramon Lucio Park. Sediment has accumulated at these locations due to the installation of flood control dams, urbanization, and natural processes. These accumulations have altered the river's morphology and natural flow patterns. In addition, deposition of sediments on or around Texas wild-rice stands causes direct mortality by smothering or burying strands.

To minimize and mitigate the impacts of incidental take from recreation and pumping during low flow periods, the City of San Marcos will remove sediment from key areas of Texas wild-rice habitat below Sewell Park.

Hydrosuction will be used to remove accumulations of sediment. The silt will be vacuumed using a hose that has screen to prevent suctioning biota greater than 0.25 inch in diameter. The divers doing the hydrosuctioning will take the following measures to minimize loss/harm of biota in the area. Divers will fin the area to be suctioned to encourage the darters and other biota to move out of the area. Divers will be trained to recognize all stages of listed species from larval to adult. The nozzle of the vacuum will be kept down in the soil and not allowed to swing through the water column during the operation. In addition, placement of stakes around the area to be suctioned will keep divers away from stands of Texas wild-rice. An observer will be on the bank to monitor the effluent for presence of listed species and all other biota, as well as for the safety of the diver.

Sediment samples will be sent to TCEQ for contaminant testing per TCEQ requirements.

5.3.7 Designation of Permanent Access Points/Bank Stabilization

To minimize the impacts of recreation, permanent access points will be combined with bank stabilization at various locations. They will serve as entry and exit ways that could be used by canoeists, tubers, swimmers, etc., while stabilizing highly eroded banks. In these areas, the bank is eroding generally due to the clearing of riparian vegetation and specifically due to intense recreational use. The City of San Marcos will stabilize banks in eroded areas, to include City Park, Hopkins Street Underpass, Bicentennial Park, Rio Vista Park, Ramon Lucio Park, and Cheatham Street underpass.

Natural rock will be used to create a stone terrace for access and bank stabilization with the bank on either side restored with riparian vegetation. Native riparian vegetation will be planted in areas adjacent to the access/stabilization areas in order to discourage river users from entering the river in places other than the access point. Prior to each construction period, the area will be swept clean of darters and enclosures will be put into place to keep darters out of the construction area. No work outside this area will occur. If additional areas along the river require stabilization, the City of San Marcos will submit a scope of work for consideration through the AMP.

The City of San Marcos will establish permanent river access points. Permanent access will be located at dog beach, Lion's Club Tube Rental, Bicentennial Park, Rio Vista Park, the Wildlife Annex, and potentially other areas (as determined during the Adaptive Management Process). Areas between access points will be planted with vegetation that discourages streamside access (*e.g.*, prickly pear and acacia).

5.3.8 Control of Non-Native Plant Species

The City will partner with Texas State University to implement an on-going non-native plant replacement program for the recreational corridor from Spring Lake to city limits. Non-native species of aquatic, littoral, and riparian plants will be replaced with native species to enhance

Covered Species habitat. The divers that will be conducting sediment control will first remove non-native aquatic plant species from the area to be worked that day. Removal will initially focus on hydrilla (*Hydrilla verticillata*) as this species causes sediment deposition and adds turbidity to the water column when disturbed. The non-native aquatic plants will be shaken and bagged for removal from the system in the same manner described in Section 5.4.3.1. Areas will be "weeded" until the natives become established at the site.

The riparian zone will be restored to at least 15 meters in width where possible. Areas will be planted at a ratio of three hard mast trees to one soft mast tree, with 20 percent of the vegetation consisting of fruit-bearing shrubs. Vegetation such as big bluestem, switchgrass, Indian grass, live oak, Texas red oak, bur oak, pecan, bald cypress, American beautyberry, and buttonbush will be used. Fencing may be required for the first two years to allow for the establishment of the species.

5.3.9 Control of Harmful Non-Native and Predator Species

Studies have shown that many fishes (especially small fish) have very similar food habitats (Hubbs *et al.* 1978). If non-native species are added to the aquatic ecosystems, greater competition or overlap among species is possible as these non-native species may be able to acquire resources with greater efficiency than native species (USFWS 1984). Suckermouth catfishes (*Loricariidae*) are a non-native fish species that has become established in the waters of Texas including the San Marcos River. (Howells 2005). Suckermouth catfishes prefer to feed on periphyton and algae. (Hoover *et al*. 2004). The fountain darter lays eggs on algae and loss of spawning habitat and possibly egg predation are potential threats from suckermouth catfish (SSC 2009). There is some concern that excessive numbers of suckermouth catfishes could cause direct (potential displacement) and indirect effects (disruption of food supply) to the fountain darter. (SSC 2009). Suckermouth catfishes also burrow into the river banks, destabilizing them and causing the introduction of additional sediment load into the habitats.

Tilapia is another non-native fish species that can impact fountain darter habitat. Tilapia destroys vegetation by making bare ground nests. During times of low flow and drought this could further reduce already limited habitat for the fountain darter. Tilapia is a tropical species that will congregate in winter near spring openings and other warm water sources. When Tilapia congregate this creates the opportunity to use seines, gill nets, cast nets, or other methods to remove large quantities with minimal impact to the habitat. Artificial heating could be one method used to congregate fish in areas away from springs and endangered species to minimize the impacts from collection efforts.

A non-native gastropod (giant ramshorn snail [*Marisa cornuarietis*]) also poses a threat to the San Marcos Springs ecosystem. The giant ramshorn snail, a species in the aquarium trade, was first discovered in Spring Lake in 1984 (McKinney and Sharp 1995). This snail grazes on aquatic plants and in the 1990s played a major role in reducing plant biomass in Spring Lake. This snail prefers clear streams and pools with temperatures of at least 66°F (19°C). When exposed to lower temperatures, the snails withdraw into their shells and only survive for short periods. The warmest temperature that the giant ramshorn snail can withstand is 102°F (39°C). Although the population has diminished since the mid-1990s, the potential for future alteration of plant communities in these two ecosystems remains and could affect endangered species (McKinney and Sharp 1995; BIO-WEST 2007c). The strong preference of fountain darters for aquatic vegetation highlights the concern posed by the grazing activities of the giant ramshorn snail (BIO-WEST 2004a).

To mitigate the impacts of incidental take by pumping and recreational activities, the City of San Marcos, in partnership with Texas State University, will implement non-native and predator

species control for the San Marcos River on a periodic basis with expanded effort of control, if needed, at low flows. The species include suckermouth catfish, tilapia, and *Melanoides* and *Marisa* snails.

The *Pterygoplichthys disjunctivus vermiculated* (sailfin catfish) adults are concentrated in Spring Lake and *Hypostomus plecostomus* (suckermouth catfish) are found downstream of Spring Lake. Currently, the most effective method of removal for both species is to hunt with a gig or similar multi-pronged spear. Other technologies, such as the heat box, fish-specific disease, and daughter-less technology require further research for their applicability to these species in the San Marcos River. Additionally, incentives, such as bounty for capture, could be established to encourage fishing for catfish.

With respect to tilapia, the adults are concentrated in the slough arm of Spring Lake. The use of gill nets during their reproductive season (Jan – May) provides an effective method of removal. Using a large mesh net along with frequent checks will prevent capture of fountain darters and other desirable species. Additionally, incentives, such as bounty for capture, could be established to encourage fishing for tilapia.

Melanoides snails and the gill parasite (*Centrocestus formosanus*) have been present in the San Marcos system, but at low levels. Controls will not be implemented initially. However, *Melanoides* snails and the gill parasite (*Centrocestus formosanus*) will be monitored and any appropriate measures implemented through the Adaptive Management process. *Melanoides tuberculata* is located throughout the upper reach of the San Marcos River. If necessary, effective removal can be accomplished by determining the locations of highest snail density and use dip nets to remove the snails weekly. (*See* Section 6.36)

Marisa cornuarietus is found sporadically in the upper reach of the San Marcos River. This snail vertically migrates at night and is easily spotted with a flashlight. The species will be controlled by diving several hours after sunset to hand-pick the snails from the submergent vegetation.

All personnel implementing any portion of the HCP for the City of San Marcos will undergo an orientation at the NFHTC to ensure awareness of the listed species and safe procedures while working in and along the San Marcos River.

5.4 Texas State University

5.4.1 Texas Wild-Rice Enhancement and Restoration

Texas State University will partner with the City of San Marcos to undertake a program of Texas wild-rice enhancement and restoration in Spring Lake and the San Marcos River within the University's campus boundaries as described in Section 5.3.1 above.

5.4.2 Management of Recreation in Key Areas

Texas State University will partner with the City of San Marcos to control recreation in Spring Lake and the San Marcos River within Texas State University campus boundaries.

To minimize the impacts from recreation, Texas State University will establish permanent access points on the east and west banks of the San Marcos River between Spring Lake dam and the Aquarena Drive bridge, and other areas as determined during the AMP. These areas will serve as entry and exit ways that could be used by canoeists, tubers, swimmers, etc. Areas between access points will be planted with vegetation that discourages streamside access (*e.g.*, prickly pear and acacia).

Additionally, TPWD will pursue creation of State Scientific Areas in the San Marcos Springs ecosystem and River that would limit recreation in these areas during low flow conditions. (*See*

Section 5.6.1). With the exception of the eastern spillway immediately below Spring Lake Dam, none of the protected areas would extend across the entire river channel which would allow longitudinal connectivity throughout the river. Kiosks showing access points, exclusion zones, and associated educational components will be installed at key locations.

5.4.3 Management of Vegetation

5.4.3.1 Management of Submerged and Floating Aquatic Vegetation in Spring Lake

To mitigate the impacts of incidental take on Covered Species from recreation, Texas State University will manage aquatic vegetation in Spring Lake through use of its harvester boat and through hand cutting of vegetation by divers authorized to dive in Spring Lake.

Each week about five springs will be cut, thus returning to cut the same springs every two to three weeks. During summer algal blooms, the springs will be managed more frequently (up to four springs per day), but mostly to remove algae. Texas State employees and supervised volunteers will fin the area around the springs to remove accumulated sediment, and then clear a 1.5-meter radius around each spring opening in Spring Lake with a scythe. Over the next 1.5-meter radius around the spring opening, they will shear vegetation to a height of 30 cm, and then to one meter over the following three meter radius. Plant material will not be collected, but carried away by the current. Cumulatively, about six meters of vegetation around each spring opening will be modified. Mosses will not be cut. The volume of plant material to be removed will vary by the amount of time between cuttings, and season.

The harvester boat will remove a range of 15-to-20 boatloads of plant material a month from Spring Lake. The harvester will clear the top meter of the water column, cutting vegetation from sections one, two, and three once a week. (*See* Figure 5.2). The harvested vegetation will be visually checked by driver for fauna caught in the vegetation. If the driver observes fauna, he/she will stop work and put the animal(s) back into Spring Lake if appropriate. Texas State employees and supervised volunteers are trained to recognize the Covered Species through the Diving for Science program (Section 5.4.7.1), and avoid contact with them.

Vegetation mats will be removed from zones four and five on an as-needed basis. (Figure 5-2). The total area cut will equal about nine surface acres.

One permanent full-time person (Spring Lake Area Supervisor) is responsible for running the harvester and managing the removal of vegetation around the spring openings. The Spring Lake Area Supervisor also schedules cleanup of nuisance floating species such as water hyacinth and water lettuce from Spring Lake. The floating plants will be collected by hand and shaken prior to removal from the river to dislodge any aquatic species caught in the plant. The plants will be deposited into dump trucks and taken to the River System Institute compost area.

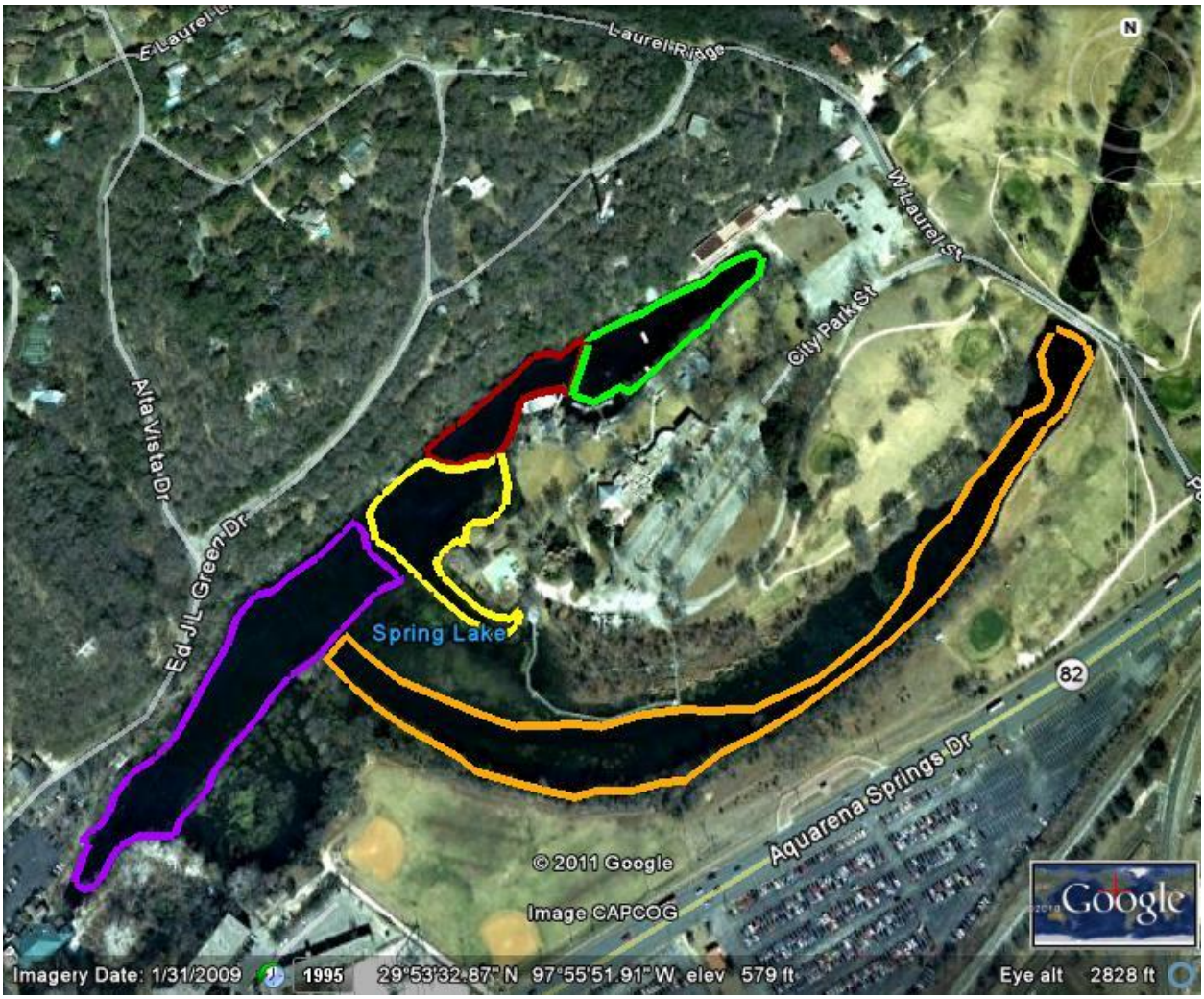
5.4.3.2 Management of Aquatic Vegetation from Sewell Park to City Park

To mitigate the impacts of incidental take from recreational activities, Texas State University will push floating vegetation downstream of any Texas wild-rice stands. Inorganic litter will be picked up weekly from the San Marcos River from Sewell Park to City Park during the recreational season (Memorial Day to Labor Day) and monthly during offseason.

Texas State University will monitor downstream Texas wild-rice stands to keep the stands clear of drifting vegetation. Divers will not pick up litter in or around Texas wild-rice stands.

University employees or others will be trained by the TPWD to recognize Texas wild-rice and to protect the plant stand while removing the accumulated floating plant material. On Texas wild-rice stands, Texas State University employees will lift (not push) the floating material from the top of the Texas wild-rice stands and allow it to float downstream. Downstream accumulations of plant material will be removed by the City of San Marcos to avoid impacts to Texas wild-rice further downstream.

Figure 5.2: Aquatic Harvester Zones



- Zone 1_Headwater Springs; Crater Bottom, Salt and Pepper 1&2, Weissmuller
- Zone 2_ Boat Path; Diversion, Cream of Wheat, Ossified Forest
- Zone 3_Boat Path; River Bed, Catfish Hotel, Deep Hole, Harvester Channel
- Zone 4_Boat Path; Archeology Site, Kettleman's, University Seminar Boat Path and Dock

- Zone 5_ Sink Creek/slough channel

5.4.4 Sediment Removal in Spring Lake and from Spring Lake Dam to City Park

Monitoring of the San Marcos River since 1990 reveals that sediment production has increased from 160 m^3/yr to 920 m^3/yr due to a combination of upstream flood control dams and sediment inflow increases (Earl and Wood 2002). Deposition of sediments on or around Texas wild-rice stands causes direct mortality by smothering or burying stands. Texas State University will mitigate the impacts of incidental take from diving activities, research activities, recreation and pumping during low flow periods by removing sediment from key areas of Texas wild-rice habitat in Spring Lake and from Spring Lake Dam to City Park.

Hydrosuction will be used to remove accumulations of sediment. The silt will be vacuumed using a hose that has an end piece covered by a 0.25-inch mesh screen to prevent suctioning biota greater than 0.25 inch in diameter. The divers doing the hydrosuctioning will take the following measures to minimize loss/harm of biota in the area. Vegetation will be finned before turning on the pump. Finning will encourage the darters and other biota to move out of the area. Divers will be trained to recognize all stages of listed species from larval to adult. The nozzle of the vacuum will be kept down in the soil and not allowed to swing through the water column during the operation. In addition, placement of stakes around the area to be suctioned will keep divers away from stands of Texas wild-rice. An observer will be on the bank to monitor the effluent for presence of listed species and all other biota, as well as for the safety of the diver.

Sediment samples will be sent to TCEQ for contaminant testing per TCEQ requirements.

5.4.5 Diversion of Surface Water

Under TCEQ Certificates 18-3865 and 18-3866, Texas State University's total diversion rate from the headwaters of the San Marcos River for consumptive use is limited to 8.1 cfs. (*See* Section 2.5.5). The total diversion rate from Spring Lake is limited to 4.88 cfs; the total diversion rate from the San Marcos River at Sewell Park is limited to 3.22 cfs. (*See* Section 2.5.5.1 and 2.5.5.2 respectively). To minimize the impacts of these diversions, when flow at the USGS gauge at the University Bridge reaches 80 cfs, Texas State University will reduce the total rate of surface water diversion by 2 cfs, *i.e.*, to a total of approximately 6.1 cfs. This reduction in pumping will occur at the pump just below Spring Lake Dam in order to maximize the benefits to salamanders, Texas wild-rice, and other aquatic resources in the San Marcos River below Spring Lake Dam. The University will reduce the total rate of surface water diversion by an additional 2 cfs when the USGS gauge reaches 60 cfs. The additional 2 cfs reduction will be made from the pumps located in the slough arm of Spring Lake, and, therefore, maximize the benefits to the aquatic resources within the main stem San Marcos River below Spring Lake Dam. When the USGS gauge reaches 49 cfs, Texas State University will reduce the total diversion rate to 1 cfs. This further reduction will be made by restricting the pumps located in the Sewell Park reach. The diversion of water will be suspended when the springflow reaches 45 cfs.

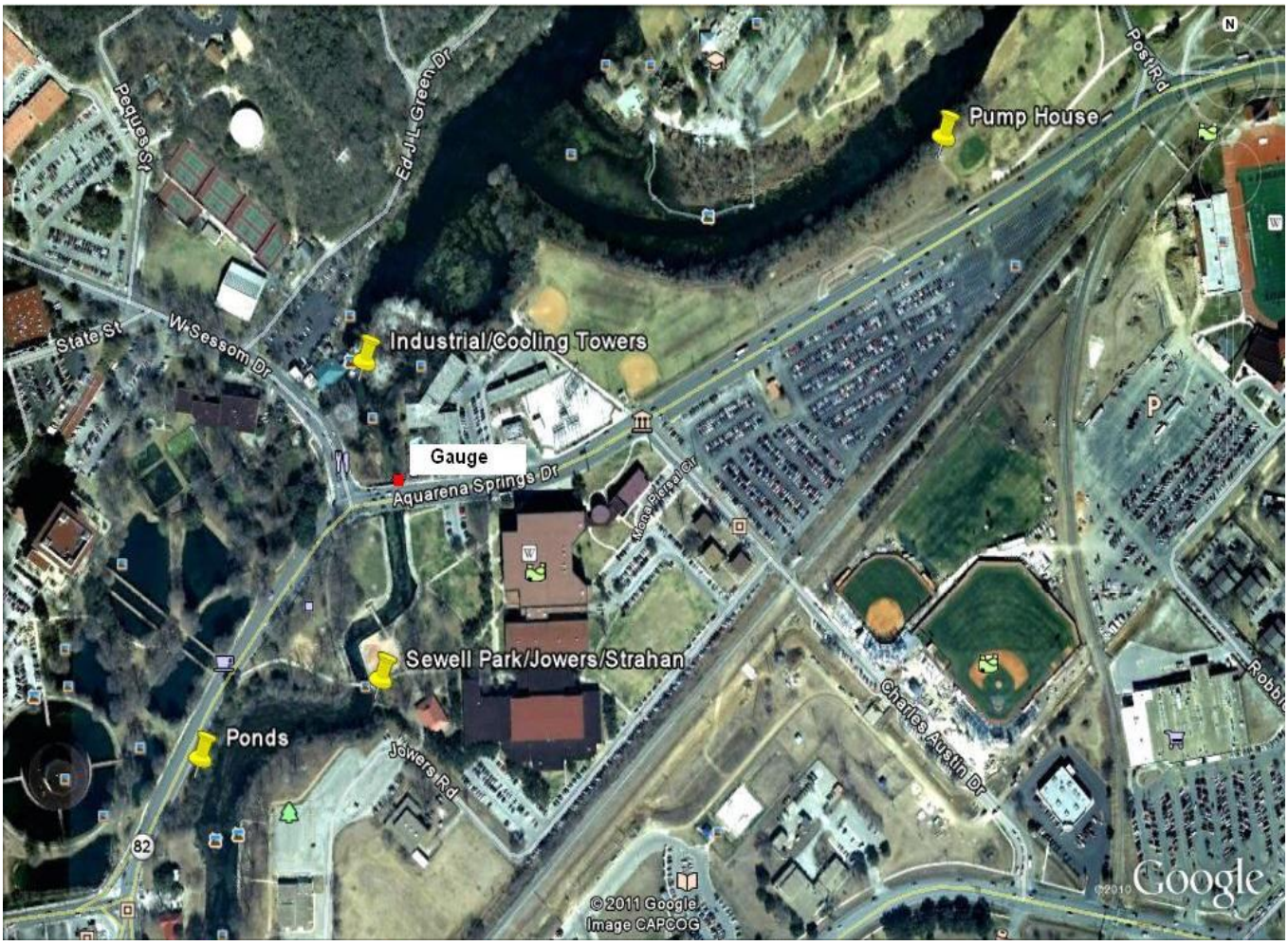


Figure 5-3. Texas State University Surface Water Diversions. The diversions are identified with stick pins. The diversions at the pump house (slough arm of Spring Lake) and industrial cooling towers are permitted under TCEQ Certificate 18-3865. The 513 ac-ft/yr municipal water right has not been exercised, and no diversion for this right currently exists. The diversions at Sewell Park and the "ponds" are permitted under TCEQ Certificate 18-3866. (*See* Sections 2.5.5.1 and 2.5.5.2 respectively).

The reductions in Texas State University's total diversion rate for consumptive use is summarized in Table 5-4 below:

Streamflow (cfs)	Spring Lake Diversions (cfs) Cert. No. 18-3865	San Marcos River Diversions (cfs) Cert. No. 18-3866	Total Diversion Rate (cfs)
>80	4.9	3.2	8.1
80 – 60	2.9	3.2	6.1
60 – 49	0.9	3.2	4.1
49-45	1.0	0	1.0
<45	0	0	0

Table 5-4. Reductions in Surface Water Diversion Rates during Low Flow Conditions under Texas State University's TCEQ Certificates 18-3865 and 18-3866.

Texas State University uses a 0.25-inch mesh screen to cover the intake for surface water diversions. These screens are routinely inspected and cleaned. Fountain darters have not been observed when the screen is cleaned; however, there is a possibility for capture of adults against the screen, but not pulled into the pipeline.

To avoid or minimize the impacts of the surface water diversions, the University will routinely monitor the screens to determine if any entrainment occurs and will make any necessary modifications to the screens to minimize any incident take from the operation of the diversions.

5.4.6 Sessom Creek Sand Bar Removal

For decades, a sand and gravel bar has been building with each major rain event at the confluence of Sessom Creek and the San Marcos River. The bar is about two-thirds meter deep, 7 meters wide, and 21 meters long (98.5 m^3). Over time it has widened, deepened, and constricted the river channel; furthermore, the continued expansion has covered a stand of Texas wild-rice. The bar has become vegetated with both littoral and terrestrial plants, and is used heavily by recreationists as it provides a shallow swimming area.

To minimize and mitigate the impacts of incidental take from recreation, Texas State University and the City of San Marcos will conduct a study of sediment removal options to determine the best procedure to remove this sand and gravel bar that minimizes impacts to listed species. Texas State University will submit the study for review though the AMP and implement the actions coming out of that process.

A separate sediment retention pond has been constructed to minimize additional deposition to this area and will be maintained to maintain an effective level of performance.

5.4.7 Diving Classes in Spring Lake

5.4.7.1 The Diving for Science Program

To minimize the impacts of the Diving for Science Program that trains and authorizes individuals to dive in Spring Lake, individuals authorized through this program must demonstrate a knowledge of listed species found in the lake and their habitat, laws and regulations impacting these species, good buoyancy control, the ability to avoid contact with listed species, the ability to avoid disturbing critical habitat, and the ability to stay off the bottom of the lake. The program is taught as a two-day class with a maximum class size of 20 and is taught in the Dive Training

Area. The program averages 350 trainees per year. Upon completion of this class, divers are allowed anywhere in Spring Lake to perform specific volunteer tasks such as finning spring areas covered with algae, and picking up litter. Projects are structured to minimize contact with listed species in an effort to ensure protection of listed species and their habitat. The Diving Supervisor coordinates and supervises all volunteer diving. No more than sixteen volunteer divers will be allowed in the lake per day, with no more than eight at one time.

Any individual diving outside of the Dive Training Area has to have completed the Diving for Science Program.

5.4.2 Texas State University Continuing Education

Texas State University Continuing Education classes for check-out dives will be conducted in the Dive Training Area. To minimize the impacts of these classes, class size will be limited to 12 students and no more than three classes will be conducted per day.

5.4.7.3 Texas State SCUBA Classes

Texas State SCUBA classes will be conducted in the Dive Training Area. To minimize the impacts of these classes, class size will be limited to 12 students and no more than three classes will be conducted per day.

5.4.8 Research Programs in Spring Lake

To minimize the impacts of its research programs, all proposals to conduct research in Spring Lake will be reviewed by the River Systems Institute to ensure there is no impact on Covered Species or their habitat. If incidental take cannot be avoided, it will be minimized by educating the researchers as to the area where the listed species are located and by requiring measures to minimize any potential impacts. All diving in support of a research study will be provided by individuals who have completed the Diving for Science program. Nothing herein is intended to obviate the need for individual research projects to obtain a permit under 16 U.S.C. § 1539(a)(1).

5.4.9 Management of Golf Course and Grounds

To minimize any impacts of the use of fertilizers and pesticides to maintain the golf course and grounds, Texas State University will develop a golf course management plan that will document current practices and include an Integrated Pest Management Plan (IPMP). The golf course management plan and IPMP will incorporate environmentally sensitive techniques to minimize chemical application, improve water quality, and reduce negative effects to the ecosystem. Any chemicals used will be applied by a licensed applicator in a manner consistent with the label instructions. Expanded water quality sampling targeted at Golf Course operations will be conducted as described in Section of 5.7.2 of the HCP. Changes in golf course management will be addressed through the AMP as set out in Article 7 of the FMA.

5.4.10 Boating in Spring Lake and Sewell Park

To minimize the impacts of boating on the Covered Species' habitat in Spring Lake, boats in Spring Lake will be confined to areas that are mowed by the harvester, thereby not impacting vegetation and specifically avoiding Texas wild-rice stands. Individuals will enter and exit boats at specified access points to avoid impacting the flora and fauna along the bank. All boats launched into Spring Lake will undergo a USFWS-approved process for cleaning.

Further, canoeing/kayaking classes in the lake will be limited to no more than 2 classes per day and each class will be in the water no more than 1 hour. Classes will have a maximum of 20 students in 10 canoes. All classes will be supervised.

To minimize the impacts of boating on the Covered Species' habitat in Sewell Park, canoeing/kayaking classes in Sewell Park will be confined to the region between Sewell Park and Rio Vista dam. Students will enter/exit canoes/kayaks at specified access points to avoid impacting the flora and fauna along the bank. Classes will be no longer than two hours and up to three classes will be held per day. Classes will have a maximum of 20 students in 10 canoes. All classes will be supervised.

5.4.11 Reduction of Non-Native Species Introduction

Texas State University will limit introductions of non-native species by aquarium dumps. Dumping aquariums into the San Marcos River and its tributaries will be minimized through education, including signage and brochures, and offering alternative disposal to citizens wanting to get rid of unwanted aquatic pets. Texas State University will partner with the City of San Marcos and local citizen groups to help distribute educational materials. Partnerships with the school districts will also be considered. Educational materials will also be provided to local pet shops.

5.4.12 Control of Non-Native Plant Species

Texas State University will partner with the City of San Marcos to implement a non-native plant replacement program for Spring Lake and the San Marcos River within the University's campus boundaries as described in Section 5.3.8 above.

5.4.13 Control of Harmful Non-Native and Predator Species

Texas State University will partner with the City of San Marcos to undertake a program of non-native and predator species control for Spring Lake and the San Marcos River within the University's campus boundaries as described in Section 5.3.9 above.

5.5 San Antonio Water System

5.5.1 Use of the SAWS ASR for Springflow Protection

The capacity and capabilities of the SAWS ASR can be used to meet SAWS ratepayer expectations and to play a significant role in maintaining a protective level of springflow in Comal and San Marcos Springs including during a repeat of a drought of record-like event. As discussed in section 5.8, this measure to minimize the impacts of incidental take from extended drought is the third element in the package of springflow protection measures (following the VISPO and municipal conservation layers). It utilizes the SAWS ASR facility for storage and delivery of Aquifer water leased by the EAA. When triggers are reached, as described below, SAWS will use water stored in the ASR to serve as a baseload supply in its service area near to the springs. As described below, an amount equivalent to the water recovered from the ASR will be used to offset SAWS's Edwards demand.

EAA will acquire through lease and option 50,000 ac-ft/yr of EAA-issued Final Initial Regular Permits. The EAA may use SAWS as its agent for this purpose. The leases and options will be acquired by EAA to fill, idle, and maintain a portion of the capacity of the SAWS ASR Project for subsequent use to protect springflows during identified drought-of-record conditions as described below.

The lease program is comprised of three components. The first one-third, approximating 16,667 acre-feet of permits, will be leased for immediate storage in the ASR. The remaining pumping rights will be placed under a lease option. One-third (16,667 ac/ft) of the total will be options exercised in the year after the 10-year moving annual average of Edwards recharge falls below 572,000 ac-ft/yr, as determined by the EAA (*see* Section 6.2.3), and is likely to continue to decrease. The last one-third will be options exercised when the 10-year moving recharge average is less than 472,000 ac-ft/yr, as determined by the EAA (*see* Section 6.2.3). When the leases are in place, this water will either be pumped to fill the SAWS ASR or not pumped for any reason. When the ASR is in recovery mode (*i.e.*, when water is being returned from the ASR), the leased water will not be pumped. The water to fill SAWS ASR is generally provided by SAWS from their existing Edwards supplies and the first one-third of the regional leases water (16,667 ac-ft) which will be maintained at all times throughout the HCP duration. SAWS will store its own unused Edwards permits in addition to the HCP leases and lease-options in the ASR when possible. SAWS, with the assistance of the Regional Advisory Group will describe in the Annual Report the storage and recovery activities.

Trigger levels for implementation of ASR management in accordance with the HCP will be 630 ft-MSL at the J-17 index well during an identified repeat of drought conditions similar to the drought of record as indicated by the ten-year rolling average of Edwards recharge of 500,000 ac-ft, as determined by the EAA. When triggered, the ASR or other supplies capable of utilizing shared infrastructure will be activated to deliver up to 60 million gallons per day to SAWS distribution system during a repeat of drought of record-like conditions. When the monthly average groundwater levels at J-17 are below 630 ft-MSL and the ten-year rolling average of Aquifer recharge is 500,000 ac-ft or less, pumping of selected wells on the northeast side of SAWS water distribution system will be reduced in an amount that on a monthly basis equals the amount of water returned from the ASR only to the extent of the Aquifer water provided by the EAA for storage in the ASR. SAWS will use up to 100 percent of the conveyance capacity of existing SAWS ASR facilities to off-set SAWS' Edwards Aquifer demand.

SAWS will attempt, to the extent practicable, to mimic the pattern of delivery developed by HDR Engineering (HDR 2011). That pattern of delivery, however, was intended to represent how the water in the ASR would have been managed in the drought of record in the 1950s. Future droughts of similar duration and magnitude undoubted will differ in the timing and pattern of recharge in a given year. Thus, the actual pattern of delivery of water from the ASR may differ from that HDR used in its modeling simulations depending on the actual course of the drought. (*See* HDR 2011). Decisions as to the actual pattern of delivery will be determined by SAWS in conjunction with the Regional Advisory Group described below.

The use of the SAWS ASR is predicated on an assumption informed by HDR Engineers' groundwater modeling that the SAWS ASR will be utilized to deliver approximately 126,000 ac-ft of water to SAWS distribution system during a decadal drought similar to the drought of record. It is further predicated on the assumption from HDR 2011 that the maximum amount of HCP water that will be delivered in a given year is 46,300 ac-ft.

The management of the ASR to protect spring flow necessarily involves some judgment and flexibility. SAWS will make the day-to-day decisions necessary to fulfill the ASR commitment. A 12-person Regional Advisory Group consisting of four representatives of SAWS, the Program Manager, and one representative each from EAA, EAA permit holder for irrigation purposes, small municipal pumpers, the Spring cities, environmental (including Texas Parks and Wildlife), industrial pumpers, and downstream interests will provide advice to SAWS regarding the implementation of the program. The Advisory Group will meet as needed but no less than quarterly. SAWS will organize and facilitate the Advisory Group.

Future droughts may not mimic the historic drought of record. SAWS, in consultation with the Regional Advisory Committee, will address future drought situations by reviewing the rolling-average recharge triggers which may result in potentially accelerating the activation of the lease-options, based on relevant indicators.

5.5.2 Phase II Expanded Use of the SAWS ASR and Water Resources Integration Program Pipeline

Based on the best available science currently available, the management objectives required to foster achievement of the biological goals include maintain daily average flows of no lower than 30 cfs (45 cfs monthly average) for no longer than a period of 6 months at a time at Comal Springs and daily average flows of no lower than 45 cfs (52 cfs monthly average) for no longer than 6 months at a time at San Marcos Springs. (*See* Section 4.2). During Phase I, additional studies on the effects of low flows on the species and their habitat will be conducted and the MODFLOW model used to simulate the effects of the Phase I Package will be improved and a new model developed. (*See* Section 6.4). Until the AMP decision-making process is complete, it is not known whether additional flow protection measures are required. Similarly, the duration and amount of additional flows that might be needed are equally unknown. To address the need now to demonstrate the ability and commitment to achieve the existing long-term biological objectives while recognizing the uncertainty associated with those objectives, the Applicants commit to implement a “presumptive” action that, when combined with the Phase I activities, is adequate to achieve the current biological objectives if such an action is needed. (*See* FMA § 7.14).

The presumptive action for Phase II of the HCP involves the use of the SAWS ASR with a planned construction of the WRIP Pipeline that is currently in the design stages and is scheduled for completion by 2020. The WRIP consists of approximately 45 miles of water transmission pipeline and a pump station that will convey water from the SAWS ASR, Carrizo, and Brackish Desalination programs located at the Twin Oaks Facility property in south Bexar County to new and existing facilities in western and northwestern Bexar County. The pipeline generally follows a north-northwest alignment from south Bexar County, through the far west portions of Bexar County to SAWS' Anderson Pump Station near the intersection of Loop 1604 and Highway 151. The WRIP will link the existing facilities and new water supplies located at the ASR site in southern Bexar County with the southwestern and western portions of San Antonio.

SAWS’ ability to expand the use of the ASR as a presumptive Phase II measure, if required, assumes that: (1) no additional water beyond those required for the Phase I use of the ASR will need to be stored; (2) the total amount of water to be returned from the ASR over the term of the permit will not exceed 126,000 ac-ft during the drought and 46,300 ac-ft in the worst year; and (3) no more than 40 percent of the capacity of the WRIP distribution system will be utilized at any time for HCP purposes.

To the extent that such a project cannot actually be designed and implemented to achieve the goals within the above-described assumptions, additional springflow protection will be obtained through additional CPM pumping cuts in Stage V or other measures that provide an equivalent measure of springflow protection to the Covered Species. The current science suggests that Stage V pumping cuts of 47 percent would be required along with the presumptive measure. (*See* Section 5.8.2).

5.6 Texas Parks and Wildlife Department

5.6.1 State Scientific Areas

A major concern regarding Texas wild-rice is recreational activity in high-quality habitat areas of the San Marcos River. Several types of recreation occur traditionally on the San Marcos River, including swimming, snorkeling, scuba, boating, tubing, wading, fishing, and recreating with dogs. All these activities can impact Covered Species and their habitat, some to a greater degree than others and while exact impacts are unknown, as discharge decreases, a greater percentage of plants are exposed to potential negative consequences.

Texas Parks and Wildlife Department (TPWD) has the authority to establish state "scientific areas" for the purposes of education, scientific research, and preservation of flora and fauna of scientific or educational value. (TPW Code § 81.501). To minimize the impacts of recreation, TPWD has created a two mile segment of the public waters of the San Marcos River as a State Scientific Area in the San Marcos Springs ecosystem. (30 TAC 57.910). This scientific area is designed to protect Texas wild-rice by restricting recreation in these areas during flow conditions below 120 cfs. The rule makes it unlawful for any person (1) to move , deface alter, or destroy any sign, bouy, boom or other such marking delineating the boundaries of the area; (2) uproot Texas wild-rice within the area; and (3) enter an area that is marked. The regulations are intended to preserve at least 1,000 m^2 of Texas wild-rice.

With the exception of the eastern spillway immediately below Spring Lake Dam, none of the protected areas extend across the entire river channel; thus, allowing longitudinal connectivity for recreation and access to be maintained downstream throughout the river. The City of San Marcos and Texas State University will install kiosks at key locations showing access points, exclusion zones, and associated educational components.

Interlocal agreements between the City of San Marcos and TPWD and Texas State University and TPWD will be used to allow for local in-water enforcement of the protected zones.

In order to protect existing and restored fountain darter habitat, TPWD will pursue creation of state scientific areas in the Comal Springs ecosystem. (*See* Section 5.2.2.2). The goal of the regulations will be to minimize impacts to habitat from recreation activities. An interlocal agreement between the City of New Braunfels and TPWD will be used to allow for local in-water enforcement of the protected zones.

5.7 Measures that Specifically Contribute to Recovery

All of the measures described above will not only minimize and mitigate the impacts of any incidental take, but will also contribute to the likelihood of the survival and recovery of the Covered Species. The EARIP, however, was established as a "recovery implementation program." As such, the Applicants committed to implement measures that are specifically intended to contribute to the recovery of the Covered Species. The following sets out those specific measures.

5.7.1 Native Riparian Habitat Restoration

The City of San Marcos will undertake a program to increase the area of the riparian zone on public lands from City Park to IH-35 using native vegetation. As plans take shape for the reestablishment of the riparian zone, private landowners will be asked to participate in the plan.

Reimbursement for the price of native plants will be provided to private landowners. Criteria to qualify for reimbursement will be established along with a list of preferred natives to replant.

Texas State University will undertake a similar program to restore the riparian zone with native vegetation in upper Sewell Park.

The City of New Braunfels will undertake a program to increase the area of the riparian zone along the Old Channel, the golf course and in the vicinity of Clemens Dam. As plans take shape for the reestablishment of the riparian zone, private landowners will be asked to participate in the plan. Reimbursement for the price of native plants will be provided to private landowners. Criteria to qualify for reimbursement will be established along with a list of preferred natives to replant.

5.7.2 Expanded Water Quality Monitoring

Early detection of water quality impairments that may negatively impact the listed species will contribute to protecting the Covered Species by allowing for investigation and adoption of any necessary measures through the AMP to address the source(s) of the concerning indicators. Such measures may include stormwater detention and water quality basins, rain gardens, storm sewer filters, or constructed wetland filters as appropriate to the indicator of concern and physical setting of the respective system. In the event that certain constituents of concern are detected at levels indicating the potential for adverse effects, Best Management Practices (BMPs) will be evaluated to reduce and/or eliminate the constituent of concern if potential sources can be identified. Examples of constituents that could lead to BMP implementation and/or modifications include, but are not limited to, polycyclic aromatic hydrocarbons (PAHs), pesticides, ash, herbicides, turbidity, fertilizers, and bacteria from human and animal/pet waste.

The EAA and its predecessor agency have conducted a program of water quality data collection since 1968. (EAA 2010b). The EAA maintains a network of groundwater and surface water monitoring sites, including sites in the Comal and San Marcos springs. Each year EAA monitors the quality of water in the Aquifer by sampling approximately 80 wells, eight surface water sites and major spring groups across the region. Under this mitigation measure, EAA will expand its monitoring program to examine stormwater runoff, including additional surface and groundwater monitoring near the Comal and San Marcos springs. Water samples are routinely analyzed in the field for selected water quality parameters (*i.e.*, temperature, pH, conductivity, and alkalinity) and in the laboratory for common major ions, metals, total dissolved solids, hardness, bacteria and nutrients. Many of the samples are also analyzed for semivolatile organic compounds and volatile organic compounds as well as pesticides, herbicides, and polychlorinated biphenyls.

EAA will manage and oversee the expanded monitoring of water quality around Landa Lake and the Comal River, and Spring Lake and the San Marcos River to include stormwater sampling and additional groundwater and surface water sampling as necessary. Particular focus will be placed on point and non-point sources. Areas that are to be targeted include, but are not limited to, large areas of impervious cover, golf courses, swimming pools, and industrial runoff areas. EAA will consult with the cities of New Braunfels and San Marcos regarding sampling locations within their respective jurisdictions.

More thorough and frequent water quality monitoring (surface, storm water, and groundwater) that takes into consideration the location, time of day, day of week, time of year, and all chemical water quality parameters believed to be significant will be established through the AMP. Sampling criteria will be developed based on need and relevance to each spring and River system's differing characteristics and setting.

5.7.3 Septic System Registration and Permitting Program

The City of San Marcos will undertake an aerobic and anaerobic septic system registration, evaluation, and permitting program to prevent subsurface pollutant loadings from potentially being introduced to the San Marcos Springs ecosystem within city limits.

5.7.4 Minimizing Impacts of Contaminated Runoff

The City of San Marcos will construct two sedimentation ponds along the river to help reduce the amount of contaminated materials that enters the river as a result of rain events. The ponds will also reduce runoff velocity which will help to reduce bank erosion, and subsequently the amount of sediment that enters the river. The sedimentation ponds will be constructed by excavating and stabilizing a specified area, and building a controlled-release structure. Water source for the ponds is solely runoff from rain events. Specific details for all ponds will be submitted through the AMP as each pond is contracted for design. Each construction area will be surrounded by silt fence/rock berm to minimize runoff. Sediment controls will be monitored daily during construction and the construction area will be covered with a tarp in the event of rain.

The first pond will be located in Veramendi Park beside Hopkins Street bridge. This area receives a large amount of street runoff from three different storm drains. The first pond will be designed to remove sediment and street pollutants from runoff prior to entering the river. The size, shape, and depth will be determined based on an analysis of the volume of water discharging from the storm drains. The City of San Marcos will detain as much as possible for treatment purposes. The City of San Marcos will undertake required maintenance of the sedimentation ponds on a regular basis. The area is easily accessible and sediment will be dredged and carried to the City of San Marcos's existing composting site at the Wastewater Treatment Plant.

The second pond will be created by widening of drainage ditches that run alongside Hopkins Street and cut directly to the San Marcos River. Widened areas will be designed to store water for a short period of time, but long enough to collect sediments and associated pollutants from roadway runoff.

5.7.5 Management of Household Hazardous Wastes

To date, water quality in the Aquifer and at the spring openings remains very good. However, as levels of development continue to increase over the recharge zone, transition zone, and even the contributing zone, the threats to water quality will increase. To reduce the potential for future water quality problems, the City of New Braunfels will initiate a hazardous household waste (HHW) program that will include accepting prescription drugs and Freon, through the TCEQ and/or the waste disposal division of the City of New Braunfels. The City of New Braunfels will establish a four-times-a-year program that could be recognized in the City's anticipated MS4 compliance and storm water permit as a contributing activity.

The City of San Marcos also will maintain a HHW program that involves the periodic collection of HHW and its disposal.

5.7.6 Impervious Cover/Water Quality Protection

Most potential water quality problems are linked to nonpoint source pollution such as fertilizer runoff and chemicals washed in from adjacent streets; however, spills and leaks from industrial and municipal infrastructure also present hazards. The potential for accidents and nonpoint

source pollution to affect the Covered Species may be exacerbated during below average flows since chemicals and nutrients would be less diluted when a lower volume of water is present. Runoff and spills originating even at long distances from the spring openings also can affect water quality at the springs.

The City of New Braunfels will establish criteria related to desired impervious cover and provide incentives to reduce existing impervious cover on public and private property in New Braunfels. The City of New Braunfels will establish criteria and incentives for the program based upon the low impact development (LID)/Water Quality Work Group Final Report (Appendix Q) recommendations for Implementation Strategies and best management practices (BMPs).

The City of San Marcos will establish a program to protect water quality and reduce the impacts of impervious cover (such as through LID). The City of San Marcos will develop criteria and incentives for the program based upon the LID/Water Quality Work Group Final Report (Appendix Q) recommendations for Implementation Strategies and BMPs.

The EAA will put together materials regarding the value of a ban on the use of coal tar sealants and work with local governments to explore and encourage their consideration of such a ban.

5.8 HDR's Analysis of the Springflow Protection Measures

5.8.1 Modeled Springflow with the Phase I Package

The flow protection measures included in the Phase I package are detailed in Sections 5.1.2 (VISPO), 5.1.3 (Conservation Program); 5.5.1 (SAWS ASR), and 5.1.4 (Stage V Emergency Withdrawal Reductions). Each element in the package is intended to contribute to maintaining an adequate level of continuous springflows during a repeat of the drought of record conditions. The elements are intended to work in a cumulative manner to provide sufficient springflow protection during a repeat of the drought of record conditions during Phase I.

To evaluate the effectiveness of the flow protection measures, the EARIP retained HDR Engineering, Inc. and Todd Engineers (collectively HDR) to simulate the springflows at Comal and San Marcos springs during a recurrence of drought of record conditions under baseline conditions and with sequential addition of each flow protection element of the Phase I measures to the baseline conditions. HDR used the U.S. Geological Survey's MODFLOW groundwater model (Lindgren *et al*. 2004) in the simulations. The details of the model and the simulation results are set out in HDR, Inc. and Todd Engineers, "Evaluation of Water Management Programs and Alternatives for Springflow Protection of Endangered Species at Comal and San Marcos Springs," October 2011 (HDR 2011).

The baseline scenario used in that simulation assumes that all of the Initial Regular Permits are being fully pumped (573,037 ac-ft) and all of the projected exempt domestic and livestock wells (13,296 ac-ft) and unpermitted federal wells (6,907 ac-ft) are being pumped to the maximum extent, subject to applicable critical period management rules. (HDR 2011). This assumption results in a projected theoretical maximum pumping of 593,240 ac-ft in each year. (*Id.*) The baseline simulations also assume that the critical period management pumping restrictions set out in SB 3 are in place, but do not assume that the continuous minimum springflow requirement of state law is implemented.

The assumption regarding the annual pumping level probably is conservative. The highest actual recorded annual level of pumping was 542,400 ac-ft, which occurred in 1989 before the creation of the Edwards Aquifer Authority. Moreover, over the last 10 years (2000-2009) total

pumping has averaged 381,000 ac-ft, with a maximum total pumping level of 456,500 ac-ft in 2006 and a minimum total pumping level of 317,600 ac-ft in 2004.

Under that baseline scenario, simulated springflow ceases at Comal Springs for 38 months during a repeat of the drought of record. Springflow at Comal Springs falls below 30 cfs (monthly average) for 54 months.

At San Marcos Springs, for the baseline scenario, springflow remains above zero during a repeat of drought of record conditions. It falls below 52 cfs (monthly average) for 20 months during a repeat of drought of record conditions. The minimum simulated springflow is two cfs (monthly average).

When the VISPO program is superimposed on that baseline, the simulated number of months in which the springflow ceases decreases by 12 months at Comal Springs (*i.e.*, goes from 38 to 26 months). The number of months in which springflow was below 30 cfs (monthly average) improved by 18 months (*i.e.*, went from 54 to 36 months).

At San Marcos Springs, the number of months in which springflow falls below 52 cfs (monthly average) is reduced by 6 months (*i.e.*, from 20 to 14 months) during a repeat of the drought of record. The minimum springflow is 16 cfs (monthly average).

When the Regional Water Conservation Program is added to the package (baseline + VISPO + Conservation) the number of months during a repeat of drought of record conditions in which springflow at Comal Springs was below zero improved by 5 months for Comal Springs (*i.e.*, goes from 26 to 21 months). The number of months in which springflow was below 30 cfs improved by two months (*i.e.*, went from 36 to 34 months).

At San Marcos Springs, springflow below 52 cfs (monthly average) is reduced by two months (*i.e.*, goes from 14 to 12 months) during a repeat of the drought of record. The minimum springflow improves to 19 cfs (monthly average).

When the use of the Phase I SAWS ASR is added to the package (baseline + VISPO + Conservation + SAWS ASR), simulated springflow at Comal Springs is always above zero cfs. The minimum springflow is 15 cfs (monthly average). The number of months in which springflow was below 30 cfs improved by 32 months (*i.e.*, went from 34 to 2 months).

At San Marcos Springs, with the addition of the Phase I SAWS ASR element to the package, the number of months that springflow falls below 52 cfs (monthly average) is reduced by nine months (*i.e.*, goes from 12 to 3 months) during a repeat of drought of record conditions. The minimum springflow improves to 49 cfs (monthly average).

When the Stage V pumping reduction is added to the package (baseline + VISPO + Conservation + SAWS ASR + Stage V), the minimum springflow at Comal Springs is 27 cfs (monthly average). The number of months in which springflow was below 30 cfs remained at two months.

At San Marcos Springs with the addition of the Stage V element to the package, the number of months that springflow falls below 52 cfs (monthly average) is reduced from three to two months during a repeat of the drought of record. The minimum springflow is 51 cfs (monthly average).

These results are summarized in Tables 5-5 and 5-6 and Figures 5-4 and 5-5.

TABLE 5-5
NUMBER OF OCCURRENCES OF SPRINGFLOW BELOW SELECTED THRESHOLDS (1947-2000)[3]

Spring	Threshold (cfs)	Number of Months				
		Baseline	VISPO	VISPO + Conservation	VISPO + Conservation + SAWS ASR	VISPO + Conservation + SAWS ASR + Stage V
Comal	0	38	26	21	0	0
	30	54	36	34	2	2
	45	62	47	41	11	7
	60	73	59	56	27	21
	100	122	112	101	90	84
San Marcos	0	0	0	0	0	0
	25	6	3	3	0	0
	52	20	14	12	3	2
	75	47	47	46	39	39
	100	121	118	116	114	114

[3] HDR 2011. Flow values are monthly average flows.

TABLE 5-6
MONTHLY AVERAGE SPRINGFLOW FOR SELECTED STATISTICS (1947-2000)

Spring	Statistic	Baseline (340K+)	VISPO	VISPO + Conservation	VISPO + Conservation + SAWS ASR	VISPO + Conservation + SAWS ASR + Stage V
Comal	Minimum Month	0	0	0	15	27
	Minimum 6-Month Moving Average	0	0	0	31	39
	Long-Term Average	178	182	186	195	196
San Marcos	Minimum Month	2	16	19	49	51
	Minimum 6-Month Moving Average	12	25	29	53	53
	Long-Term Average	153	153	154	154	155

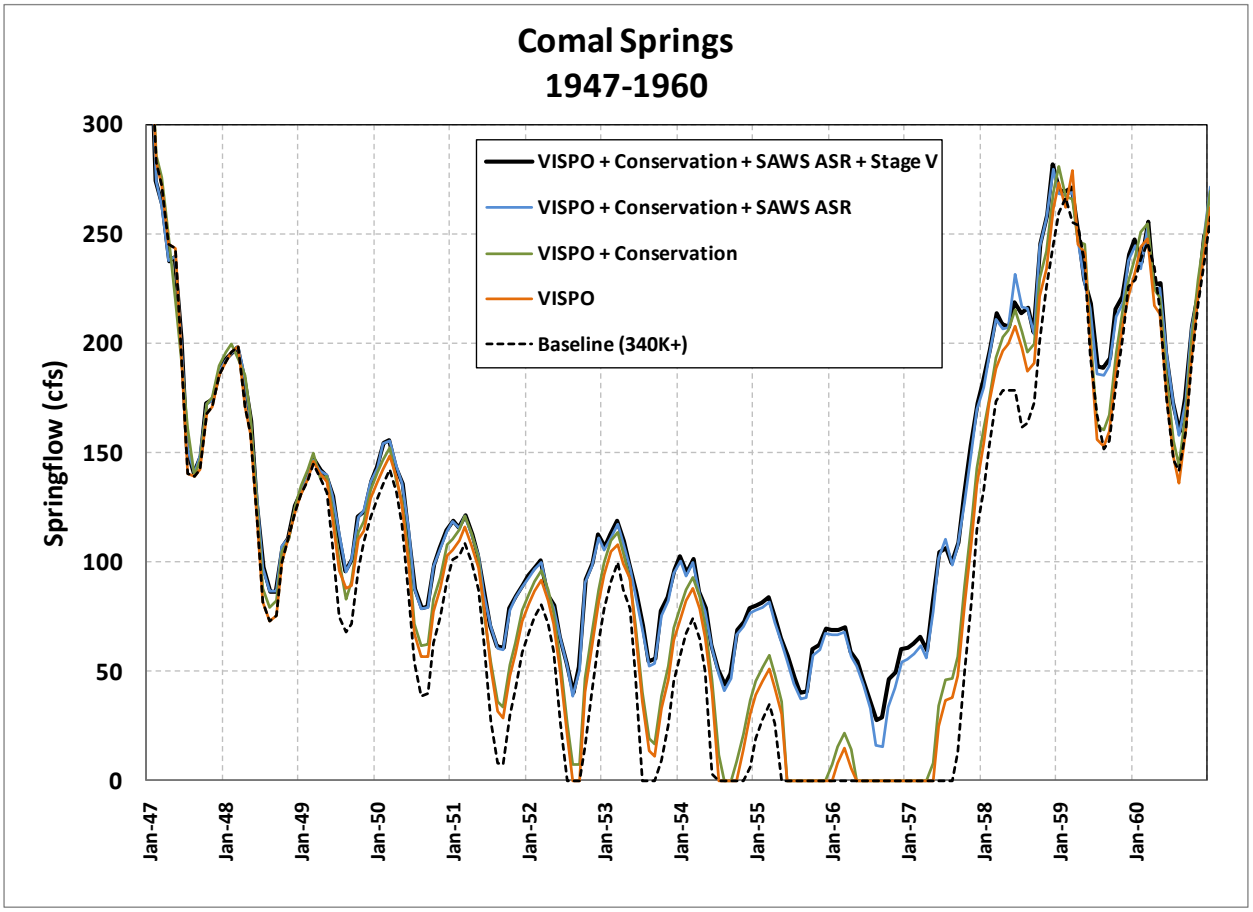


Figure 5-4. Simulated Monthly Average Springflow at Comal Springs (1947-1960)

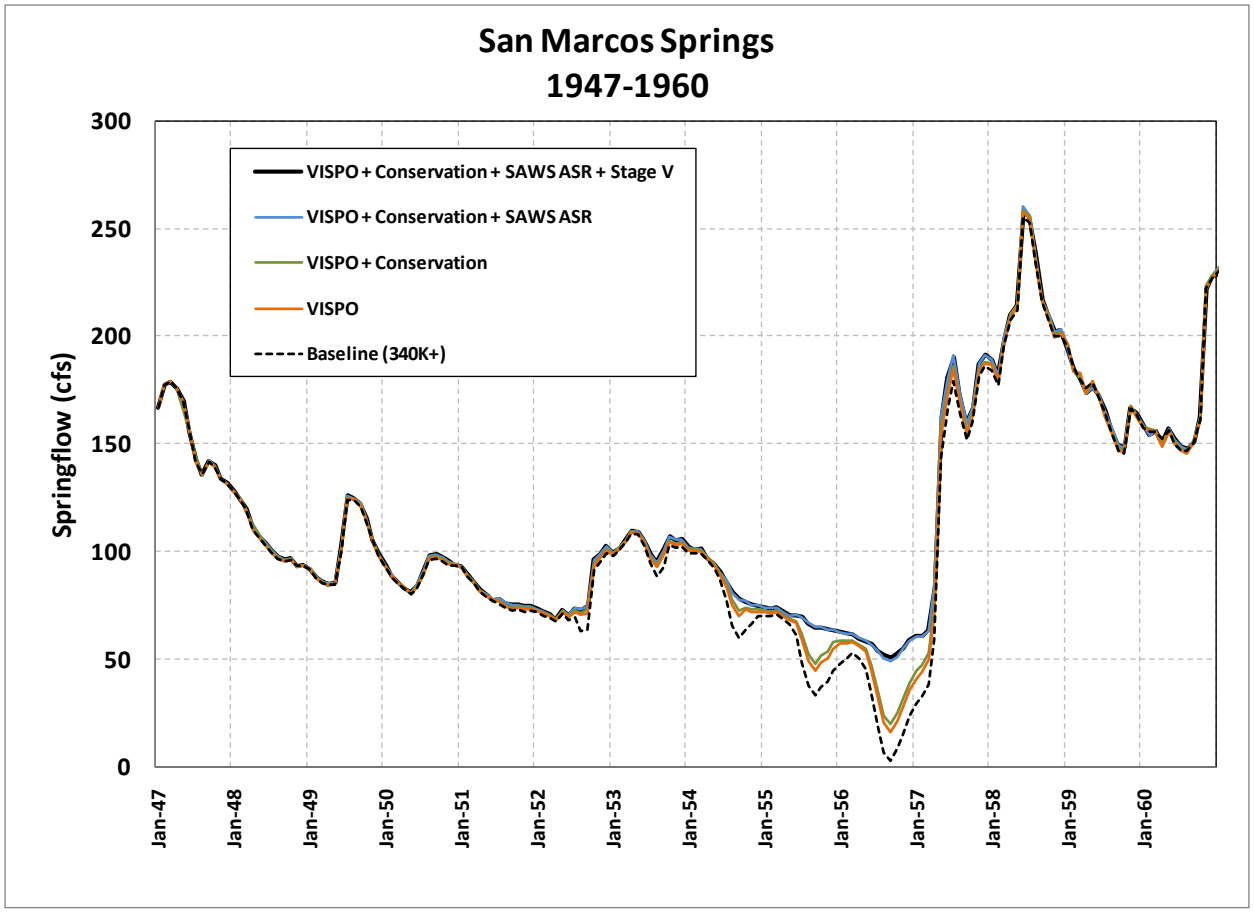


Figure 5-5. Simulated Monthly Average Springflow at San Marcos Springs (1947-1960)

5.8.2 Modeled Springflow with the Phase I Package and the Presumptive Phase II Measure

The presumptive action for Phase II of the HCP, should it be determined to be necessary after completion of the strategic AMP, involves the continuation of the Phase I measures including the use of the SAWS ASR with the addition of the WRIP Pipeline that is currently in the design stages and is scheduled for completion by 2020. The WRIP will link the existing facilities and new water supplies located at the ASR site in southern Bexar County with the southwestern and western portions of San Antonio.

Currently, the 60-inch pipeline from the ASR constrains the ability of the ASR Trade-Off element in the Phase I package to enhance springflow at the worst part of a repeat of a drought of record-like event (*i.e.*, 1955 and 1956). The WRIP pipeline extension will add capacity to the ASR distribution system that will allow more water to be returned from the ASR in a given time period and expand the geographic distribution served by the ASR. Simply removing the existing capacity bottleneck may enable the SAWS ASR Trade Off element to provide the necessary additional springflow to meet the current minimum flow objectives (45 cfs minimum monthly average at Comal Springs and 52 cfs minimum monthly average at San Marcos Springs). If removing the bottleneck of the ASR, under the operating assumptions set out below, is unable to fully meet the modeled necessary additional springflow to meet the current minimum flow

objectives, the balance will be obtained through alterations to the conservation measures outlined in Chapter 5 including an increase in Stage V withdrawal reductions, if necessary.

SAWS' ability to expand the use of the ASR as a presumptive Phase II measures, if required, assumes that: (1) no additional water will need to be stored; (2) the total amount of water to be returned from the ASR over the term of the permit will not exceed 126,000 ac-ft and 46,300 ac-ft in the worst year; and (3) the maximum annual utilization of the WRIP will be no more than 40 percent of the capacity of the WRIP distribution system at any time.

HDR simulated the hydrograph of the flow protection elements in the Phase I Package with the addition of the WRIP Pipeline during a drought of record-like event. Using the current hydrological model, the current minimum flow objective cannot be met at the Comal Springs, with the above-stated assumptions, without additional Stage V cutbacks. Using the three assumptions set out above, to achieve the current minimum flow objective at Comal Springs, an additional 3 percent increase was required in the Stage V withdrawal reductions over that required in Phase I, *i.e.*, the withdrawal cutback in Stage V would be 47 percent rather than 44 percent.

Using the three assumptions and an additional three percent Stage V cutback, the minimum monthly average springflow at Comal Springs is 47 cfs. The number of months in which the flows fall below 60 cfs (monthly average) decreases from 73 months under the No Action Baseline to 17 months. (*See also* Section 4.2.)

The minimum monthly average springflow at San Marcos Springs is 52 cfs. This simulated minimum springflow occurs for one month during 1956.

The required Stage V withdrawal reductions are based on the best available aquifer model existing at this time. Based on this model's known limitations and the biological uncertainties that will be addressed during Phase I, the three percent increase in the Stage V cutback may prove unnecessary to meet the current minimum flow objectives.

These results are summarized in Tables 5-7 and 5-8 and Figures 5-6 and 5-7.

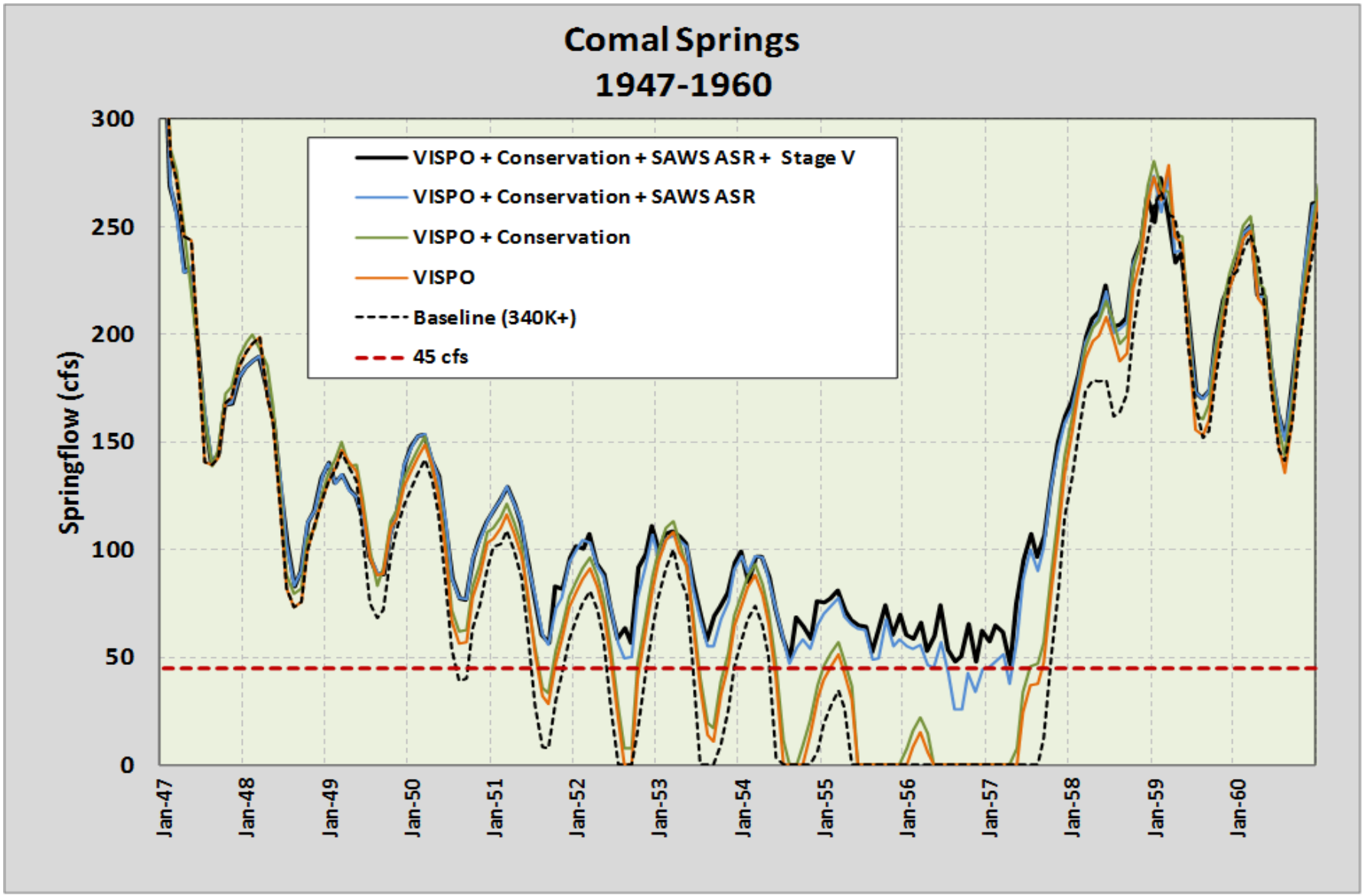
Table 5-7. Springflow occurrences below selected thresholds with Phase I and II Measures (1947-2000)

Springflow Occurrences below Selected Thresholds (1947-2000)						
Spring	Threshold (cfs)	Number of Months				
		Baseline (340K+)	VISPO	VISPO + Conservation	VISPO + Conservation + SAWS ASR	VISPO + Conservation + SAWS ASR + Stage V
Comal	0	38	26	21	0	0
	30	54	36	34	2	0
	45	62	47	41	7	0
	60	73	59	56	32	17
	100	122	112	101	87	86
San Marcos	0	0	0	0	0	0
	25	6	3	3	0	0
	52	20	14	12	3	0
	75	47	47	46	41	36
	100	121	118	116	114	114

Table 5-8. Springflow for selected conditions with Phase I and II Measures (1947-2000)

Springflow for Selected Conditions (1947-2000) Units: cfs						
Spring	**Statistic**	**Baseline (340K+)**	**VISPO**	**VISPO + Conservation**	**VISPO + Conservation + SAWS ASR**	**VISPO + Conservation + SAWS ASR + Stage V**
Comal	**Minimum Month**	**0**	**0**	**0**	**26**	**47**
	Minimum 6-Month Moving Average	**0**	**0**	**0**	**36**	**54**
	Long-Term Average	**178**	**182**	**186**	**195**	**196**
San Marcos	**Minimum Month**	**2**	**16**	**19**	**49**	**52**
	Minimum 6-Month Moving Average	**12**	**25**	**29**	**53**	**55**
	Long-Term Average	**153**	**153**	**154**	**155**	**155**

Figure 5-6. Simulated monthly average springflow at Comal Springs (1947-1960) with the specified Phase II Presumptive Measure



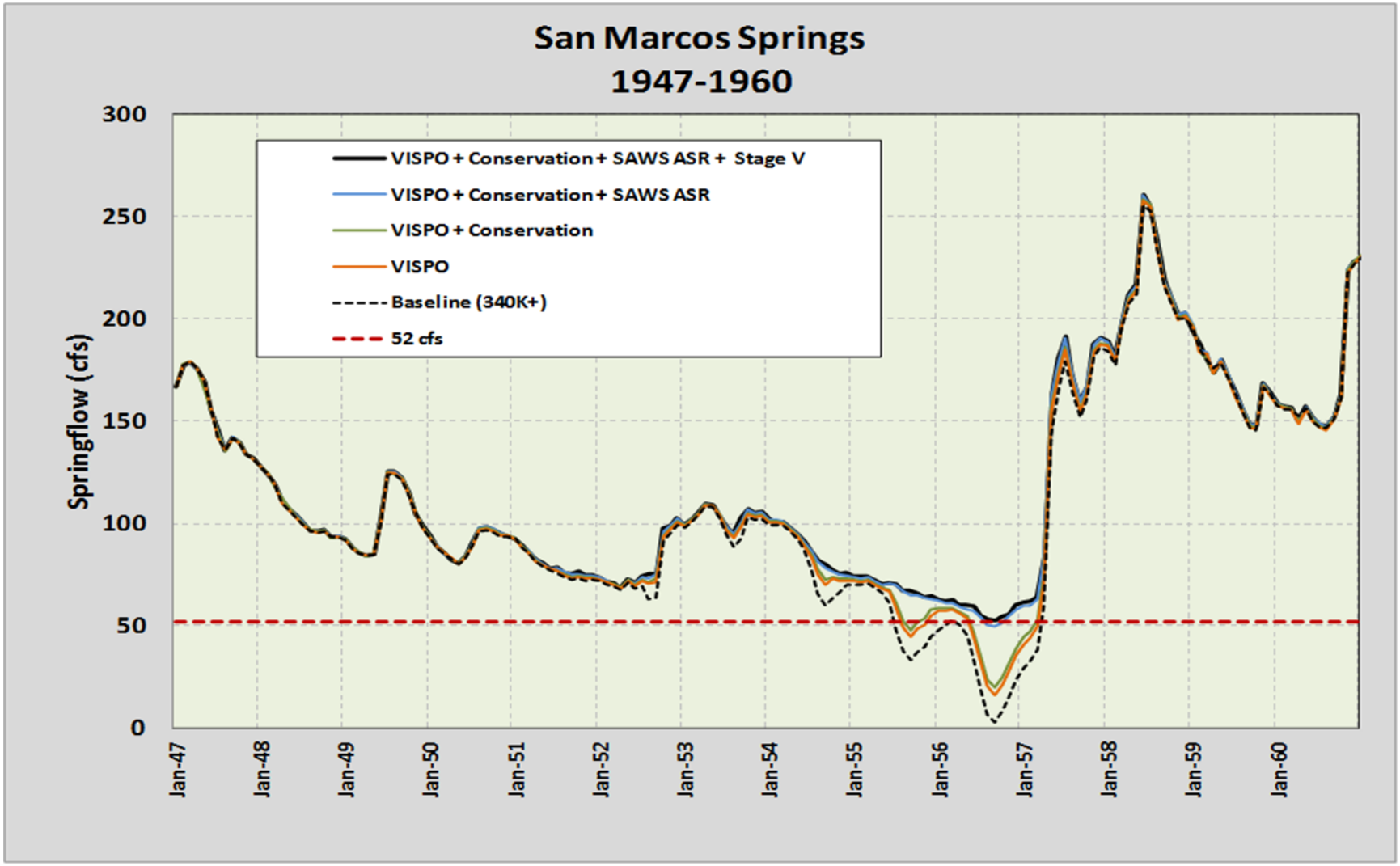


Figure 5-7. Simulated monthly average springflow at San Marcos Springs (1947-1960) with the specified Phase II Presumptive Measure

5.8.3 The Impacts of Incidental Take Are Minimized and Mitigated to the Maximum Extent Practicable

One of the ITP issuance criteria prescribed in 50 C.F.R. § 17.22(b)(2), 50 CFR § 17.32(b)(2) and Section 10(a)(2)(B) is that the impacts of the incidental take be minimized and mitigated to the maximum extent practicable. This finding typically requires consideration of two factors: adequacy of the minimization and mitigation program, and whether it is the maximum that can be practically implemented by the applicant. To the extent that the minimization and mitigation program can be demonstrated to provide substantial benefits to the species, less emphasis can be placed on the second factor. (USFWS 1996c).

5.8.3.1 The Minimization and Mitigation Measures Provide Substantial Benefits to the Covered Species

As detailed above, the Phase I package of springflow protection measures provides substantial benefit to the Covered Species. (*See* Section 5.8.1). Under No Action Baseline conditions, Comal Springs is simulated to cease to flow for 38 months during a repeat of drought of record conditions, and the springflows are predicted to be below 30 cfs (monthly average) for 54 months. At San Marcos Springs, in the simulation of a repeat of the drought of record, the minimum flow will be 2 cfs, and springflows will be below 52 cfs (monthly average) for 20 months.

By contrast, with the Phase I springflow protection measures, Comal Springs is predicted to have continuous springflow during a repeat of drought of record conditions. Indeed, springflow will only fall below 30 cfs[4] for 2 months, with the simulated minimum monthly average flow during that time of 27 cfs. At San Marcos Springs, springflow will only fall below 52 cfs for two months, with the simulated minimum monthly average flow of 50 cfs. Hardy (2011) found that these springflows will not appreciably reduce the likelihood of survival of these species and recovery during a one time repeat of drought of record conditions during Phase I so long as all recommended measures are implemented to restore and protect the habitat of the Covered Species. Currently available information indicates that the presumptive Phase II measures, if implemented, will provide the necessary additional springflow to meet the currently defined minimum flow objectives necessary to attain the biological goals. (*See* Section 5.8.2)

In addition to protecting springflow, the minimization and mitigation measures will markedly diminish the impacts of recreation during low flows. A major concern regarding Texas wild-rice is recreational activity in high-quality habitat areas of the San Marcos River. The creation of state scientific areas in the spring and river ecosystem will establish a mechanism to exclude recreation from these areas during low flows. Similar state scientific areas will be established in the Comal River to protect restored fountain darter habitat. These measures to address recreational impacts will be augmented by limiting access points for recreational activities, sediment removal, and educational programs.

The gill parasite is a significant stressor of the fountain darter in the Comal ecosystem the effects of which may be exacerbated by low flows. The City of New Braunfels will implement a gill parasite control program to minimize this impact

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[4] Except where specifically expressed as a daily average flows, the springflows in this section are set out as monthly average springflows.

The Applicants will also implement other minimization and mitigation measures to limit the impacts of low flows on the Covered Species and their habitat. These include, but are not limited to, removal of non-native plants and replacing them with native vegetation favored by the Covered Species, maintenance of dissolved oxygen through removal of decaying aquatic vegetation during low flows, and programs to limit the impacts of predation and competition.

The Applicants have committed to a wide-range of minimization and mitigation measures, developed using the best available, peer-reviewed science, to reduce and mitigate the impacts from these threats. In addition, the Applicants will also implement measures that will contribute to the recovery of the Covered Species including measures to protect water quality and to restore riparian zones. Further, the Applicants will develop a predictive ecological model and conduct applied research to evaluate potential adverse ecological effects from Covered Activities, fill important data gaps, and put forward alternative conservation approaches or mitigation strategies to better benefit the Covered Species.

5.8.3.2 The Minimization and Mitigation Measures Represent Compliance with the Maximum Extent Practicable Requirement

The Applicants estimate the costs for implementation of the Phase I package alone will average approximately $17.5 million over the duration of the permit and over $18.6 million over the first seven years of the permit. (*See* Table 7-1). The costs cannot be measured entirely by money. SAWS will, for example, be sacrificing capacity in its ASR. Smaller municipalities may have to obtain additional water supplies to be able to meet the Stage V Critical Period Management reductions. (*See* Section 5.1.4.2).

The costs of the minimization and mitigation measures will be borne primarily by the holders of municipal and industrial permits issued by the EAA to withdraw groundwater from the Aquifer through increased Aquifer Management Fees (AMF). Irrigators will not contribute to funding the costs despite being major users of the Aquifer. (*See* Section 5.1.2.1). Irrigators' fees are capped by the EAA Act at $2/acre-foot of water pumped each year and these payments are already consumed in paying for the administrative costs of existing EAA operations. (*See* EAA Act § 1.29(e)). It is estimated that, as a result of the HCP, the AMFs for municipal and industrial pumpers, may increase from the current $39/acre-foot of permitted withdrawals to between $88 to $116/acre-foot of permitted withdrawals. These costs will create greater costs for water users which cannot be easily absorbed throughout the region at this time.

During the development of the HCP, the Applicants also considered numerous alternative minimization and mitigation measures (*see* Section 1.7) designed to ensure springflows during extended periods of drought. A single strategy that would rely only on restricting pumping at a level that would assure springflows considered protective of the listed species would create serious adverse impacts to human health and safety. Other programs for establishing alternative water supply sources for use in recharge augmentation or displacement of pumping were evaluated. The preliminary cost estimates associated with these programs were considered to be impractical due to costs ranging into the many hundreds of millions of dollars and potential regulatory, technical, or political impediments to their implementation.

Based on the predicted effectiveness of the springflow protection measures and other conservation measures, the substantial financial commitment required of municipal and industrial pumpers, and the excessive cost of alternate approaches identified, the Applicants

believe that minimization and mitigation measures in this HCP satisfy the "maximum extent practicable" requirement for issuance of the ITP.

5.9 EAA's Authority to Implement Measures to Maintain Springflow Prior to the Complete Implementation of the Phase I Package

The Plan Area at the time of the preparation of this HCP is experiencing drought conditions. While the Applicants at this time are unable to identify the exact nature, extent, or severity of the drought conditions, the potential exists that on the effective date of the Permit (in the event the Service approves the ITP application), the Plan Area will be in drought conditions of sufficient magnitude that immediate actions are required prior to the time that the Applicants are able to fully implement the minimization and mitigation measures described in Chapter 5. If so, EAA has the authority to take appropriate actions to protect the Covered Species while the Applicants are taking steps to fully implement their respective minimization and minimization measures under Chapter 5.

The EAA is a conservation and reclamation district created pursuant to Article XVI, Section 59 of the Texas Constitution. As such, the EAA is a political subdivision which has those powers expressly granted by statute and those necessarily implied as incident to its express powers. The EAA Act grants express power to the Authority to take action to protect the Covered Species and their habitat outside of the context of the HCP. Section 1.14(h) of the EAA Act provides that the EAA "through a program, shall implement and enforce water management practices, procedures, and methods to ensure that, not later than December 31, 2012, the continuous minimum springflows of the Comal Springs and the San Marcos Springs are maintained to protect endangered and threatened species to the extent required by federal law and to achieve other purposes provided by Subsection (a) of this section ... ." The relevant parts of subsections (a)(6) and (7) of Section 1.14 provide that the EAA is to, among other things, protect aquatic and wildlife habitat, and listed threatened or endangered species. In support of this broad authority to protect species, Section 1.115(e) of the EAA Regulations provides that the Board of Directors of the EAA may adopt emergency rules "in anticipation of imminent harm to human health, safety, or welfare, or if compliance with [normal rulemaking] procedures . . . would prevent an effective response to emergency aquifer or springflow conditions." Emergency rules may be adopted after five days' notice and are effective immediately on adoption for a period of 120 days and may be renewed once for not more than 60 days.

Thus, EAA has broad authority and an independent state-law based mandate to take actions necessary to protect the Covered Species in the event the Plan Area is in severe drought on the effective date of the Permit and in advance of the ability of the Applicants to fully implement their respective minimization and mitigation measures. The scope and nature of any such measures would depend on the extent and severity of the drought conditions and their potential impact on the Covered Species.

Chapter 6 Adaptive Management

6.1 Adaptive Management Process

The adaptive management process (AMP) is designed to enhance the effectiveness of the HCP by addressing uncertainty in the conservation of a species by an HCP. 65 FR 35,242, 35,252 (June 1, 2000). The AMP proactively addresses the level of uncertainty that often exists in the management of natural resources through a process of experimentation and verification. Specifically, the AMP envisioned in the HCP is a process for examining alternative strategies for meeting the biological goals and objectives, and then, if necessary adjusting the minimization and mitigation measures in Chapter 5 according to what has been learned through the AMP.

USFWS' 5-Point Policy regarding HCPs addresses five issues: (1) biological goals and objectives; (2) adaptive management; (3) monitoring; (4) permit duration; and (5) public participation. (*Id.* at 32,250-256) The AMP described in this chapter covers the elements of adaptive management in USFWS' 5-Point Policy: (1) upfront identification of the uncertainty for a particular species, biological goal or objective, or efficacy of a minimization or mitigation measure; (2) the identification and incorporation of a possible range of alternatives for addressing the uncertainty; (3) implementation of a monitoring program to evaluate the probable success of the alternatives; and (4) providing for an interactive decision-making process based on the results of the monitoring program from which changes or adjustments should be made, if necessary, to the existing minimization and mitigation measures that are initially implemented. (65 FR at 35,252).

It is not the intent of the Applicants that the AMP should substitute for the implementation of minimization and mitigation measures reasonably expected to meet the long-term biological goals and objectives in Section 4.1 of the HCP, or to delay addressing difficult or intractable issues. On the contrary, the minimization and mitigation measures have undergone considerable scrutiny and evaluation. The measures will, based on the best scientific evidence available at the time of the issuance of the ITP, result in minimization and mitigation of impacts of the incidental take stemming from the Covered Activities to the maximum extent practicable, and will appreciably increase the likelihood of the survival and recovery of the Covered Species in the wild.

The details of the AMP for the HCP and its governance are found in Article Seven of the Funding and Management Agreement (FMA) that is attached hereto and incorporated herein for all purposes at Attachment R.

6.2 Monitoring

The Applicants and the USFWS will develop and oversee a monitoring program designed to identify and assess potential impacts from Covered Activities while also providing a better

understanding and knowledge of desirable water quality- and springflow-related habitat requirements of the Covered Species inhabiting the Comal and San Marcos Springs/River ecosystems as well as the species' life cycles. The monitoring program will provide information for the USFWS and the Applicants to: (1) evaluate compliance with the HCP; (2) determine if progress is being made toward meeting the long-term biological goals and objectives; and (3) provide scientific data and feedback information for the AMP. The Applicants, through the AMP, will continually evaluate the data collected through the monitoring program, the results of the research and modeling, and other information as appropriate.

The monitoring program will include, but will not be limited to, the hydrological data collection program by EAA, including water quality monitoring (*see*, *e.g.*, EAA 2010(b)), the biological sampling program conducted by EAA as described in Section 6.3.1, the recharge monitoring data collected by EAA as described in Section 6.2.3, and the expanded water quality monitoring program monitoring that will be conducted by EAA as described in Section 5.7.4. The results of these programs as well as information on the implementation of the minimization and mitigation measures will be included in the annual reports to allow the USFWS to fulfill its responsibility to monitor the implementation and success of the HCP, including the adaptive management commitments.

6.2.1 Compliance Monitoring

The purpose of compliance monitoring is to provide a public record accessible to all participants, the public, and the USFWS demonstrating the Applicants' compliance with the terms and conditions of the ITP, HCP, and IA. The compliance monitoring process for the HCP will consist of the preparation and submittal of annual reports by the Applicants, as described in Chapter 9 below, to the USFWS for review and comment.

This information, along with compliance with TCEQ Texas Pollution Discharge Elimination System (TPDES) dry weather field screening program data, BMP treatment capabilities, and compliance with the Texas Surface Water Quality Standards (TSWQS) will help support adaptive management decisions and if applicable, will be included in the Annual Report.

The intent of the compliance monitoring is to ensure that the HCP is fully functioning during the term of the ITP, as well as to provide a focus for minor modifications and adjustments to better meet the goals and objectives of the ITP. In addition, the Phase I reports will provide a means to document the progress of the Adaptive Decision Making Process during the several years prior to the end of Phase I and in anticipation of the transition to Phase II.

6.2.2 Effects and Effectiveness Monitoring

Effects and Effectiveness Monitoring will evaluate the success of the HCP in meeting its stated biological goals and objectives. The Applicants will design and implement targeted studies to evaluate, at a minimum, each of the hypotheses set out in Section 6.3.4 below.

6.2.3 Recharge Monitoring

The EAA will accurately measure the amount of water (in ac-ft) recharging the Edwards Aquifer in the area described in Section 1.2 of this Plan. EAA will publish this measurement not later than June 1st of each year for the purposes of guiding the activities in Section 5.5.1. EAA will then maintain this information on an ongoing basis in an appropriate publication.

6.2.4 Monitoring Reports

The Applicants will prepare and submit a Monitoring Report to be included as part of the Annual Report to be submitted to the USFWS. (*See* Section 9.3). The first Monitoring Report will be submitted for inclusion in the 2013 Annual Report to be submitted to USFWS at the end of the first quarter of 2014.

6.3 Adaptive Management Research and Modeling for the Phase I Adjustments and Phase II Strategic Adaptive Management Decisions

Pursuant to the AMP, the Applicants will ensure that research and modeling efforts sufficient to support and inform the Phase II Adaptive Management Decisions are complete and all relevant data are compiled no later than December 31, 2017. Details of the research and modeling are presented below.

6.3.1 Biological Monitoring

A comprehensive biological monitoring plan (Variable Flow Study) was established by the EAA in 2000 to gather baseline and critical period data to fill important gaps in the ecological condition of the Comal and San Marcos springs and river ecosystems. The EAA will continue this comprehensive sampling plan for the term of the ITP (with modifications as identified through the AMP process) and will provide a means of monitoring changes to habitat availability and the population abundance of the Covered Species that may result from Covered Activities.

This comprehensive monitoring plan will continue to accumulate baseline data for refinement of estimates of “average” community conditions. The monitoring will also increase in magnitude, including increased frequency and number of parameters examined, as discharge falls to specific levels. Additional monitoring during low-flow periods will enhance perceptibility of critical changes in important habitat parameters, new and existing threats, and water quality tolerance thresholds. The discharge “trigger” levels for additional monitoring and other management responses were chosen based on available data that suggest that significant changes in population dynamics or habitat availability may occur when discharge falls to, or below, these values. These trigger levels may be refined as additional data are gathered and ecological modeling is conducted through the AMP.

In addition to long-term monitoring efforts that increase in intensity in response to the specified trigger events, a critical period monitoring component is incorporated into the Variable Flow Study that initiates full-scale sample efforts at specified trigger levels. Over the past decade, only a handful of critical period events have triggered additional sampling. As part of the long-term monitoring component of this HCP, the critical period monitoring component of the Variable Flow Study will be maintained until sufficient documentation of low-flow events has been completed. It is this monitoring strategy that will be integrated into the long-term comprehensive monitoring to help refine critical monitoring trigger levels and appropriate management responses. Data gathered during this full-scale effort will also provide information on potential impacts of the sampling methodology on reduced habitat and potentially reduced populations.

The scope of the Variable Flow Study currently can be modified on a yearly basis as provided in the FMA with agreement by the USFWS. The current Variable Flow Study has the following monitoring components:

- Aquatic vegetation mapping for select reaches;
- Fountain darter sampling (drop nets, dip nets, visual);
- San Marcos salamander sampling (SCUBA and snorkel);
- Texas wild-rice physical observations and annual mapping;
- Comal Springs riffle beetle monitoring;
- Comal invertebrate sampling (drift net sampling over spring orifices);
- Comal Springs salamander sampling;
- Parasite evaluations concerning the fountain darter; and
- Ramshorn and other exotic snail monitoring.

Components to be incorporated into the Variable Flow Study upon permit issuance will include sampling for two additional non-listed species, the Edwards Aquifer diving beetle, and Texas troglobitic water slater. Additionally, monitoring of the type and quantity of nutrients (*e.g.*, dissolved carbon) in the spring water will assist in determining the effects of variable flow on aquifer species.

The study components, as currently designed and as refined through the AMP, will provide information to effectively determine whether the conservation measures are achieving the biological goals and objectives set forth in the HCP. A more detailed description of the sampling methodologies, frequencies, and sample locations is found in the Variable Flow Study Annual Reports. (*See*, *e.g.*, BIO-WEST 2010a, b).

6.3.2 Groundwater Modeling

Computer groundwater models are mathematical representations of complex physical environments. The groundwater model for the Aquifer used by the EAA, at the time this HCP was written, was created by the United States Geological Survey (USGS) between 2000 and 2004. This model uses a finite difference computer code called MODFLOW, a software program created by the USGS. The MODFLOW model was used during the EARIP process to provide the model results for assessing the efficacy of the minimization and mitigation measures identified in Chapter 5 of the HCP. Like all groundwater models, the MODFLOW model has limitations and data gaps that manifest uncertainty in model results. By December 31, 2014, the EAA will take appropriate steps to reduce the level of uncertainty in the MODFLOW model by filling in the data gaps to the extent practicable and by reducing the number of structural limitations in the model.

As part of the adaptive management commitment, the EAA will create another model to reduce uncertainty in the model results for use during the AMP and to provide assurance/confirmation that modeling results for the Aquifer and springflows are more reliable and defensible. This additional groundwater model is expected to be a finite element model. This additional model will be developed and ready for use by December 31, 2014. The new model development process will run concurrently with the EAA's effort to improve the existing MODFLOW model.

6.3.3 Ecological Modeling

The EAA will oversee and retain a contractor to develop a predictive ecological model to evaluate potential adverse ecological effects from Covered Activities and to the extent that such effects are determined to occur, to quantify their magnitude. The model results will help the Applicants develop alternative approaches or possible mitigation strategies, if necessary.

Ecological models are numeric or computer-based abstractions of ecological systems, and as such, they are simplifications of real-world processes and interactions. The complexity of ecological models varies from the relatively simple, such as some numeric models, to extremely complex, such as dynamic simulation models. Ecological models are used for a wide variety of purposes, including: (1) to better understand ecological relationships, processes, and interactions of the systems being studied; (2) project ecological responses over time; and (3) predict ecological responses to changes in environmental conditions. A predictive ecological model can project ecological responses to levels of environmental stressors beyond what are likely to be encountered during Phase I of the HCP. Therefore, the model will provide the ability to investigate potential impacts to these ecosystems from extreme short-term and sustained long-term impacts from natural and anthropogenic factors, including local and regional groundwater withdrawals.

The two primary purposes for including a predictive ecological model in the AMP are to identify and describe ecological responses and to predict and quantify impacts. Three objectives are associated with each of the two purposes.

Identify and describe specific ecological responses:

- to predict specific ecological responses of the Comal and San Marcos Springs/River ecosystems and associated Covered Species to various environmental factors, both natural and anthropogenic;
- to assist in establishing potential threshold levels for these ecosystems and associated species relative to potential environmental stressors; and
- to assist the overall scientific effort to better understand the interrelationships among the various ecological factors affecting the dynamics of these ecosystems and associated species.

Quantify, predict, and project impacts:

- to assist in identifying and quantifying the effects of various environmental factors, including groundwater withdrawal, recreation, parasitism, restoration, etc. on ecological changes in these ecosystems and associated species;
- to project long-term effects of the Covered Activities on these ecosystems and associated species to facilitate designation of Phase II biological goals and strategies for achievement; and
- to assist in mitigation design, implementation, and monitoring, where applicable.

There are three broad categories of predictive ecological models, with numerous variations of each. These three categories are: (1) statistical models, (2) state-and-transition models, and (3) mechanistic simulation models. Each category has advantages and disadvantages associated with their use. For the HCP, a mechanistic simulation model will be used as it best simulates how the ecological systems actually function (examples include Daly *et al*. 2000, Childress *et al*. 2002, Mata-Gonzalez *et al*. 2008). Most mechanistic simulation models are at least moderately-complex models, and some are extremely complex. The most sophisticated of the mechanistic simulation ecosystem models simulate a wide variety of ecological processes including hydrology, aquatic plant growth, aquatic species population dynamics, sedimentation, recreation, and climatic fluctuations, along with their interactions, at spatial scales ranging from small (less than 1 m^2) to entire landscapes. For the HCP, dynamics would be simulated on the species-level for the Comal and San Marcos aquatic systems, and for time steps ranging from hours or days to decades.

One major advantage of mechanistic simulation models is that complex ecological interactions can be simulated without *a priori* assumptions being made about the outcomes of these interactions. The other advantages include their ability to: (1) simulate complex ecological interactions; (2) test complex ecological hypotheses; (3) test potential impacts of changes in environmental conditions over time; (4) test potential effects of extreme values of various

environmental factors; and (5) investigate the existence of, and help quantify, threshold values for various ecological variables and systems.

To accomplish the objectives stated above, the following criteria should be met by the predictive ecological model.

- The model should be a mechanistic ecological simulation model.
- The model should be capable of simulating the dynamics of both terrestrial and aquatic ecosystems, at the appropriate time scales, and integrate both types of ecosystems on a landscape-scale where appropriate.
- The model should be capable of including plant, animal, hydrological, climatic, and management variables, and simulating interactions among all of these components.
- The model should be capable of simulations on spatial scales ranging from 1 m^2 to the entire Edwards Aquifer region.
- The model should be capable of being linked to the groundwater model(s), so that simulations can be conducted for integrated surface and groundwater systems.
- The model should be sufficiently flexible that changes in algorithms can be made as needed, based on new data and improved understanding of the ecological dynamics of the Comal and San Marcos ecosystems. Revisions to the parameter values used in the model data base should be possible in a user-friendly manner such that routine upgrades to this data base can be made as additional site-specific data become available.
- The model should be capable of being run on commercially available PC hardware and using commercially available software operating systems.
- The model should have a history of producing accurate (80-90 percent) simulations of ecological dynamics in groundwater-influenced ecosystems, as demonstrated by field validation studies.
- The model should have user-friendly interfaces such that it can be used by a range of experienced personnel, upon completion of some degree of specific training on the use of the model.

6.3.4 Applied Research Facility Experimental Channel at the USFWS National Fish Hatchery and Technology Center

6.3.4.1 Description of the Applied Research Facility

As discussed throughout this HCP, applied research coupled with ecological modeling is a valuable component of the Phase I package. During Phase I, applied research will be conducted to better understand the ecological dynamics of the Comal system, particularly under low flow conditions. Initially, an on-site research channel at Landa Park in the Comal system for conducting these experiments was considered to limit costs and maximize effectiveness. BIO-WEST (2011c). However, an appropriate site could not be obtained in the Comal ecosystem. Accordingly, an applied research experimental facility will be constructed at the USFWS National Fish Hatchery and Technology Center (NFHTC) in San Marcos, Texas. The NFHTC has the existing infrastructure (Aquifer exempt wells, ponds, containment areas, recirculation and reuse capabilities, etc.) to allow for construction and operation of an applied research facility to inform Phase II decisions regarding the Covered Species and, to the extent possible, adjustments to conservation Measures during Phase I.

Although termed “applied research facility,” the conceptual design is a series of man-made channels with earthen substrate intertwined with the existing ponds available at the NFHTC. This will allow water use and reuse through the plumbing already in place while allowing the flexibility to pump water through several research channels for experimentation. To recreate the natural environment to the extent possible, considerable effort will be needed to simulate channel configuration, substrate, instream debris, riparian zone structure (trees, shrubs, grass), aquatic vegetation, and other natural and anthropogenic conditions present in the Comal River. These components will be carefully designed and constructed to provide the most authentic simulation practicable. A riffle beetle upwelling and spring run area (similar to that proposed in BIO-WEST 2011c) will be created at the headwaters of two of the research channels.

The EAA will support and coordinate the NFHTC’s construction and maintenance of the Applied Research Center. EAA will contract for the research activities in the Applied Research Center identified in this Section or developed as part of the AMP. The Program Manager will coordinate, supervise and oversee the implementation of all such research.

6.3.4.2 Research in the Experimental Channels

The main focus of the research channels will be to evaluate the effects of low-flow on Covered Species and their habitat. This evaluation will include springflow conditions that bracket the range of 5 cfs to 100 cfs. Considering the Phase I schedule and the need to first get this facility designed, permitted, and constructed, it is likely that only five years will be available for Phase I experimentation. As such, key questions will need to be addressed during this time period, which will require a strict schedule and intense focus. The applied research at the NFHTC facility for Phase I will focus on the fountain darter relative to Comal (although research should

be transferable to the San Marcos system) and the Comal Spring riffle beetle, as these are the two species with the greatest potential for impact relative to the Phase I package. This applied research will be further divided into three tiers. Tier A will focus on habitat requirements and responses; Tier B will focus on low-flow impacts directly on the fountain darter and Comal Springs riffle beetle; and Tier C will investigate the implications of the timing, frequency, and duration of multiple events in varying sequences and include specific research efforts designed to assess ecological model predictions (*e.g.,* model validation). The experimental design for the research will be prepared prior to the initiation of the reseach. The experimental design for the research will receive input from the Science Committee prior to its initiation and on issues that arise during the conduct of the reasrch. (FMA Section 7.13.2),

Tier A – Fountain Darter Habitat and Food Supply

- ***Low-flow effects on native aquatic vegetation***

A key unknown is the tolerance of native aquatic vegetation to reduced flow conditions in these systems. The timing and duration of these low-flow events will be studied relative to the native vegetation, starting with the plant species identified in the long-term biological goals for the fountain darter. Decay of the above ground and below ground biomass will be measured over time. Above ground biomass is important for Covered Species habitat while below ground biomass is critical for root establishment and holding the plant in place during any subsequent pulse event. Water quality will be continuously measured to evaluate the before, during, and after effects of vegetation decay on water temperature, dissolved oxygen, carbon dioxide, and pH. Additional water quality parameters such as nutrients may also be studied. In addition to studying the effect of vegetation decline, decay and ultimately death, studies will be designed to evaluate recovery of native vegetation following various stages of aquatic vegetation decline and decay.

- ***Low-flow effects on macroinvertebrates (fountain darter food source)***

Another critical component of fountain darter habitat that is presently unknown is the relationship of macroinvertebrates (fountain darter's main food source) to low-flow conditions. Studies will be designed to evaluate the simulated effects of changing water quality conditions and aquatic vegetation composition on the macroinvertebrate (mainly amphipods) community. It may be that the amphipods are affected much earlier than actual vegetation decline or decay which would mean impacts to the darter from reduced food supply could potentially occur prior to even vegetation decline. Conversely, it may be that decomposing vegetation provides ample habitat for macroinvertebrates to the point of near vegetation death and as such the food source would not be the limiting factor to the fountain darter during periods of extremely low flow. Similar to the aquatic vegetation study, not only will simulated impacts be assessed during extended periods of simulated low flow, but recovery following these periods will be studied to learn response time (amphipod recovery) following a severe event.

Tier A – Comal Springs Riffle Beetle Habitat Associations and Movement

- **Effects of flow levels on Comal Springs riffle beetle movement**

Upon completion of the artificial upwelling and spring run habitat within the created channel, Comal Springs riffle beetles will be collected from the wild and introduced into the artificial habitats. The first step will be to assess the survival success of adults. Once an adult population is established, flow manipulations will be performed to study the affinity of riffle beetles to flow and to track movement from surface to subsurface habitats and vice versa. The immediate goal is not to establish a reproducing riffle beetle population but to evaluate movement patterns of riffle beetles during periods of varying springflow. This study will be complicated by uncertainties in the ability to replicate food sources for the riffle beetle similar to what is experienced in the wild, so considerable trial and error is likely.

- **Extended Low-flow period effects on Comal Springs riffle beetles**

Once a population is established in the experimental habitat, extended periods of low-flow will be tested to evaluate the effect of these periods on riffle beetle survival and habitat use. Surface habitat will be completely removed for extended periods of time, water quality will be altered to simulate extreme conditions, and other factors adjusted (*e.g.*, reductions in leaf material or detritus, etc.) to simulate conditions that might be experienced in the wild during these conditions. As with other proposed Tier A efforts, recovery following impacts will also be investigated.

- ***Test spring run connectivity***

Once a population is established and the above two Tier A riffle beetle studies performed, the concept of spring run connectivity will be tested. This will involve simulating subsurface habitat cutoff from surface habitat and riparian detritus, and subsurface habitats that are connected to surface habitats via the trickling of water across the surface habitat. This is a key study to assess the value of this concept as an additional protection measure in Spring Run 3 of the Comal system as discussed in BIO-WEST (2011).

Tier B – Direct Impacts to Covered Species

- ***Low-flow effects on fountain darter movement, survival, and reproduction***

A series of low-flow experiments with various timing and durations will be evaluated while examining direct impacts to fountain darters. A whole host of questions can be addressed under this topic with just a few examples including:

- when and where do darters move as vegetation decays and water quality deteriorates;
- when does reproduction stop or does it;
- does compensatory reproduction get triggered, and if so, when and what causes it; and
- what is the effect of predation on fountain darter population size?

Since the fountain darter is a visual predator, and turbidity from stormwater run-off and recreational activities both increase turbidity, behavioral impacts of the fountain darter under different turbidity levels will also be examined in relation to feeding success. An endless number of scenarios are available to discuss under this heading which highlights the importance of a focused study design and schedule.

- ***Low-flow effects on Comal Springs riffle beetle survival and reproduction***

A series of low-flow experiments with various timing and durations will be evaluated while examining direct impacts to Comal Springs riffle beetles. A core question is: when are reproduction and survival compromised as physical habitat (surface and subsurface) declines and water quality deteriorates? The reproduction component assumes that a reproducing population can be established in the study habitat during Phase I. If a reproducing population is successfully established, this flow manipulation research could be expanded to include evaluation of desirable and threshold environmental conditions for larval and pupae stages.

Tier C – Testing repeat occurrences of low-flow or combination of effects.

- ***System Memory***

Upon completion of Tier A and B studies certain components and parameters will likely show impacts and some will not. Tier C is designed to take those components or parameters that do show impacts at varying springflow levels and to evaluate potential additive effects of repeat occurrences. As with all other studies, careful study design will be needed to maximize the efficiency of any system memory studies.

- ***Ecological Model Validation***

Existing information and data gathered during Tiers A and B applied research and through continued ecological monitoring and on-site studies will be entered into the ecological models developed for these ecosystems. Towards the end of Phase I, specific studies will be designed and conducted to test the validity of ecological model results. This may involve simple or complex parameters and single or multiple low-flow events depending on Phase II questions that may be relevant at that time.

Regardless of what Tier is involved, to be useful, studies will need to be designed to achieve an endpoint that can provide input to the ecological model or directly answer specific questions for the Phase II decision-making process or refinement of Phase I measures.

6.3.4.3 Additional Studies

Additional physical habitat activities/studies will be performed in the field. The following activities will be conducted within the Comal and San Marcos systems as part of the implementation of minimization and mitigation measures. Although not specifically covered

under Applied Research at the NFHTC these activities have the potential to directly influence study design at the applied research facility and, thus, are included to close this section.

Aquatic Vegetation Restoration and non-native plant removal

- Evaluate transplant methodologies for various types of native aquatic vegetation
- Evaluate success of transplants over extended time period
- Evaluate methodologies for removal of non-native plants
- Track maintenance required to keep non-native species from re-establishing

Old Channel ERPA

- Evaluate the need for channel manipulation for the enhancement of fountain darter habitat in the Old Channel. (Section 5.2.2.1).

Other biological interaction studies such as an evaluation of non-native animal species interactions with the fountain darter or gill parasite/snails/fountain darter interactions cannot be conducted at the NFHTC and thus will also be tied directly to on-site activities associated with those HCP conservation measures.

6.3.5 Texas Wild-Rice Enhancement

As discussed in Sections 5.3.1 and 5.4.1, restoration and enhancement of Texas wild-rice will be conducted during Phase I of the HCP. Initially, these activities will involve an applied research component. Methods for Texas wild-rice enhancement will need to be investigated to understand the potential for increased areal coverage of Texas wild-rice through implementation of this measure. Non-native vegetation mixed in with Texas wild-rice or surrounding existing Texas wild-rice plants but still located within optimal habitat areas will be removed to see if areal coverage of Texas wild-rice will expand in those areas. The specific areas chosen for evaluation will include only areas that would be suitable over the full range of discharges between the long term average and Phase I minimum flows. Once proven successful or not, this information can be beneficial for the Strategic Adaptive Management Decisions.

6.3.6 Monitoring and Reduction of Gill Parasites

A major concern in the Comal Springs ecosystem is the continued presence of an Asian trematode, *Centrocestus formosanus*. This parasite was first discovered on fountain darters in the Comal River during October 1996. The parasite attaches to the fish's gill filaments causing extensive gill tissue proliferation and damage (Mitchell *et al*. 2000) with mortality in the wild being reported following the discovery in 1996 (Tom Brandt, USFWS, personal communication). A non-native snail, *Melanoides tuberculatus*, that has been in central Texas since 1964 (Mitchell *et al*. 2005) has been confirmed as its central Texas first intermediate host (Mitchell *et al*. 2000). Parasite monitoring via examination of presence on fountain darter gills to determine *C.*

formosanus levels in the Comal River has been ongoing since the late 1990s by the USFWS, Texas State University, and BIO-WEST (EAA Variable Flow Study).

Through the EAA Variable Flow Study monitoring, the USFWS NFHTC sampled three sites in the Comal River during two sampling periods; first during 2006–2007, and again during 2009–2010. Two of the sites were located in the Upper Spring Run reach, and the third site was located downstream of Landa Lake in the Old Channel of the river. A significant decline in cercarial density was observed between the first and second sampling periods. Abiotic factors, such as total stream discharge and wading discharge, did not change significantly ($p>0.05$)[1] between sampling periods. Abiotic factors do not adequately explain the observed long-term decline in cercarial density (Johnson *et al*. 2011). Johnson *et al*. (2011) speculates that observed decline over time is likely a reflection of the typical pattern followed by most invasive species as they gradually become integrated into the local community following an initial explosive growth in population. Johnson *et al*. (2011) concluded that although cercarial densities may be abating, fountain darters in the Comal River are still threatened by the parasite, and conservation efforts will focus on reducing levels of infection pressure from the parasite whenever possible.

Informal observations suggest that the density of *C. formosanus* cercariae in the water column increases as stream discharge decreases and vice versa (T. Brandt, USFWS, personal communication), but there has been little definitive proof of this. If this relationship does exist between *C. formosanus* cercariae and discharge in the Comal River, there are concerns that increased levels of infection pressure would exacerbate the other stresses of low-flow periods on the fountain darter. Elimination of the parasite from the river probably cannot be accomplished. However, a possible practical approach to managing the parasite in the Comal River might be to control the parasite's snail host, *M. tuberculata*. USFWS and U.S. Environmental Protection Agency (EPA) authorizations to use chemicals known to be lethal to the snail likely cannot be obtained for the Comal River. Therefore, alternative methods need to be explored for decreasing abundances of *M. tuberculata* and the associated parasite.

In 2010, the EARIP funded a study (USFWS NFHTC and BIO-WEST 2011) to determine the effectiveness of *M. tuberculata* removal by physical methods on lowering drifting gill parasite numbers in the Comal River. The results from the study support the hypothesis that removing *M. tuberculata* from the Comal River correlates with a decrease in *C. formosanus* in the water column. These results support *M. tuberculata* control as an important HCP measure. However, there are several management and research questions still unanswered that may play a role in snail/parasite control and the relationship between the snails and the cercariae they release. The following activities to address these uncertainties will be conducted.

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[1] Statistical level of significance.

The initial activity will be the evaluation of alternative methods for snail removal so that removal can be accomplished in the most effective, yet least destructive manner. The second activity deals with understanding the magnitude of snail removal necessary to affect downstream cercaria concentrations in the water column. Once the magnitude of snail removal for effective control of water column cercaria is identified, a study is necessary to evaluate the long-term benefits of that removal. For instance, it is important to understand if the snails repopulate the area within a short period of time and cercaria concentrations quickly return to near original levels, or if both snail populations and cercaria counts stay suppressed for an extended period of time.

Additionally, although cercarial densities may be abating in the Comal system (Johnson *et al*. 2011), *C. formosanus* still poses a threat to fountain darters in the Comal River, especially during low-flows. As such, continued monitoring is essential and the following activities are included within this HCP conservation measure:

- A system-wide survey of snail population density and cercarial concentrations will be conducted to provide a baseline condition;
- Based on that system-wide survey, a decision will be made following the process set out in the AMP Agreement as to whether an initial system-wide removal effort is necessary, and if so, how to facilitate the performance of that effort;
- Based on the system-wide survey, a gill parasite monitoring program will be designed and implemented. Cercarial concentrations will be monitored in multiple areas along the Comal River on at least a semi-annual basis, and more frequently when spring flow drops initially below 150 cfs or other springflow triggers that are developed. Corresponding fountain darter sampling to examine correlations between cercariae densities and fountain darter impacts in the wild will also be part of that monitoring effort.

6.4 Core Adaptive Management Actions

This section outlines the AMP actions to protect habitat and populations of Covered Species in both the Comal and San Marcos Springs/River ecosystems in the event of limited recharge.

6.4.1 Risk Assessment, Estimation of Take, and Drought of Record

Because biological data typically has great variability and there are many habitat and population parameters that potentially affect the population dynamics of a species, it is very difficult to assess the threat of extirpation. In any natural setting, the unpredictability of the effects of an individual event (*e.g.*, extended low flow period) are often highly correlated with conditions immediately prior to the event complicating development of target conditions necessary to maintain habitat. For the AMP outlined here, a range of parameters is used to assess biological

risks associated with deviating from the objectives set forth in Chapter 4 above for the individual species.

Although protection of springflows to minimize the level of take is incorporated into the Phase I package, it is possible that conditions may reach or exceed the level of take during a repeat of conditions similar to those in the drought of record. This plan provides a framework for addressing such conditions, if they should occur, by providing measures to mitigate effects of such droughts on the species. The Phase I package should limit the time at and magnitude of impacts, but in the event that discharge falls to these levels, additional measures need to be in place to monitor changes closely and further protect habitat and the Covered Species.

The AMP proposes a conservative approach that incorporates regular biological monitoring before and after and frequent monitoring during such events. It is important to accurately define dynamic ecosystem conditions prior to the onset of a limited recharge period to assess potential threats during an extended period under those conditions. Biological monitoring during a period of declining spring discharge will permit a close examination of actual population and habitat conditions when flow declines to or below modeled levels of concern. This approach differs from the traditional one of establishing one fixed number for total discharge below which the species is at risk and above which it is not. Instead, fixed numbers of total discharge are used to trigger additional sampling and used in conjunction with those sampling results to more accurately define biological risk and population changes. Fixed sampling outcomes coupled with fixed discharge levels elicit specific management responses. This is a more dynamic process that takes into account actual conditions rather than predetermined hypotheses of what conditions might be expected at certain discharge levels based on limited data. It is also anticipated that the ecological modeling discussed above will prove instrumental in projecting potential impacts allowing for informed and timely management decisions.

6.4.2 Plan Outline

This Section outlines key parameters that are important to each species and provides the critical values that will elicit management responses. These responses include increased vigilance of ecosystem conditions (more frequent sampling) and increased levels of habitat restoration and enhancement measures (native vegetation restoration, ERPA, Texas wild-rice enhancement, etc.) targeted at maintaining populations and habitat in the wild. Finally, although not anticipated, nor projected, for the Phase I package, salvage efforts and off-site refugia are included as a safety net should conditions deteriorate beyond what is expected calling into question the likelihood of continued species existence in the wild.

The adaptive management response triggers and biological relevance that are incorporated into the response for each action were based on existing biological data. Absent specific low flow data which will be collected as indicated (Critical Period monitoring or applied research), the critical values indicated below should be sufficient to support viable populations of Covered Species and their habitats.

One of the adaptive management response options for Covered Species is off-site refugia. Although the Phase I package and adaptive management responses are designed to maintain conditions that allow populations of Covered Species to persist in the wild through periods of limited recharge that may be reasonably expected during Phase I of the HCP, there remains the slight possibility that salvage efforts (off-site refugia) will be necessary. The initiation for such efforts differs by species; an outline is provided below for conditions necessary to resort to this step for each respective species.

The ERPA presents an option for protecting the fountain darter and other Covered Species in the wild during periods of low springflow. Preliminary study (BIO-WEST 2011) has documented the feasibility of such actions in the protection of the fountain darter in the wild. In the Comal system, native aquatic vegetation restoration and habitat protection (via flow-split management and high flow deflection) in the Old Channel will be relied on as one tool for protecting fountain darters during periods of decreasing low flows.

6.4.3 Comal Springs/River Ecosystem Adaptive Management Activities

6.4.3.1 Fountain Darter

The proposed Adaptive Management objectives and trigger levels for initiation of management responses for the fountain darter in the Comal Springs/River ecosystem are:

Adaptive Management Objectives

- Maintain adequate springflow and manage other factors to meet the following conditions:

  - Minimize extent of range and time that water temperature is >25°C;

  - Maintain >75 percent of mean abundance[2] of aquatic vegetation in prime habitat;

  - Maintain >25 percent of mean abundance of aquatic vegetation in marginal habitat; and

  - Maintain adequate (within historical range) water quality.

- Determine potential effect of parasite(s) and other non-native species, and if impacts are evident, minimize those impacts); and

- Determine potential impact of predation and competition during lower flows, and, if present during lower flows, minimize those impacts.

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[2] Based on existing 10 years of Variable Flow Study data (will be updated by future sampling events where total discharge >150 cfs in the Comal River).

Triggered Monitoring

As a consequence of discharge dropping to the springflow level of concern (150 cfs) in the Comal River, the following specific monitoring activities will occur every other month until discharge falls to 80 cfs or increases to above 150 cfs.

- Aquatic vegetation mapping—Four sites established by Variable Flow Study to include Upper Spring Run reach, Landa Lake, Old Channel reach, and New Channel reach; and.

- Dip net sampling/visual parasite evaluations—Presence/absence surveys to be conducted at 50 sites in high quality habitat (Upper Spring Run reach (5), Landa Lake (20), Old Channel reach (20), and New Channel reach (5).

If discharge continues to decline and falls to 60 cfs or lower, increased risk may be observed. Under these conditions, the same sampling procedures discussed above will be conducted but more frequently (monthly for aquatic vegetation mapping and weekly for dip netting).

Old Channel ERPA

The two minimization and mitigation measures specifically associated with the Old Channel ERPA for the fountain darter in the Comal River are native aquatic vegetation restoration and flow-split management. Flow split management is proposed for all conditions but with special emphasis when flows fall below 150 cfs. Native aquatic vegetation restoration and maintenance is proposed to be in place under all conditions. The objective of the Old Channel ERPA is to maintain water temperatures and high quality fountain darter habitat in the Old Channel at a level suitable for darter reproduction (in the spring) and larval and adult darter survival during the remaining portion of the year.

Off-site Refugia

The habitat triggers for off-site refugia are not solely dependent on discharge. Off-site refugia efforts could be triggered as high as 60 cfs or not at all, if habitat and population abundances are maintained above trigger levels.

Two variables will be considered in concert with total discharge in the Comal River to assess the need to initiate refugia efforts for fountain darter populations: availability of sufficient habitat (aquatic vegetation), and presence/absence of darters throughout the known range. The total amount of aquatic vegetation under such conditions will be compared to mean aquatic vegetation coverage during favorable conditions (determined from all past and future Variable Flow Study samples at or above 150 cfs, but excluding samples initiated specifically to study “high flow events”). Data collected outside of favorable conditions (below 150 cfs or after high flow events) are extremely valuable to determine low and high flow impacts, respectively, but should not be used to adjust the value used as an indicator of average habitat condition. The mean will be calculated by assigning a rank value to each vegetation type based on fountain darter preference and multiplying this weighting factor by the sum of each type from all four

reaches used in the Variable Flow Study. The second variable, fountain darter presence/absence will be calculated as a proportion of dip-net samples that have fountain darters present. Sampling will consist of presence/absence dipnet surveys at 50 sites within the Comal system. As an example, 10 sites with darters out of 50 sites equals 20% and 15 sites with darters equals 30 percent.

Using both of these variables, in addition to total discharge, increases the likelihood of correctly identifying deteriorating conditions that might not be easily observed using one method. Similarly, it reduces the probability of initiating a massive salvage effort when unwarranted. The modification of mean habitat condition with future data also provides an advantage by allowing for the refinement of comparison data over time.

The proposed trigger levels are as follows:

- *Less than 50 percent mean aquatic vegetation (Landa Lake and Old Channel) AND less than 20 percent darter presence system-wide,*

OR

- *Less than 25 percent mean aquatic vegetation (Landa Lake and Old Channel) AND less than 30 percent darter presence system-wide.*

The reason for the higher percentage of darter abundance for the second trigger level is the expectation that the number of darters in high quality habitat will increase as the amount of available habitat decreases (clumping effect).

Confirmation samples will be very important for this management plan. The trigger levels are designed to provide a conservative buffer that will allow time to verify conditions with a follow-up sample. In addition, when low discharge triggers additional monitoring, sampling will be frequent enough to observe a trend in conditions over time to help evaluate whether conditions have truly deteriorated to the point that off-site refugia are necessary. For the fountain darters, habitat assessment (aquatic vegetation mapping) is too time consuming to verify with a follow-up sample; however, dip-net sampling can be accomplished by one person within one day. Therefore, triggering the off-site refugia with one of the two scenarios listed above will also require a follow-up dip-net sample the succeeding day to confirm the results. If confirmed, action will be taken to initiate off-site refugia collections.

6.4.3.2 Comal Springs Riffle Beetle

The proposed Adaptive Management objectives and trigger levels for initiation of management responses for the Comal Springs riffle beetle are presented below.

Adaptive Management Objectives

- Maintain horizontal and upwelling flows in >50 percent of surface habitat;
- Maintain adequate water quality (parameters maintained within historical ranges); and

- Determine extent of subsurface use and spatial distribution (if subsurface use is common, modify surface habitat requirements and modify objectives to include subsurface habitat availability).

Triggered Monitoring

When the springflow of concern (120 cfs) is reached, monitoring of the Comal Springs riffle beetle populations via cotton lures will be conducted every two weeks at three sites (Spring Run 3, western shore of Landa Lake, and Spring Island upwelling) until discharge increases to a level above 120 cfs.

ERPAs

There are currently no plans to establish an ERPA for Comal Springs riffle beetles in the Comal system. As discussed in Section 4.3, the flow levels supported by the Phase I package are deemed sufficient to protect the species during a repeat of conditions similar to the drought of record. One additional concept discussed in BIO-WEST (2011c) but not currently considered in the HCP measures is spring run connectivity. Should it be determined during applied research conducted at the NFHTC during Phase I that spring run connectivity is effective and that additional protection may be required for the Comal Springs riffle beetle, then some version of that component may be implemented during Phase II.

Off-site Refugia

Off-site refugia efforts will be initiated below 30 cfs when biological sampling reveals a substantial decline in the number of individuals in the surface layer of substrate in high quality habitat areas (Spring Run 3, Western Shoreline, Spring Island).

The proposed trigger level for off-site refugia is:

- *When only one of the three monitored sites continues to have six or more adult beetles (collected in a 24 hour sampling period using cotton lures).*

6.4.3.3 Comal Springs Dryopid Beetle, Peck's Cave Amphipod, and Edwards Aquifer Diving Beetle

Proposed Adaptive Management objectives and trigger levels for initiation of management responses for the Comal Springs dryopid beetle, Peck's Cave amphipod, and Edwards Aquifer diving beetle are presented below.

Comal Springs Dryopid Beetle Adaptive Management Objectives

- Maintain adequate water quality within aquifer (parameters maintained within historical ranges);
- Monitor bad water line;

- Determine spatial and temporal distribution in the Aquifer;
- Determine life history characteristics (life span, tolerance to water quality changes, reproduction, food sources) and minimize impacts; and
- Determine how food sources, particularly those that originate from far away (*e.g.*, organic material washed in from recharge features and chemolithoautotrophic bacteria in deep aquifer) vary naturally and minimize impacts as appropriate.

Peck's Cave Amphipod Adaptive Management Objectives

- Maintain adequate water quality within aquifer (parameters maintained within historical ranges);
- Monitor bad water line;
- Determine spatial and temporal distribution in the Aquifer; and
- Determine life history characteristics (life span, tolerance to water quality changes, reproduction, food sources) and minimize impacts; and
- Determine how food sources, particularly those that originate from far away (*e.g.,* organic material washed in from recharge features and chemolithoautotrophic bacteria in deep aquifer) vary naturally and minimize impacts as appropriate.

Edwards Aquifer Diving Beetle Adaptive Management Objectives

- Maintain adequate water quality within aquifer (parameters maintained within historical ranges);
- Monitor bad water line;
- Determine spatial and temporal distribution in the Aquifer; and
- Determine life history characteristics (life span, tolerance to water quality changes, reproduction, food sources) and minimize impacts; and
- Determine how food sources, particularly those that originate from far away (*e.g.*, organic material washed in from recharge features and chemolithoautotrophic bacteria in deep aquifer) vary naturally and minimize impacts as appropriate.

Triggered Monitoring

Below 30 cfs total Comal springflow, weekly monitoring for standard water quality parameters (dissolved oxygen, conductivity, pH, and temperature) will be conducted at a network of three wells located within the immediate vicinity of Comal Springs. At 20 cfs total Comal springflow

the weekly water quality monitoring will be expanded from standard parameters to include conventional water quality parameters (nutrients, TDS, TOC) at the same network of three wells.

ERPAs

There are currently no plans for creating an ERPA for subterranean species in the Comal system. The flow levels supported by the Phase I package are deemed sufficient to protect the species during a repeat of conditions similar to the drought of record.

Off-site Refugia

Off-site refugia efforts will be initiated when water quality sampling reveals a substantial decline in one or more of the parameters measured.

The proposed trigger for off-site refugia is when:

- *Any standard or conventional water quality parameter exceeds the historical range of the water quality parameter for the Edwards Aquifer by 10 percent or more.*

6.4.3.4 Comal Springs Salamander

Proposed Adaptive Management objectives and trigger levels for initiation of management responses for the Comal Springs Salamander are presented below.

Adaptive Management Objectives

- Clarify the taxonomy of the species, including the species range and the connectivity with other populations, if they exist; and
- Maintain adequate springflow and manage other factors to meet following conditions:
- Maintain >75 percent of physical habitat (silt-free rocks) at all times;
    - Maintain adequate water quality (parameters maintained within historical ranges); and
    - Minimize extent of range and time that water temperature is >27°C.

Triggered Monitoring

When the springflows of concern (120 cfs) is reached, the following monitoring activity is triggered and will occur every other week (regardless of duration of similar flow) until the next level is triggered (80 cfs) or flows are increased to above 120 cfs.

Salamander snorkel surveys will be conducted at the three sites established by Variable Flow Study to include Spring Runs 1 and 3 and the Spring Island area. When springflow falls below 80 cfs, the same sampling effort will occur weekly until flows increase to above 80 cfs.

ERPAs

There are currently no plans to create an ERPA for the Comal Springs Salamander. As discussed in Section 4.3, the flow levels supported by the Phase I package are deemed sufficient to protect the species during a repeat of conditions similar to the drought of record. Should it be determined during applied research conducted at the NFHTC during Phase I that spring run connectivity is effective for the Comal Springs riffle beetle and that additional protection may be required for the Comal Springs salamander, then additional testing on the salamander at the NFHTC applied research facility will be conducted. Upon proven applicability and success, some version of that component may be implemented during Phase II.

Off-site Refugia:

It is important to note that the proposed habitat triggers for off-site refugia are not solely dependent on discharge. Off-site refugia efforts could be triggered as high as 120 cfs, or not at all, if habitat and population abundances remain above trigger levels.

As with the fountain darter, two variables will be considered in concert with total discharge to assess the need to initiate off-site refugia efforts for the Comal Springs salamander population: availability of suitable habitat and salamander density throughout the known range. The total amount of suitable habitat measured under such conditions will be compared to a mean of total suitable habitat available during favorable conditions (determined from all past and future Variable Flow Study samples at or above 120 cfs, but excluding samples initiated specifically to "high flow events"). Data collected outside of favorable conditions (below 120 cfs or after high flow events) are extremely valuable to determine low and high flow impacts, respectively, but should not be used to adjust the value used as an indicator of average habitat condition. The second variable, salamander density, will be calculated by finding the mean density among the three sites sampled for the Variable Flow Study. As with the suitable habitat variable, the mean density observed during each sample will be compared to a mean density of all samples taken during favorable conditions (all past and future Variable Flow Study samples at or above 120 cfs, but excluding high-flow events).

Using both of these variables, in addition to total discharge, increases the likelihood of correctly identifying deteriorating conditions that might not be easily observed using one method. Similarly, it reduces the probability of initiating a massive salvage effort when unwarranted. The modification of mean habitat condition with future data also provides an advantage by allowing for the refinement of comparison data over time.

The proposed trigger levels are as follows:

- *Less than 50 percent suitable habitat (Variable Flow Study monitoring locations) AND less than 20 percent salamander density*

OR

- *Less than 25 percent suitable habitat (Variable Flow Study monitoring locations) AND less than 30 percent salamander density.*

The reason for the higher percentage of salamander density for the second trigger level is that it is anticipated that the number of salamanders in high quality habitat will increase as the amount of suitable habitat decreases (clumping effect).

6.4.4 San Marcos Springs and River Ecosystem Adaptive Management Activities

6.4.4.1 Fountain Darter

Proposed Adaptive Management objectives and trigger levels for initiation of management responses for the fountain darter in the San Marcos Springs/River ecosystem are found below.

Adaptive Management Objectives

- Maintain adequate springflow and manage other factors to meet the following conditions:

  - Minimize extent of range and time that water temperature is >25°C;

  - Maintain >75 percent of mean abundance[3] of aquatic vegetation in prime habitat;

  - Maintain >25 percent of mean abundance of aquatic vegetation in marginal habitat; and

  - Maintain adequate (within historical range) water quality.

- Determine potential effect of parasite(s) and other non-native species (if impacts evident, minimize impacts); and
- Determine potential impact of predation and competition during lower flows (if present during lower flows, minimize impacts).

Triggered Monitoring

As a consequence of discharge declining to the level of take (80 cfs) in the San Marcos River, the following specific monitoring activities will occur every other month (regardless of duration of similar flow) until discharge falls to 50 cfs or increases to above 100 cfs.

- Aquatic vegetation mapping—Three sites established by Variable Flow Study to include Spring Lake Dam reach, City Park reach, and IH-35 reach.
- Dip Net sampling/visual parasite evaluations—Presence/absence surveys to be conducted at 50 sites in high quality habitat (Spring Lake [20], Spring Lake Dam reach [10]), City Park reach [10], and IH-35 reach [10]).

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[3] Based on existing 10 years of Variable Flow Study data (will be updated by future sampling events where total discharge >100 cfs in the San Marcos River).

When springflow is less than 50 cfs, aquatic vegetation mapping will be conducted monthly, while dip net sampling and visual parasite evaluations will occur weekly.

ERPAs

There are currently no plans to create an ERPA for the fountain darter in the San Marcos system. As discussed in Section 4.3, the flow levels supported by the Phase I package are deemed sufficient to protect the species during a repeat of conditions similar to the drought of record. Should data collected during Phase I applied research or monitoring show that additional protection may be required for the fountain darter, then activities (such as an Eastern Spillway ERPA) discussed in BIO-WEST (2011c) may warrant further exploration.

Off-Site Refugia

It is important to note that the proposed habitat triggers for off-site refugia are not solely dependent on discharge. Off-site refugia efforts could be triggered as high as 50 cfs or not at all, if habitat and population abundances remain above trigger levels.

As in the Comal River, two variables will be considered in concert with total discharge to assess the need to initiate off-site refugia efforts for the fountain darter population: availability of sufficient habitat (aquatic vegetation), and presence/absence of darters throughout the known range. These variables will be measured and calculated in the same manner as in the Comal River to determine when a trigger has been reached.

The proposed trigger levels are as follows:

- *Less than 50 percent mean aquatic vegetation (Variable Flow Study monitoring reaches including Spring Lake) AND less than 20 percent darter abundance,*

OR

- *Less than 25 percent mean aquatic vegetation (Variable Flow Study monitoring reaches including Spring Lake) AND less than 30 percent darter abundance.*

The reason for the higher percentage of darter abundance for the second trigger level is that it is anticipated that the number of darters in high quality habitat will increase as the amount of available habitat decreases (clumping effect).

Confirmation samples will be very important for this management plan. These trigger levels have been designed to provide a conservative buffer that will allow time to verify conditions with a follow-up sample. In addition, when low discharge triggers additional monitoring, sampling will be frequent enough to observe a trend in conditions over time to help evaluate whether conditions have actually deteriorated to the point that off-site refugia are necessary. For the fountain darters, habitat assessment (aquatic vegetation mapping) is too time consuming to verify with a follow-up sample; however, dip-net sampling can be accomplished by one person within one day. Therefore, triggering the off-site refugia with one of the two scenarios listed above will also require a follow-up dip-net sample the succeeding day to confirm the results. If confirmed, action would be taken to initiate off-site refugia collections.

6.4.4.2 San Marcos Salamander

Proposed Adaptive Management objectives and trigger levels for initiation of management responses for the San Marcos salamander are presented below.

Adaptive Management Objectives

Maintain adequate springflow and manage other factors to meet following conditions:

- Maintain >75 percent of physical habitat (silt-free rocks) at all times;
- Maintain adequate water quality (parameters maintained within historical ranges); and
- Minimize extent of range and time that water temperature is >27°C.

Triggered Monitoring

When the springflow level of concern (80 cfs) is reached, the following specific monitoring activity is triggered and will occur every other week (regardless of duration of similar flow) until the next level is triggered or flows are increased to above 80 cfs.

Salamander surveys (SCUBA and snorkel) will be conducted at the three sites established by Variable Flow Study to include Hotel Area (Site 2), Riverbed Area (Site 14), and eastern spillway of Spring Lake dam (Site 22). When springflow falls below 50 cfs, the same sampling effort will occur weekly until flows increase to above 50 cfs.

ERPAs

There are currently no plans to create an ERPA for the San Marcos salamander in the San Marcos system. As discussed in Section 4.3, the flow levels supported by the Phase I package are deemed sufficient to protect the species during a repeat of conditions similar to the drought of record. Should data collected during Phase I applied research or monitoring show that additional protection may be required for the San Marcos salamander, then activities (such as an Eastern Spillway ERPA) discussed in BIO-WEST (2011c) may warrant further exploration. The objective of the Eastern Spillway ERPA is to maintain high-quality silt-free rock habitat, native vegetation to host salamander prey items, and recreation-disturbance-free high quality salamander habitat, particularly during average and low flows.

Off-site Refugia

The habitat triggers for off-site refugia are not solely dependent on discharge. Off-site refugia efforts could be triggered as high as 80 cfs, or not at all, if habitat and population abundances remain above trigger levels.

As with the fountain darter, two variables will be considered in concert with total discharge to assess the need to initiate off-site refugia efforts for the San Marcos salamander population: availability of suitable habitat and salamander density throughout the known range. The total amount of suitable habitat measured under such conditions will be compared to a mean of total suitable habitat available during favorable conditions (determined from all past and future Variable Flow Study samples at or above 80 cfs, but excluding samples initiated specifically to

"high flow events"). Data collected outside of favorable conditions (below 80 cfs or after high flow events) are extremely valuable to determine low and high flow impacts, respectively, but should not be used to adjust the value used as an indicator of average habitat condition. The second variable, salamander density, will be calculated by finding the mean density among the three sites sampled for the Variable Flow Study. As with the suitable habitat variable, the mean density observed during each sample will be compared to a mean density of all samples taken during favorable conditions (all past and future Variable Flow Study samples at or above 80 cfs, but excluding high-flow events).

Using both of these variables, in addition to total discharge, increases the likelihood of correctly identifying deteriorating conditions that might not be easily observed using one method. Similarly, it reduces the probability of initiating a massive salvage effort when unwarranted. The modification of mean habitat condition with future data also provides an advantage by allowing for the refinement of comparison data over time.

The proposed trigger levels are as follows:

- *Less than 50 percent suitable habitat (Variable Flow Study monitoring locations) AND less than 20 percent salamander density*

OR

- *Less than 25 percent suitable habitat (Variable Flow Study monitoring locations) AND less than 30 percent salamander density.*

The reason for the higher percentage of salamander density for the second trigger level is that it is anticipated that the number of salamanders in high quality habitat will increase as the amount of suitable habitat decreases (clumping effect).

6.4.4.3 Texas Blind Salamander and Texas Troglobitic Water Slater

Proposed Adaptive Management objectives and trigger levels for initiation of management responses for the Texas blind salamander and Texas troglobitic water slater are presented below.

Adaptive Management Objectives

- Maintain adequate water quality (parameters maintained within historical ranges) within the aquifer;
- Monitor bad water line;
- Determine spatial and temporal distribution in the aquifer;
- Determine life history characteristics (life span, tolerance to water quality changes, reproduction, food sources) and minimize impacts; and
- Determine how food sources, particularly those that originate from far away (*e.g.*, organic material washed in from recharge features and chemolithoautotrophic bacteria in deep aquifer) vary naturally and minimize impacts as appropriate.

Triggered Monitoring

Below 50 cfs, weekly monitoring for standard water quality parameters (dissolved oxygen, conductivity, pH, and temperature) will be conducted at a network of three wells located within the vicinity of San Marcos Springs. When springflow falls below 30 cfs, the weekly water quality monitoring is expanded from standard parameters to include conventional water quality parameters (nutrients, TDS, total organic carbon) at the same network of three wells.

ERPAs

There are currently no plans to create an ERPA for subterranean species in the San Marcos system. As discussed in Section 4.3, the flow levels supported by the Phase I package are deemed sufficient to protect the species during a repeat of conditions similar to the drought of record.

Off-site Refugia

Off-site refugia efforts will be initiated below 30 cfs when water quality sampling reveals a substantial decline in one or more of the parameters measured.

The proposed trigger for off-site refugia is when:

- *Any standard or conventional water quality parameter exceeds the historical range of the water quality parameter for the Edwards Aquifer by 10 percent or more.*

6.4.4.4 Texas Wild-Rice

Proposed Adaptive Management objectives and trigger levels for initiation of management responses for Texas wild-rice are presented below.

Adaptive Management Objectives

- Maintain >3,500 m^2 of Texas wild-rice plants at all times;
- Maintain Texas wild-rice stands at a minimum of three distinct longitudinal sections of the San Marcos River as described by the Variable Flow Study;
- Maintain adequate water quality (parameters maintained within historical ranges);
- Minimize extent of vegetative mats and time that mats cover Texas wild-rice plants; and
- Determine and minimize impacts from herbivory and recreation during low flow.

Triggered Monitoring

When springflow level of concern (100 cfs) is reached, the following specific monitoring activities are also triggered and will occur at the specified frequency (regardless of duration of similar flow) until the next level is triggered or flows are increased above 100 cfs.

- At 100 cfs, mapping of Texas wild-rice coverage for the entire San Marcos River will be conducted; and
- From 100 cfs to 60 cfs, physical parameters of Texas wild-rice will be monitored every other week in designated “vulnerable” areas as established by the Variable Flow Study.

When springflow is less than 80 cfs, total Texas wild-rice coverage will be mapped monthly under the guidelines specified above and physical visual observations will occur weekly.

ERPAs

There are currently no plans to create an ERPA for Texas wild-rice in the San Marcos system. As discussed in Section 4.3, the flow levels supported by the Phase I package are deemed sufficient to protect the species during a repeat of conditions similar to the drought of record. However, because of uncertainties associated with habitat modeling for Texas wild-rice, additional restoration and enhancement activities described in Chapter 6 are proposed for Texas wild-rice. Additionally, recreation control in key Texas wild-rice areas during low-flow conditions is also recommended.

As previously stated, regardless if the eastern spillway is turned into an ERPA as discussed in BIO-WEST (2011c), access to this area will be restricted through its inclusion in the State Scientific Area discussed in Section 5.6 above. This alone will greatly enhance the protection of fountain darter, San Marcos salamander, and Texas wild-rice in the reach immediately below Spring Lake Dam.

Off-site Refugia

It is important to note that the proposed habitat triggers for off-site refugia are not solely dependent on discharge. Off-site refugia efforts could be triggered as high as 80 cfs or not at all, if areal coverage remains above trigger levels.

The proposed trigger levels are as follows:

- *Less than 3,500 m^2 total coverage in the San Marcos River*

OR

- *Texas wild-rice stands exist at fewer than three distinct sections as described by the Variable Flow Study seven sections.*

Chapter 7 Costs and Funding

7.0 Introduction

To issue the ITP, USFWS must find that the Applicants "will ensure that adequate funding for the [HCP] will be provided." (16 U.S.C. § 1539(a)(2)(B)(iii)). To satisfy this requirement, the costs of implementing the HCP are set out below along with the assurance that funding will be available to implement the HCP. Specifics regarding the funding arrangements for the HCP are found in Articles Three and Five of the FMA, (Appendix R) and that are generally described briefly in Sections 7.1.1 and 9.1.1 below.

Consistent with the phasing of the HCP, the costs and funding for implementation of the HCP are discussed below with respect to Phase I and Phase II of the HCP. Cost estimates are more detailed for Phase I, reflecting the prioritization of minimization and mitigation measures and task specific estimates derived from efforts of the Ecosystem Restoration Subcommittee, HDR Engineering, Inc., and BIO-WEST, Inc. with input from knowledgeable stakeholders. Although the measures may be modified during the term of the ITP as provided for in the AMP, the funding commitment will continue through the term of the ITP, with a potential augmentation in Phase II as described below, subject to the AMP.

7.1 Phase I Measures

7.1.1 Annual Implementation Costs

The estimated annual cost of implementing the minimization and mitigation measures in Chapter 5 and conducting the AMP in each year of the HCP is presented in Table 7.1. Implementation of some measures in the Phase I program will entail the expenditure of non-recurring funds at the early years of the HCP for the habitat minimization and mitigation measures at Comal and San Marcos springs. Accordingly, the costs in the initial years are higher than in later years. The annualized costs in year 7 are expected to continue through Phase II, unless changed by the AMP.

The cost of the SAWS ASR springflow protection measure was based on the experience of SAWS and other members of the SAWS ASR Work Group in leasing water and SAWS' experience in operating its ASR. (*See* Appendix S). HDR Engineering, Inc. participated in the development of these cost estimates. The costs include the annual cost of leasing water for the SAWS ASR ($4,759,000) and the annual O&M costs related to the use of the ASR ($2,194,000). These costs are average annual costs based on a probabilistic analysis of the triggers for leasing the water and recovering water from the ASR. (*See* Section 5.5.1)

The cost of the Regional Water Conservation Program was developed by the Conservation Work Group based largely on SAWS's experience with its conservation program. (*See* Appendix T). HDR Engineering, Inc. reviewed these cost estimates.

The estimated costs of the habitat minimization and mitigation measures were initially developed by the Ecosystem Restoration Subcommittee. (*See* Appendix U). To the extent possible, these estimates were based on experience in the springs ecosystem or comparable projects implemented elsewhere. Subsequently, the costs were refined by the cities of San Marcos and New Braunfels and included, where possible, preliminary estimates by potential contractors. The costs were reviewed and further refined by BIO-WEST with the participation of representatives from the spring cities.

Table 7.1: ANNUALIZED IMPLEMENTATION COSTS

ACTIVITY	Annual Costs (Years 1-7)							TOTAL
	2013	2014	2015	2016	2017	2018	2019	TOTAL Annual
CPM Stage V (§ 5.1.4)	NA	NA	NA	NA	NA	NA	NA	
Use of SAWS ASR for Springflow Protection Trade Off (§ 5.5.1)								
Obtaining Leases and Options for Water	$ 4,759,000	$ 4,759,000	$ 4,759,000	$ 4,759,000	$ 4,759,000	$ 4,759,000	$ 4,759,000	$ 33,313,000
O&M Costs related to the actual use of the ASR	$ 2,194,000	$ 2,194,000	$ 2,194,000	$ 2,194,000	$ 2,194,000	$ 2,194,000	$ 2,194,000	$ 15,358,000
Regional Water Conservation Program (§ 5.1.3)	$ 493,250	$ 986,500	$ 1,973,000	$ 1,973,000	$ 1,973,000	$ 1,973,000	$ 1,973,000	$ 11,344,750
Voluntary Irrigation Suspension Program Option (§ 5.1.2)	$ 4,172,000	$ 4,172,000	$ 4,172,000	$ 4,172,000	$ 4,172,000	$ 4,172,000	$ 4,172,000	$ 29,204,000
SAN MARCOS SPRINGS - Measures to Reduce the Impacts of Drought and Recreation and Enhance the Viability of the Listed Species								
Texas wild-rice enhancement and restoration (§ 5.3.1, § 5.4.1)	$ 250,000	$ 175,000	$ 175,000	$ 125,000	$ 125,000	$ 100,000	$ 100,000	$ 1,050,000
Sediment removal - Sewell Park (§ 5.3.6, § 5.4.4)	$ 500,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 650,000
Aquatic vegetation restoration (non-native removal and native re-establishment) and maintenance - San Marcos River (§ 5.3.8, § 5.4.3, § 5.4.12)	$ 375,000	$ 175,000	$ 125,000	$ 125,000	$ 75,000	$ 50,000	$ 50,000	$ 975,000
Management of floating vegetation mats and litter removal (Spring Lake and San Marcos River) (§ 5.3.3, § 5.4.3)	$ 80,000	$ 80,000	$ 80,000	$ 80,000	$ 80,000	$ 80,000	$ 80,000	$ 560,000
Non-native animal species control (§ 5.3.5, § 5.3.9, § 5.4.11, § 5.4.13)	$ 35,000	$ 35,000	$ 35,000	$ 35,000	$ 35,000	$ 35,000	$ 35,000	$ 245,000
Sessom Creek sand bar removal (§ 5.4.6)	$ 25,000	$ 75,000	$ -	$ -	$ -	$ -	$ -	$ 100,000
Low Impact Development / BMPs (§ 5.7.3)	$ 500,000	$ 500,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 2,000,000
Recreation control in key areas (enforcement) (§ 5.3.2, §5.4.2)	$ -	$ 56,000	$ 56,000	$ 56,000	$ 56,000	$ 56,000	$ 56,000	$ 336,000
Restoration of riparian zone with native vegetation (§ 5.7.1)	$ 100,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 220,000
Bank stabilization / Permenant access points (§ 5.3.7)	$ 500,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 120,000
Bio-monitoring (§ 6.3.1)	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 1,400,000
Water Quality Monitoring and Protection (§ 5.7.2, 5.7.6)	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 700,000
Household hazardous waste program (§ 5.7.5)	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 210,000
Other Measures								
Management of public recreational use (§ 5.3.2.1)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Prohibition of hazardous materials route (§ 5.3.4)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Diversion of Surface Water (§ 5.4.5)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Diving Classes in Spring Lake (§ 5.4.7)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Creation of Scientific Areas (§ 5.6)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Research Programs in Spring Lake (§ 5.4.8)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Boating in Spring Lake and Sewell Park (§ 5.3.10)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Septic system registration and permitting program (§ 5.7.3)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Management of golf course grounds (§ 5.4.9)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
TOTAL	$ 2,695,000	$ 1,491,000	$ 1,066,000	$ 1,016,000	$ 966,000	$ 916,000	$ 916,000	$ 9,066,000
COMAL SPRINGS - Measures to Reduce the Impacts of Drought and Recreation Enhance the Viability of the Listed Species								
Old Channel ERPA - Includes aquatic vegetation restoration and maintenance; limited channel modifications as necessary to enhance fountain darter habitat, and removal of the sediment island (§ 5.2.2.1)	$ 400,000	$ 175,000	$ 175,000	$ 125,000	$ 125,000	$ 100,000	$ 100,000	$ 1,200,000
Flow-split management - old and new channels (§ 5.2.1)	$ 150,000	$ -	$ -	$ 30,000	$ -	$ -	$ 30,000	$ 210,000
Landa Lake and Comal River - aquatic vegetation restoration and maintenance (§ 5.2.2 except § 5.2.2.1)	$ 200,000	$ 220,000	$ 125,000	$ 100,000	$ 100,000	$ 50,000	$ 50,000	$ 845,000
Non-native animal species control (§ 5.2.5, § 5.2.9)	$ 135,000	$ 135,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 645,000
Decaying vegetation removal program (§ 5.2.4)	$ 750,000	$ 15,000	$ 15,000	$ 15,000	$ 15,000	$ 15,000	$ 15,000	$ 840,000
Riparian improvements and sediment removal specific to the Comal Springs riffle beetle (§ 5.2.8)	$ 100,000	$ 75,000	$ 50,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 325,000
Gill parasite control and non-native snail removal program including optimization research(§ 5.2.6)	$ 175,000	$ 175,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 725,000
Restoration of riparian zone with native vegetation (§ 5.7.1)	$ 200,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 800,000
Prohibition of hazardous materials route (§ 5.2.7)	$ 10,000	$ -	$ -	$ -	$ -	$ -	$ -	$ 10,000
BMPs for stormwater control (§ 5.7.6)	$ 200,000	$ -	$ -	$ 50,000	$ -	$ -	$ 50,000	$ 300,000
Incentive program for low impact development (§ 5.7.6)	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 700,000
Bio-monitoring (§ 6.3.1)	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 1,400,000
Water Quality Monitoring (§ 5.7.4)	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 700,000
Household hazardous waste program (§ 5.7.5)	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 210,000
Other Measures								
Creation of state scientifc areas (§ 5.6)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Management of public recreational use (§ 5.2.3)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
TOTAL	$ 2,750,000	$ 1,325,000	$ 1,045,000	$ 1,025,000	$ 945,000	$ 870,000	$ 950,000	$ 8,910,000
BOTH SYSTEMS - MODELING AND RESEARCH								
Development of Mechanistic Ecological Model (§ 6.6.3)	$ 175,000	$ 175,000	$ 175,000	$ 175,000	$ 175,000	$ 50,000	$ 25,000	$ 950,000
Applied Environmental Research at the USFWS NFHTC (§ 6.3.4)	$ 750,000	$ 1,750,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 4,750,000
Science Review Panel	$ -	$ 50,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 550,000
Improve Groundwater Model	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
TOTAL	$ 925,000	$ 1,975,000	$ 725,000	$ 725,000	$ 725,000	$ 600,000	$ 575,000	$ 6,250,000
BOTH SYSTEMS - NFHTC REFUGIA (§ 5.1.1)	$ 1,678,597	$ 1,678,597	$ 1,678,597	$ 1,678,597	$ 1,678,597	$ 1,678,597	$ 1,678,597	$ 11,750,179
Project Management Costs	$ 750,000	$ 750,000	$ 750,000	$ 750,000	$ 750,000	$ 750,000	$ 750,000	$ 5,250,000
TOTAL	$ 20,416,847	$ 19,331,097	$ 18,362,597	$ 18,292,597	$ 18,162,597	$ 17,912,597	$ 17,967,597	**$ 130,445,929**

Table 7.1: ANNUALIZED IMPLEMENTATION COSTS (Continued)

ACTIVITY	Annual Costs (Years 8-15)								TOTAL
	2020	2021	2022	2023	2024	2025	2026	2027	TOTAL Annual
CPM Stage V (§ 5.1.4)	NA	NA	NA	NA	NA	NA	NA	NA	NA
Using SAWS ASR for springflow protection (§ 5.5.1)									
Obtaining Leases and Options for Water	$ 4,759,000	$ 4,759,000	$ 4,759,000	$ 4,759,000	$ 4,759,000	$ 4,759,000	$ 4,759,000	$ 4,759,000	$ 38,072,000
O&M Costs related to the actual use of the ASR	$ 2,194,000	$ 2,194,000	$ 2,194,000	$ 2,194,000	$ 2,194,000	$ 2,194,000	$ 2,194,000	$ 2,194,000	$ 17,552,000
Regional Water Conservation Program (§ 5.1.3)	$ 1,973,000	$ 1,973,000	$ 1,479,750	$ 986,500	$ 493,250	$ 493,250	$ 493,250	$ 493,250	$ 8,385,250
Voluntary Irrigation Suspension Program Option (§ 5.1.2)	$ 4,172,000	$ 4,172,000	$ 4,172,000	$ 4,172,000	$ 4,172,000	$ 4,172,000	$ 4,172,000	$ 4,172,000	$ 33,376,000
SAN MARCOS SPRINGS - Measures to Reduce the Impacts of Drought and Recreation and Enhance the Viability of the Listed Species									
Texas wild-rice enhancement and restoration (§ 5.3.1, § 5.4.1)	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 800,000
Sediment removal - Sewell Park (§ 5.3.6, § 5.4.4)	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 200,000
Aquatic vegetation restoration (non-native removal and native re-establishment) and maintenance - San Marcos River (§ 5.3.8, § 5.4.3, § 5.4.12)	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 400,000
Management of floating vegetation mats and litter removal (Spring Lake and San Marcos River) (§ 5.3.3, § 5.4.3)	$ 80,000	$ 80,000	$ 80,000	$ 80,000	$ 80,000	$ 80,000	$ 80,000	$ 80,000	$ 640,000
Non-native animal species control (§ 5.3.5, § 5.3.9, § 5.4.11, § 5.4.13)	$ 35,000	$ 35,000	$ 35,000	$ 35,000	$ 35,000	$ 35,000	$ 35,000	$ 35,000	$ 280,000
Sessom Creek sand bar removal (§ 5.4.6)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Low Impact Development / BMPs (§ 5.7.3)	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 1,600,000
Recreation control in key areas (enforcement) (§ 5.3.2, §5.4.2)	$ 56,000	$ 56,000	$ 56,000	$ 56,000	$ 56,000	$ 56,000	$ 56,000	$ 56,000	$ 448,000
Restoration of riparian zone with native vegetation (§ 5.7.1)	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 160,000
Bank stabilization / Permenant access points (§ 5.3.7, § 5.4.5)	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 140,000
Bio-monitoring (§ 6.3.1)	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 1,600,000
Water quality monitoring and protection (§ 5.7.2 and 5.7.6)	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 800,000
Household hazardous waste program (§ 5.7.5)	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 240,000
Other Measures									
Management of public recreational use (§ 5.3.2.1)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Prohibition of hazardous materials route (§ 5.3.4)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Diversion of Surface Water (§ 5.3.5)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Diving Classes in Spring Lake (§ 5.4.7)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Creation of Scientific Areas (§ 5.6)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Research Programs in Spring Lake (§ 5.4.8)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Boating in Spring Lake and Sewell Park (§ 5.3.10)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Septic system registration and permitting program (§ 5.7.3)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Management of golf course grounds (§ 5.4.9)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
TOTAL	$ 916,000	$ 916,000	$ 916,000	$ 916,000	$ 916,000	$ 916,000	$ 916,000	$ 916,000	$ 7,328,000
COMAL SPRINGS - Measures to Reduce the Impacts of Drought and Recreation and Enhance the Viability of the Listed Species									
Old Channel ERPA - Includes aquatic vegetation restoration and maintenance; limited channel modifications as necessary to enhance fountain darter habitat, and removal of the sediment island (§ 5.2.2.1)	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 800,000
Flow-split management - old and new channels (§ 5.2.1)	$ -	$ -	$ 30,000	$ -	$ -	$ 30,000	$ -	$ -	$ 60,000
Landa Lake and Comal River - aquatic vegetation restoration and maintenance (§ 5.2.2 except § 5.2.2.1)	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 50,000	$ 400,000
Non-native animal species control (§ 5.2.5, § 5.2.9)	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 600,000
Decaying vegetation removal program (§ 5.2.4)	$ 15,000	$ 15,000	$ 15,000	$ 15,000	$ 15,000	$ 15,000	$ 15,000	$ 15,000	$ 120,000
Riparian improvements and sediment removal specific to the Comal Springs riffle beetle (§ 5.2.8)	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 200,000
Gill Parasite Control and non-native snail removal program including optimization research (§ 5.2.6)	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 75,000	$ 600,000
Restoration of riparian zone with native vegetation (§ 5.7.1)	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 800,000
Prohibition of hazardous materials route (§ 5.2.7)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
BMPs for stormwater control (§ 5.7.6)	$ -	$ -	$ 50,000	$ -	$ -	$ 50,000	$ -	$ -	$ 100,000
Incentive program for low impact development (§ 5.7.6)	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 800,000
Bio-monitoring (§ 6.3.1)	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000	$ 1,600,000
Water Quality Monitoring (§ 5.7.4)	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000	$ 800,000
Household hazardous waste program (§ 5.7.5)	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 240,000
Other Measures									
Creation of state scientifc areas (§ 5.6)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Management of public recreational use (§ 5.2.3)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
TOTAL	$ 870,000	$ 870,000	$ 950,000	$ 870,000	$ 870,000	$ 950,000	$ 870,000	$ 870,000	$ 7,120,000
BOTH SYSTEMS - MODELING AND RESEARCH									
Development of Mechanistic Ecological Model (§ 6.6.3)	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 200,000
Applied Environmental Research at the USFWS NFHTC (§ 6.3.4)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Science ReviewPanel	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Improve Groundwater Model	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
TOTAL	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 200,000
BOTH SYSTEMS - NFHTC REFUGIA (§ 5.1.1)	$ 1,678,597	$ 1,678,597	$ 1,678,597	$ 1,678,597	$ 1,678,597	$ 1,678,597	$ 1,678,597	$ 1,678,597	$ 13,428,776
Project Management Costs	$ 750,000	$ 750,000	$ 750,000	$ 750,000	$ 750,000	$ 750,000	$ 750,000	$ 750,000	$ 6,000,000
TOTAL	$ 17,337,597	$ 17,337,597	$ 16,924,347	$ 16,351,097	$ 15,857,847	$ 15,937,847	$ 15,857,847	$ 15,857,847	**$ 131,462,026**

7.1.2 Funding Assurances

Funding to implement the HCP will come from two sources: (1) "aquifer management fees" ("AMF") assessed by the EAA; and (2) third-party contributions. Through AMFs, the EAA will "fully fund" the implementation of the HCP during both Phase I and Phase II of the term of the ITP. (*See* FMA §§ 3.2, 5.2.1). Section 1.29 of the EAA Act authorizes the EAA to assess aquifer management fees to finance its administrative expenses and authorized programs. Among the expenses and programs authorized by the EAA Act is the implementation of the HCP. (*See* EAA Act §§ 1.11(d)(9), 1.14(h), and 1.26A). In addition to AMFs assessed by the EAA to fund its non-HCP programs and expenses, the EAA will also assess a separate AMF to fund the costs of implementing the HCP. (*See* FMA §§ 1.1.41, 5.1, 5.2.2). This AMF is referred to as the "Program Aquifer Management Fee." (*Id*. § 1.1.41).

Third-party contributions will be remitted to the EAA by other entities who are not users of the Aquifer and, therefore, do not pay AMFs. (*See* Joint Funding Agreement (JFA). These other entities include at this time the City of Victoria, Guadalupe-Blanco River Authority ("GBRA"), City Public Service Energy of the City of San Antonio,[1] San Antonio River Authority, Union Carbide Corporation, and the Guadalupe Basin Coalition. The aggregate of the third-party contributions will total at least $ 735,000 annually towards the costs of the implementation of the HCP. Of that amount, GBRA and Union Carbide Corporation initially will contribute $400,000 and $200,000 annually. This amount may be increased by an amount not to exceed 2 percent over the prior year's amount for a calendar year during the term of the JFA based on an increase in the costs of implementing the HCP as certified by the EAA. (*See* JFA § 4(c)). Similarly, the amount may also be reduced but not below the initial amount. (*Id*.). These commitments are legally enforceable as reflected in Section 10 of the JFA.

The funding levels that are required to "fully fund" the implementation of the HCP for each year of the term of the ITP are the amounts shown in Table 7.1. (*See id.* §§ 3.2, 5.2.1). The funding levels in Table 7.1 are estimated costs and may be adjusted up or down in light of experience acquired over time in the field and through the securing of actual implementation costs through the procurement process. (*See id.* § 5.2.1). However, the EAA will not be required to provide annual funding from AMFs for Phase I or Phase II in excess of the amount shown in Table 7.1 for 2013 "adjusted for a 2 percent increase, compounded annually, for the years that have elapsed since 2013." (*Id.*). The actual amount for any particular year during the term of the ITP to be budgeted and funded by the EAA will be set by the EAA based on a recommendation of the Implementing Committee through the unanimous vote of all of the Parties to the FMA with the agreement of the Board of Directors of the EAA. (*See id.* §§ 4.5, 5.2.1, 7.7.5, 7.7.6, 7.11.4, 7.12.4.d., 7.14.5.a.). The amount of funding provided by the EAA for any particular year during

[1] CPS Energy is actually a user of the Aquifer and holds groundwater withdrawal permits issued by the EAA, and, therefore, pays AMFs to the EAA. It is also a downstream surface water user.

the term of ITP is referred to as the "Annual Funding Obligation" which will correlate with the "Annual Program Budget." (*Id*. §§ 1.1.4, 1.1.5, 4.5, 5.2.1).

The EAA will create within the EAA a restricted account known as the "HCP Program Account." (*See id.* § 1.1.27, 5.4). The Account will have two funds – an operations fund and a reserve fund. (*Id.*). Generally, the EAA will deposit in the operations fund of the HCP Program Account: all Program AMF revenues, third-party contributions, and earnings on investments associated with the HCP Program Account. The EAA will disburse amounts from the operations fund for expenditures for the Annual Program Budget. (*Id*. § 5.4).

To the extent there is a "Fund Balance" (*id*. § 1.1.24) in any particular year over "Program Expenditures," (*id*. § 1.1.43), the EAA will accumulate the balance in the reserve fund of the HCP Program Account. (*Id*. § 5.5.4). However, the amount that the EAA may accumulate is capped at $46 million dollars. (*Id*.). This cap is referred to as the "Fund Balance Cap." (*Id*. § 1.1.25). The reserve fund will allow the accumulation of funds for the projected costs of the VISPO and SAWS ASR measures, full funding for which is needed at irregular periods and is based on a probabilistic analysis of the number of years in which these measures will be triggered as provided in Chapter 5.

In the event the reserve fund is fully funded and the Fund Balance Cap is exceeded, then the "Excess Fund Balance" (*id*. § 1.1.23) will be applied to reduce the Annual Funding Obligation (or Annual Program Budget) of the EAA for the next calendar year. (*Id*. § 5.5.4).

The EAA will begin collecting Program AMFs during fiscal year 2012 prior to the effective date of the ITP to ensure that sufficient funding will be available on January 1, 2013, to begin implementation of the HCP. (*Id*. § 5.2.3).

7.2 Funding Assurances for Any Additional Phase II Measures

To address the need now to demonstrate both the ability and commitment to achieve the existing long-term biological objectives, while recognizing the uncertainty associated with those objectives, SAWS will commit to implement a "presumptive" action that is adequate to achieve the minimum flow management objective. The presumptive action for Phase II of the HCP involves the expanded use of the SAWS ASR associated with a planned construction of the WRIP Pipeline that is currently in the design stage and is scheduled for completion by 2020.

To the extent that such a project cannot be designed and implemented to achieve the goals within the above-described assumptions, additional springflow protection will be obtained through additional CPM pumping cuts in Stage V or other measures that provide an equivalent measure of protection to the Covered Species in San Marcos and Comal springs. (*See* Section 5.8.2).

SAWS will allow the expanded use of its ASR, if it is needed, to achieve the current biological goals. The opportunity for this commitment is due to SAWS' construction of the WRIP, which is

being done independent of the HCP, and which will be completed by 2020. Although they are not anticipated, there may be increases in the cost of using the ASR, such as operating and maintenance costs or water leasing costs beyond those for which financial assurances in Phase I have already been provided for in the FMA. If so, additional funding may be necessary beyond that already covered in the FMA, subject to the funding limitation for the EAA in Sections 3.2 and 5.2.1 of the FMA. Because of the uncertainty regarding whether the Phase II presumptive measure will be necessary and what additional costs, if any, there may be, no decision has been made regarding the sources of any additional funds. If it is determined through the AMP that additional funds are required for Phase II that exceed the financial assurances made in Section 7.1.2 as limited by Sections 3.2 and 5.2.1 of the FMA, any necessary additional funding assurances will be provided promptly after that decision has been made. *See* Section 8.1.1

The inability of the Phase II presumptive measure to function as expected within the stated assumptions constitutes a changed circumstance provided for in the HCP. The response to such a change circumstance would be alterations to the conservation measures outlined in Chapter 5 and/or increased Stage V Critical Period Management reductions. Thus, the commitment of the expanded use of the SAWS ASR defines the maximum obligation for funding of Phase II of the HCP under the No Surprises Rules.

7.3 Alternative Funding

The Applicants will actively pursue alternative sources of funding to offset or augment Phase I and to fund any additional Phase II implementation activities. The potential sources of funding include Federal, State, and private funding and grant programs. Moreover, the Applicants intend to continue efforts through the 2017 legislative session to have the Texas Legislature authorize a vote by the citizens of the region on the use of a regional sales tax to cover the costs of the Phase I minimization and mitigation measures and any additional springflow protection measures that may be needed in Phase II.

In the event that an alternative funding source adequate to fund HCP-related activities is created or secured, the funding obligation of the EAA and the third-party contributors will be reduced or terminated as provided in Sections 6.3 and 6.4.1 of the FMA and 11(a)(1) of the JFA, respectively. Thereafter, funding responsibilities for the EAA will, to the extent of the alternative new funding source, be the responsibility of the administrator of the tax as provided by the legislation establishing such a tax, or the documents establishing another funding source. (FMA § 6.4).

Chapter 8 Changed Circumstances, Unforeseen Circumstances, No Surprises, and Other Federal Commitments

8.0 Introduction

ESA regulations require that an HCP specify the procedures to be used for dealing with changed and unforeseen circumstances that may arise during the implementation of the HCP. (50 C.F.R. §§ 17.22(b)(2) and 17.32(b)(2)). The Service's regulations regarding its No Surprises Rule describe the obligations of the permittee and the Service with respect to changed and unforeseen circumstances. (50 C.F.R. §17.22(b)(5) and § 17.32(b)(5)). The purpose of the No Surprises Rule is to provide assurance to the holders of an ITP that no additional land or water restrictions or financial compensation will be required for species covered by the permit under a properly implemented HCP without the consent of the permittee. 63 Fed. Reg. 8859 (Feb. 23, 1998).

8.1 Changed Circumstances

FWS defines the term "changed circumstances" to mean "changes in circumstances affecting a species or geographic area covered by a conservation plan or agreement that can reasonably be anticipated by plan or agreement developers and the Service and that can be planned for (*e.g.,* the listing of new species, or a fire or other natural catastrophic event in areas prone to such events). (50 C.F.R. § 17.3). In terms of the assurances provided, FWS distinguishes between changed circumstances which are specifically provided for in the HCP and those that are not provided for in the HCP. (50 C.F.R. § 17.22(b)(5)(i) and (ii)).

8.1.1 Changed Circumstances Provided for in the HCP

If additional conservation and mitigation measures are deemed necessary to respond to changed circumstances and were provided for in the plan's operating conservation program, the permittee will implement the measures specified in the plan. (50 C.F.R. § 17.22(b)(5)(i)).

Table 8-1 outlines the changed circumstances and responsive measures that have been identified by the Applicants and USFWS through development of this HCP. Responsive measures will be implemented through the AMP and within the Applicants' funding commitments as described in Chapter 7 of this HCP.

TABLE 8-1
CHANGED CIRCUMSTANCES AND RESPONSE MEASURES

Changed Circumstance	*Responsive Measures*
New species listings or critical habitat designations: The USFWS lists a new species and the Covered Activities could result in take of the newly listed species or designates new Critical Habitat for the new species or any of the currently non-listed Covered Species that could be adversely affected by the implementation of this HCP.	*The Applicants and the Service will work together through the AMP to determine whether the minimization and mitigation measures adequately address any impacts to such new species or critical habitat. If modification of those measures is necessary and can be effectively accomplished in this HCP, the Applicants will consider amending this HCP to include such new species as Covered Species.*
Covered Species adversely affected by an acute pollution event: An acute contamination event occurs within the Plan Area and has the potential to affect the Covered Species or its associated Critical Habitat. Examples might include a spill of hazardous chemicals or petroleum products.	*Immediately after the Applicants acquire knowledge of an acute contamination event, the Applicants will notify the appropriate state and local authorities and USFWS, and will cooperatively determine the best measures for addressing the contamination event. If the contamination presents an immediate threat to the Covered Species, the Applicants will coordinate with appropriate state and local agencies and take such measures as may be authorized by state law to address that threat taking into consideration any primary jurisdiction or authority that may be possessed by the appropriate state or local agencies. Every reasonable effort will be made to coordinate emergency responses with USFWS. In some cases, capture and transfer of Covered Species to refugia may be appropriate.*
Covered Species adversely affected by invasive species: USFWS reasonably determines that invasive species of plants or animals are adversely affecting Covered Species to a degree not contemplated in the HCP.	*Though the AMP, the Applicants will develop and implement an invasive species control plan. Such a plan might include capture or destruction through mechanical, biological, and, in carefully limited circumstances, chemical measures.*
Covered Species adversely affected by flooding: A flood event with a peak streamflow equal to or less than 31,300[1] at the	*Through the AMP, approved by USFWS, the Applicants will promptly develop and implement a flood remediation plan. Such a plan will assess whether any minimization and*

[1] The maximum peak streamflow for the flood event at New Braunfels in 2010 was 31,300 cfs.

TABLE 8-1
CHANGED CIRCUMSTANCES AND RESPONSE MEASURES

Changed Circumstance	*Responsive Measures*
USGS gauges in the Comal and San Marcos rivers and that adversely affects a Covered Species or their habitat to a degree not contemplated in the HCP.	*mitigation measures need to be repaired or restored and, for those such measures that changes that are needed, a priority for making them. Such activities may include replanting native species, removing sediment, removing or preventing the reestablishment of exotic species. The plan will also include an assessment of what additional monitoring may be required to protect water quality. The Applicants will implement any actions identified in the plan. The cost of such actions is covered as part of the Program Funding but is not subject to the budgeting process in the FMA if the actions must be implemented immediately.* .
Inability to use the Phase I SAWS ASR as set out in Section 5.5 to achieve springflow protection: USFWS reasonably determines that the SAWS ASR cannot be effectively used in the manner contemplated in the HCP to achieve the springflow protection levels expected for the Phase I package because of requirements imposed by involuntary expansion of utility service obligations imposed by statute, or requirements to provide Edwards-equivalent-quality potable water services compliant with EPA primary and secondary drinking water standards.	*SAWS and the EAA along with the other Applicants as provided in the AMP will coordinate with USFWS to identify and implement modifications to the minimization and mitigation measures to achieve the expected level of springflow protection. The measures considered will include alterations to the conservation measures outlined in Chapter 5 in addition to an increase in Stage V withdrawal reductions.*
Recreational activities having adverse effects: USFWS reasonably determines that recreational activities are adversely affecting Covered Species to a degree not contemplated in this HCP.	*If the effect is increased impairment to a water quality parameter, then response will be:* *1. Determine the specific parameter, the locations and distribution of the increased impairment to parameter, and, if possible, the point source through Section 5.7.2; then* *2. Through the AMP, adjust one or more Phase I conservation measures to address the increased impairment parameter of concern and, if feasible, the identified point source, within the established HCP Budget and AMP;*

TABLE 8-1
CHANGED CIRCUMSTANCES AND RESPONSE MEASURES

Changed Circumstance	*Responsive Measures*
	then *3. If adjustments to Phase I conservation measures are not successful or feasible to address the increased impairment, additional conservation measures may be considered through the AMP and within the HCP Budget process.* *If the effect is a decrease in available habitat or reduction in quality of habitat, then response will be:* *1. Through the AMP, make possible manipulations and adjustments to the Flow Split Management regime in Section 5.2.1 of the HCP; and/or* *2. Through the AMP, adjust one or more Phase I conservation measures in Sections 5.2.2, 5.2.2.1, 5.2.2.3, and 5.2.5 of this HCP to address the habitat concern; then* *3. If adjustments to Phase I conservation measures are not successful or feasible to address the habitat concern, through the AMP additional conservations measures may be considered through the AMP and within the HCP Budget process.* *If the effect is other than one listed above, through the AMP, the Applicants will seek to modify the Phase I conservation measures to minimize and mitigate for the impacts of recreation. As a final option through the AMP, adjustments to the flow triggers or amount of habitat protected could be considered so long costs are funded with Program Funding.* *Any limitations on recreational activity imposed in response to changed circumstances will not restrict recreational access in any particular area to an unreasonable extent and, specifically, will not prevent longitudinal connectivity for river recreation between areas supporting a high volume of recreation activity.*
Term Permits: The EAA issues a term	*Prior to the EAA's issuing any such term*

TABLE 8-1
CHANGED CIRCUMSTANCES AND RESPONSE MEASURES

Changed Circumstance	*Responsive Measures*
permit(s) under the EAA Act (*see* Section 1.19) that causes the amount of actual annual pumping for a particular year or years to exceed the theoretical maximum modeled pumping used for modeling purposes (*see* Section 5.8.1).	*permit, the AMP will be used to determine what modifications, if any, are needed to the minimization and mitigation measures such that the anticipated levels of impacts in the event of a recurrence of the drought of record will not be exceeded. If the AMP determines that no modifications to the minimization and mitigation measures are necessary, the EAA will report to the USFWS on the permit issuance in the annual report provided for in Section 9.3. If the AMP determines that modifications to the minimization and mitigation measures are necessary, the Applicants will implement those measures prior to EAA's issuing any term permit.*
Emergency Permits: The EAA issues an emergency permit(s) under the EAA Act (*see* Section 1.20) that causes the amount of actual annual pumping for a particular year or years to exceed the theoretical maximum modeled pumping used for modeling purposes (*see* Section 5.8.1).	*Due to the circumstances surrounding emergency permits, the EAA will report to the USFWS on the permit issuance in the annual report provided for in Section 9.3.*
Recharge Recovery Permits: The EAA issues a recharge recovery permit(s) under the EAA Act (*see* Section 1.44) and its rules that causes the amount of actual annual pumping for a particular year or years to exceed the theoretical maximum modeled pumping used for modeling purposes (*see* Section 5.8.1).	*Prior to the EAA's issuing any such recharge recovery permit, the AMP will be used to determine what modifications, if any, are needed to the minimization and mitigation measures such that the anticipated levels of impacts in the event of a recurrence of the drought of record of record expected in this HCP will not be exceeded. If the AMP determines that no modifications to the minimization and mitigation measures are necessary, the EAA will report to the USFWS on the permit issuance in the annual report provided for in Section 9.3. If the AMP determines that modifications to the minimization and mitigation measures are necessary, the Applicants will implement any such modifications prior to EAA's issuing any recharge recovery permit.*
Exempt wells: The EAA registers additional wells exempt from the metering and reporting	*The AMP will be used to determine what modifications, if any, are needed to the*

TABLE 8-1
CHANGED CIRCUMSTANCES AND RESPONSE MEASURES

Changed Circumstance	*Responsive Measures*
requirements under the EAA Act (*see* Section 1.33) that cause the amount of actual annual pumping for a particular year or years to exceed the theoretical maximum modeled pumping used for modeling purposes (*see* Section 5.8.1).	*minimization and mitigation measures such that the anticipated levels of impacts expected in this HCP and in the event of a recurrence of the drought of record will not be exceeded.*
Financial Assurance for any Phase II Measure: Because of the uncertainty regarding whether the Phase II presumptive measure will be necessary and what additional costs, if any, there may be, no decision has been made regarding the sources of any additional funds.	*If it is determined through the AMP that additional funds are required for Phase II that exceed the financial assurances made in Section 7.1.2 as limited by Sections 3.2 and 5.2.1 of the FMA, any necessary additional funding assurances will be provided promptly after that decision has been made.*
Phase II presumptive measure: The the Phase II presumptive measure is unable to function as expected within the stated assumptions.	*The AMP will be used to alter the conservation measures outlined in Chapter 5 and/or increased Stage V Critical Period Management reductions.* Thus, the commitment of the expanded use of the SAWS ASR defines the maximum obligation for funding of Phase II of the HCP under the No Surprises Rules.

8.1.2 Changed Circumstances Not Provided for in the HCP

If additional conservation and mitigation measures are deemed necessary to respond to changed circumstances and such measures were not provided for in the plan's operating conservation program, the USFWS “will not require any conservation and mitigation measures in addition to those provided for in the plan without the consent of the permittee, provided the plan is being properly implemented.” (50 C.F.R. § 17.22(b)(5)(ii)).

All Covered Species are considered adequately addressed by this HCP for the purposes of the No Surprises Rule. Thus, changed circumstances not addressed in Section 8.1.1 shall be considered “changed circumstances not provided for in the plan” for the purposes of the No Surprises Rule. An example of a changed circumstance not provided for in the HCP includes:

- Invasion by exotic species and/or habitat-specific or species-specific disease that threaten Covered Species or their habitats and which cannot be effectively controlled by

currently available methods or technologies or which cannot be effectively controlled without resulting in greater harm to other Covered Species than to the affected Covered Species.

8.2 Unforeseen Circumstances

USFWS defines the term "unforeseen circumstances" to mean "changes in circumstances affecting a species or geographic area covered by [the HCP] … that could not reasonably have been be anticipated by plan … developers and the Service at the time of [the HCP's] negotiation and development, and that result in a substantial and adverse change in status of the covered species." (50 C.F.R. §17.3). "In negotiating unforeseen circumstances, [USFWS] will not require the commitment of additional land, water, or financial compensation or additional restrictions on the use of land, water, or other natural resources beyond the level otherwise agreed upon for the species covered by the conservation plan without the consent of the permittee." (50 C.F.R. § 17.22(b)(5)(iii); 50 C.F.R. § (b)(5)(iii)).

When these unforeseen circumstances necessitate additional conservation and mitigation measures, USFWS "may require additional measures of the permittees where the [HCP] is being properly implemented, but only if such measures are limited to modifications within the conserved habitat areas, if any, or to the [HCP's] operating conservation program for affected species, and maintain the original terms of the [HCP] to the maximum extent possible... ." (*Id.* at 17.22(b)(5)(iii)(A)). Any such additional measures "will not involve the commitment of additional land, water or financial compensation or additional restrictions on the use of land, water, or other natural resources … without the consent of the permittee." (*Id.*)

For the purposes of this HCP, "unforeseen circumstances" are any events not identified as a changed circumstance and specifically include:

- Natural catastrophic events such as fire, droughts worse than the drought of record[2] (or equivalent to the drought of record in duration and extent but occurring more than once during the 15-year term of ITP), hurricanes, tornados, severe wind or water erosion, flood events with a peak streamflow greater than 31,300 cfs, and landslides (including landslides, faulting, or alteration of the springs or aquifer as a result of earthquakes) of a magnitude exceeding that expected to occur during the term of the ITP.

Prior to making a determination regarding the occurrence of any unforeseen circumstances, the USFWS shall comply with the following procedure:

[2] A drought is worse than the drought of record if the average recharge for any seven-year period less than 168,700 ac-ft. From 1950 through 1956, the average recharge was 168,700 ac-ft.

8.2.1 Notice to Applicants and Participants

The USFWS shall provide written notice to the Applicants together with a detailed statement of the facts regarding the unforeseen circumstance involved, the anticipated impact thereof on the Covered Species and its habitat, and all information and data that supports the allegation. In addition, the notice shall include any proposed conservation measure(s) that is believed would address the unforeseen circumstance, an estimate of the cost of implementing such conservation measure, and the likely effects upon (a) the Applicants and its permittees and (b) the existing plans and policies of any involved Federal or State agencies.

8.2.2 Response through the Adaptive Management Plan

The Applicants, in consultation with the USFWS, may choose to perform an expedited AMP analysis of the Covered Species or its habitat affected by the alleged unforeseen circumstance and to modify or redirect existing conservation measures to mitigate the effects of the unforeseen circumstance, within the scope of existing funded conservation actions. To the extent that these modified or redirected conservation measures do not affect conservation of other species, habitats, or key areas, this may be deemed an adequate response to the unforeseen circumstance. If the proposed modifications or redirected conservation actions could affect the conservation of other Covered Species or its habitat, the procedure outlined below will be followed.

8.2.3 Submission of Information by Applicants

The Applicants shall have a meaningful opportunity to submit information to the USFWS and shall submit such information to the USFWS within 60 days of the written notice as provided above. Upon the written request of any Applicant, the time for submission of said information may be extended by the USFWS, which request will not be unreasonably denied.

8.2.4 Applicants Review

Within 90 days after the close of the period for submission of additional information, the Applicants shall assess: (a) the alleged unforeseen circumstances; (b) the proposed additional conservation measure(s); (c) its effects upon the species and its habitat and the economy of the Applicants; and (d) possible alternatives to the proposed additional conservation measures which would result in the least adverse impacts upon the economy of the Applicants.

8.2.5 Burden of Proof

USFWS will have the burden of demonstrating that unforeseen circumstances exist, using the best scientific and commercial data available. These findings must be clearly documented and based upon reliable technical information regarding the status and habitat requirements of the affected species. USFWS will consider, but not be limited to, the following factors:

(1) Size of the current range of the affected species;

(2) Percentage of range adversely affected by the conservation plan;

(3) Percentage of range conserved by the conservation plan;

(4) Ecological significance of that portion of the range affected by the conservation plan;

(5) Level of knowledge about the affected species and the degree of specificity of the species' conservation program under the conservation plan; and

(6) Whether failure to adopt additional conservation measures would appreciably reduce the likelihood of survival and recovery of the affected species in the wild.

In addition, based on the results of an expedited AMP analysis of the unforeseen circumstance and the information provided by the Applicants and Participants, the USFWS shall provide the justification and approval for any reallocation of funds necessary to respond to the unforeseen circumstance within the existing commitments of the Applicants under the HCP.

8.3 Additional Federal Commitments

8.3.1 Section 7 Consultations and Conferences

Except as may be provided elsewhere in this HCP, nothing in the HCP is intended to apply to any activity on federal lands or federally funded projects that are governed by Section 7 of the Endangered Species Act (ESA). The USFWS shall cause and does intend for any minimization and mitigation measures that result from the authorization of incidental take pursuant to Section 7 and contained within any biological opinion or conference report to be consistent with the minimization and mitigation measures required by this HCP. However, nothing contained in this HCP is intended to prohibit or proscribe the USFWS from requiring minimization and mitigation in excess of that provided for in the HCP, if USFWS determines that its Biological Opinion related to approval of this HCP and issuance of the Permit did not address the impacts in question.

8.3.2 Consideration of the HCP in Section 4 Findings

The USFWS will specifically inform the Applicants, in writing, of any 90-day and 12-month findings under Section 4 of the ESA for species in the Edwards Aquifer, Comal Springs, San Marcos Springs, or Guadalupe River Watershed. To the extent permitted by law, the USFWS will consider this HCP and actions undertaken by the Applicants in making its determination.

Chapter 9 Permit Administration

9.1 Governance

9.1.1 Implementing Agreement and Related Documents

Section 10(a)(2)(iv) of the ESA states that a conservation plan must specify "such other measures that the Secretary may require as being necessary or appropriate for the purposes of the plan." 16 U.S.C. § 1539(a)(2)(iv). The USFWS believes it may be necessary and appropriate to prepare an Implementing Agreement (IA) for conservation plans that involve multiple parties and complex implementation. (USFWS 1996c). The purpose of the IA is to ensure that each party understands its obligations under the HCP and the ITP and to provide remedies should any party fail to fulfill its obligations. In this instance, the IA, in conjunction with an accompanying Funding and Management Agreement (FMA), will serve the additional purpose of establishing and defining a continuing role for the EARIP stakeholders and science review process that have been instrumental to the development of the HCP. Therefore, an Implementing Agreement has been prepared for this HCP.

The IA will be executed by the EAA, the City of New Braunfels, the City of San Marcos, the City of San Antonio acting by and through its San Antonio Water System Board of Trustees, Texas State University – San Marcos, the Texas Parks and Wildlife Department (TPWD), and the USFWS. The EAA, the Cities and the University will be signing as permittees under the Section 10(a) permit. The TPWD will be signing to reflect certain limited obligations it will undertake to issue regulations creating state scientific areas in the Comal and San Marcos rivers. The IA will also reflect the signatures of the Texas Commission on Environmental Quality, the Texas Department of Agriculture, and the Texas Water Development Board for the sole purpose of discharging certain obligations imposed by the Texas Legislature when it instituted the EARIP.

The parties have also prepared an intergovernmental Funding and Management Agreement (FMA). This agreement will be executed only by the five permittees under the Section 10(a)(1)(B) permit. The purpose of the FMA is to establish in greater detail the procedures and mutual commitments among the permittees for funding and management of the HCP and adaptive management process. Key components include:

a. A description of the Program Management Responsibilities (Article Two)
b. A further commitment by each permittee to discharge its duties and responsibilities to implement the HCP (Article Three);
c. A process by which the Implementing Committee will develop and amend as necessary a comprehensive work plan and budget to identify the conservation measures, adaptive management activities, and associated costs necessary to implement the HCP (Article Four);

d. A commitment by the EAA to fund the conservation measures and adaptive management activities with special aquifer management fees paid to the EAA by industrial and municipal pumpers from the Edwards Aquifer (Article Five);
e. A commitment by the EAA to create and maintain appropriate restricted HCP funds (Article Five);
f. A process by which the EAA will provide funding to implement conservation measures (Article Six); and
g. General rights and remedies of the Parties, including additional mutual remedies in the event of non-performance by any party (Article Eight).

Article Seven of the FMA sets out the details of the AMP. Specifically, Article Seven provides the procedural steps and responsibilities of the permittees, the USFWS, and other EARIP stakeholders for making AMP decisions and the actions that will be taken as a result of the decisions. Key components include:

a. A description of the phases of adaptive management;
b. A monitoring program to include both compliance, effects and effectiveness;
c. Procedures to address adaptive management decisions of a routine, non-routine, and strategic nature;
d. Creation of an Implementing Committee comprised of one representative from each permittee as voting members and certain other non-voting members;
e. Creation of a voluntary Stakeholder Committee comprised of one representative from each of a diverse array of regional interest groups;
f. Creation of a Science Committee to consult with, advise and make recommendations to the Program Manager, Implementing Committee and Stakeholder Committee upon request on any adaptive management decision;
g. Procedures for the supplementation of the existing scientific record for the Covered Species and their habitat;
h. Procedures for identification of necessary research and modeling to be overseen by the Implementing Committee;
i. Creation of an independent Science Review Panel to provide scientific advice on issues related to the AMP; and
j. Procedures for action on the Scientific Record, including involvement of the Science Committee and independent Science Review Panel.

Article Seven is intended to provide the specifics of the process and procedures that support the substantive elements of the AMP set out in Chapter 6 of this HCP.

The FMA is attached hereto and incorporated in this HCP by reference herein. The USFWS is not a signatory to this Agreement. Because it is part of the HCP and will be relied on by USFWS in deciding whether the HCP meets the issuance criteria, the Applicants agree that they will not amend the FMA in a manner that will cause the FMA to diverge from or create an inconsistency with the Permit, the IA, or this HCP except through the process for HCP amendments described below.

9.2 Permit Amendments

9.2.1 Clarifications and Minor Administrative Amendments

From time to time it may be necessary for the USFWS and the Applicants to clarify provisions of the HCP, the IA, or the ITP to deal with issues that arise with respect to the administration of the process or the precise meaning and intent of the language contained within those documents. Clarifications do not change the substantive provisions of any of the documents in any way but merely clarify and make more precise the provisions as they exist.

In addition, it is contemplated that, from time to time, it may be necessary to make Minor Administrative Amendments to the documents that do not make substantive changes to any of the provisions of the documents, but which may be necessary or convenient, over time, to more fully represent the overall intent of the Applicants and the USFWS. Clarifications may be approved locally by the Field Supervisor of the Austin Fish and Wildlife Office and the Program Manager, after concurrence of the Applicants. Minor Administrative Amendments may be approved by the local Field Supervisor, but in some instances may require Regional Office approval. Clarifications and Minor Administrative Amendments to the documents shall be memorialized by letter agreement or by substituted Plan Documents which are modified to contain only the Clarification or Minor Administrative Amendment. It is proposed that any request for Clarification or any proposed Minor Administrative Amendment will be processed and a response provided within 30 days after receipt by the USFWS or the Applicants, as the case may be.

The HCP may be amended without amending the ITP when the amendments are of a minor or technical nature such that the net effect on Covered Species involved and the levels of take resulting from the amendment are not meaningfully different from those described in the original HCP and the Service's decision documents. Examples of minor amendments to the HCP that would not require an ITP amendment include, but are not limited to, (a) minor revisions to monitoring or reporting procedures and (b) minor revisions in accounting procedures.

To amend the HCP without amending the ITP, the Applicants must submit to the USFWS, in writing, a description of: (a) the proposed amendment; (b) an explanation of why the amendment is necessary or desirable; and (c) an explanation of why the Applicants believe the effects of the proposal are not different from those described in the original HCP. The Program Manager will publish the proposed amendment on the Program website and allow opportunity for public comment. If the USFWS concurs with the proposed amendment, then it shall authorize the HCP amendment in writing, and the amendment shall be considered effective upon the date of the written authorization from the USFWS.

9.2.2 Substantive Amendments

Except as provided for in Clarifications and Minor Administrative Amendments, neither the HCP, ITP, nor IA may be amended or modified in any way without the written approval of the Applicants and the USFWS. Any amendment involving the activities of the TPWD must be approved in writing by the TPWD. All proposed Substantive Amendments shall be reviewed by the Applicants. Substantive changes shall be processed as an amendment to the permit in accordance with the provisions of the ESA and regulations at 50 CFR Parts 13 and 17 and shall be subject to appropriate environmental review under the provisions of NEPA.

Substantive Amendments to the ITP would be required for major changes such as changes in location, activity, amount or type of take, or species covered by the permit. Examples of major changes include: (a) the listing under the ESA of a new species not currently addressed in the HCP that may be taken by Covered Activities; (b) the modification of any Covered Activity or minimization and mitigation measure under the HCP, including funding, that may affect take, the effects of the Covered Activities, or the nature or scope of the minimization and mitigation measures in a manner or to an extent not previously considered in issuing the ITP; and (c) any other modification of the Covered Activities that causes an effect to the Covered Species or critical habitat not considered in the original ITP.

A Substantive Amendment of the ITP must be treated in the same manner as an original permit application. Permit applications typically require a revised conservation plan, a permit application form, an implementing agreement, a NEPA document, and a 30-day public comment period. However, the specific documentation needed in support of a permit amendment may vary depending upon the nature of the amendment.

9.3 Annual Reporting

An annual report of Covered Activities as well as management activities undertaken under the terms of this HCP will be prepared by the Applicants and submitted to the USFWS's Austin Field Office no later than the end of the first quarter after the preceeding calender year has been completed. The report will summarize information on the monitoring and management of the HCP including:

9.3.1 Monitoring Report

- EAA Permitted withdrawals
- Reference well levels
- Springflows at Comal and San Marcos Springs
- Aquifer recharge

- Aquifer discharge from wells and springflow
- Critical period management reductions
- Water quality data
- Location of sampling sites
- Methods for data collection and variables measured
- Frequency, timing, and duration of sampling for the variables
- Description of the data analysis and who conducted the analysis

9.3.2 HCP Management

- Adaptive management activities undertaken during the year
- Expenditures by the EAA on implementation activities
- Proposed activities for the next year
- Report on the status of implementation of minimization and mitigation measures and their effectiveness
- Interim updates and final copies of any research, thesis or dissertation, or published studies accomplished in association with the EARIP or HCP
- Description of species-specific research and management actions undertaken with specific reference to the biological goals and objectives identified for each species.
- Any changes to the Biological Goals and Key Management and Flow-related Objectives of the HCP
- Any changes to the objectives for the monitoring program
- Effects on the Covered Species or Permit Area
- Evaluation of progress toward achieving the Biological Goals and Objectives.
- Any recommendations regarding actions to be taken.

9.4 Subsequent Listing of Covered Species

The Applicants have elected to address unlisted species in the HCP and to have them included on the ITP. Therefore, if the species is subsequently listed, the Applicants would be in compliance with the Permit with respect to that species and the incidental take of the species would be authorized.

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Chapter 11 Abbreviations and Acronyms

Ac-ft—Acre-Feet
AM—Adaptive Management
AMF—Aquifer Management Fee
AMP—Adaptive Management Program
ASR—Aquifer Storage and Recovery
BMP—Best Management Practices
C—Celsius
CCSP—Climate Change Science Program
CEQ—Council on Environmental Quality
C.F.R.—Code of Federal Regulations
cfs—cubic feet per second
CFU—Colony Forming Units
CHU—Critical Habitat Unit
CO_2—Carbon dioxide
CPM—Critical Period Management
CZ—Contributing Zone
DOR—Drought of record
EAA—Edwards Aquifer Authority (the Authority)
EARIP—Edwards Aquifer Recovery Implementation Program
EDYS—Ecological Dynamics Simulation
EIS—Environmental Impact Statement
EPA—Environmental Protection Agency
ERPA—Environmental Restoration and Protection Area
ESA—Endangered Species Act
F—Fahrenheit
FBOC/CBOC—Fine/Coarse Benthic Organic Carbon
FEMA—Federal Emergency Management Agency
FIRM—Flood Insurance Rate Map
ft—foot
GBRA—Guadalupe–Blanco River Authority
GHG—Greenhouse gas
HCP—Habitat Conservation Plan
HHW—Household Hazardous Waste
HSPF—Hydrologic Simulation Program Fortran
IA—Implementing Agreement
IH—Interstate Highway
IPCC—International Panel on Climate Change
IPM—Integrated Pest Management Plan
ISD—Independent School District

ITP—Incidental Take Permit
JFA—Joint Funding Agreement
LID—Low Impact Development
LLNL—Lawrence Livermore National Laboratory
MCL—Maximum Contaminant Levels
mg/L—milligrams per liter
MPO—Metropolitan Planning Organization
MS4—Municipal Separate Storm System
MSA—Metropolitan Statistical Area
MSL (or msl)—Mean Sea Level
NAFTA—North American Free Trade Agreement
NAICS—North American Industrial Classification System
NEPA—National Environmental Policy Act
NFHTC—National Fish Hatchery and Training Center
NMFS—National Marine Fisheries Service
NRI—National Resources Inventory
NTU – Nephelometric turbidity units
PCB—polychlorinated biphenyls
PCE—Primary Constituent Elements
PCL—Protective Concentration Levels
PDSI—Palmer Drought Severity Index
pH—measure of acidity/alkalinity of a solution
POC/DOC—Particulate/Dissolved Organic Carbon
POS—Public Outreach Subcommittee
ROD—Record of Decision
SAWS—San Antonio Water System
SB—Senate Bill
SCTRWP—South Central Texas Regional Water Plan
SCTRWPG—South Central Texas Regional Water Planning Group
SCTWAC—South Central Texas Water Advisory Committee
SCUBA—Self-contained Underwater Breathing Apparatus
SEP—Southern Edwards Plateau
SIC—Standard Industrial Classification
SMCISD—San Marcos Consolidated Independent School District
SNA—State Natural Area
SSC—Science Subcommittee
SVOC—Semi-volatile Organic Compounds
TCEQ—Texas Commission on Environmental Quality
TDS—Total Dissolved Solids
TNRCC—Texas Natural Resource Conservation Commission (now TCEQ)
TOC---Total Organic Carbon
TPWD—Texas Parks and Wildlife Department
TRRP—Texas Risk Reduction Program

TSDC—Texas State Data Center
TSWQS—Texas State Water Quality Standards
TWC—Texas Water Commission
TWDB—Texas Water Development Board
USAA—United Services Automobile Association
USACE—United States Army Corps of Engineers
U.S.C. —United States Code
USDA—United States Department of Agriculture
USFWS—United States Fish and Wildlife Service
USGS—United States Geological Survey
VISPO—Voluntary Irrigation Suspension Program Option
VOC—Volatile Organic Compound
WPAP—Water Pollution Abatement Plan
WORD—Water-oriented Recreation District
WRIP—Water Resources Integration Program

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APPENDIX A:

MEMORANDUM OF AGREEMENT FOR THE EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM WITH THE UNITED STATES FISH AND WILDLIFE SERVICE, 2008

MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM

This Memorandum of Agreement ("MOA") is intended to serve as the Memorandum of Agreement for the Edwards Aquifer Recovery Implementation Program (the "Program") under the Endangered Species Act and as the Memorandum of Agreement required by Senate Bill 3. It is made and agreed to by the Parties signing below and is effective on the Effective Date. The Parties will work together in good faith and cooperation to achieve the purposes and goals provided in the following provisions of this MOA.

Article 1. Purposes

Section 1.1. The purpose of this MOA is to formally initiate the development and implementation of the Edwards Aquifer Recovery Implementation Program. The Program is a collaborative initiative among stakeholders to participate in efforts to contribute to the recovery of the Edwards Species, develop aquifer management measures, and develop conservation measures for the Edwards Aquifer.

Section 1.2. During the 80th Regular Session, the Texas Legislature enacted Senate Bill 3, establishing, among other things, minimum requirements applicable to the Program. It is the intent of the Parties to comply with those minimum requirements and to build upon them to ensure that the Program is as effective and as inclusive as is reasonably possible, while also maintaining compliance with applicable provisions of the Endangered Species Act.

Section 1.3. The Parties acknowledge that Program efforts will be mindful of minimizing impacts on other protected species when advancing Program initiatives. The Parties also acknowledge the necessity of finding ways to balance the Program's contribution to recovery of Edwards Species with human water needs, while maintaining compliance with applicable provisions of the Endangered Species Act.

Article 2. Goals

Section 2.1. The goals of the Program, which are intended to be broadly interpreted, include, but are not limited to, the following:

(a) review, develop, and implement sound scientific research, analysis and other measures which contribute to understanding and meeting the needs of the Edwards Species;
(b) review, develop, and implement strategies which balance the needs of the Edwards Species with overall water use and supply in the Edwards Aquifer region;
(c) develop and complete an implementing agreement by December 31, 2009;
(d) develop and complete a program document by September 1, 2012, that shall take effect December 31, 2012, and may be in the form of a habitat conservation plan for the Edwards Species;
(e) implement the program document; and

(f) secure federal, state, and other available funding to assist with the development and implementation of the Program.

Section 2.2. The Parties to this MOA will participate in good faith in a cooperative, consensus-based process consistent with the purposes of the Program, and the requirements and deadlines imposed by Senate Bill 3. The Parties acknowledge that reasonable flexibility to adapt Program activities, particularly in response to new information and changed circumstances, is necessary to effectively meet the purposes of the Program.

Article 3. Definitions and Construction.

Section 3.1. Definitions. In this MOA, the following terms shall have the meanings assigned in this section unless the context clearly specifies a different meaning:

"Edwards Aquifer" means the same as the definition for "Aquifer" used in The Edwards Aquifer Authority Act.

"Edwards Species" means aquatic species that (1) are listed as threatened or endangered pursuant to the Endangered Species Act, and (2) are found in the Edwards Aquifer or found in or around the springs associated with the Edwards Aquifer. The Edwards Species, as of the Effective Date, are as follows: fountain darter, San Marcos gambusia, San Marcos salamander, Texas blind salamander, Comal Springs riffle beetle, Comal Springs dryopid beetle, Peck's cave amphipod, and Texas wild rice. This definition may be expanded by decision of the Steering Committee, without amending the MOA, to include additional species that are proposed for listing as threatened or endangered and that otherwise meet the definition of Edwards Species.

"Effective Date" means the date this MOA is effective, which shall be that date on which the MOA has been executed by duly authorized representatives of (1) the Edwards Aquifer Authority, United States Fish and Wildlife Service, Texas Commission on Environmental Quality, Texas Parks and Wildlife Department, Texas Department of Agriculture, Texas Water Development Board and (2) of other interests designated in Senate Bill 3 as initial members of the Steering Committee such that, collectively, at least 75% of the initial members of the Steering Committee have signed the document.

"Endangered Species Act" means the federal Endangered Species Act of 1973, as amended, 16 U.S.C. §§ 1531, et seq.

"Habitat Conservation Plan" means a conservation plan as referred to in Section 10 (a)(2), 16 U.S.C. § 1539 (a)(2), of the Endangered Species Act.

"Recovery" means the process by which the decline of an endangered or threatened species is arrested or reversed, and threats removed or reduced so that the species' long term survival in the wild can be ensured.

"Senate Bill 3" means Article 12 of Senate Bill 3, 80th Regular Session, 2007, of the Texas Legislature and Article 2 of House Bill 3, 80th Regular Session, 2007, of the Texas Legislature.

The Articles amend the Edwards Aquifer Authority Act ("Act"), Chapter 626, Acts of the 73rd Legislature, Regular Session, 1993, Section 1.26(A) of the Act provides for the development of a recovery implementation program. Identical provisions are included in Article 2 of House Bill 3, 80th Regular Session of the Texas Legislature.

Section 3.2. Construction. The Parties intend this MOA to be construed to comply with Senate Bill 3 establishing, among other things, minimum requirements applicable to the Program and with applicable requirements of the Endangered Species Act.

Article 4. Participation

Section 4.1. The Parties pledge to participate in good faith in an open, voluntary, and cooperative process that will strive to reach consensus on issues that further the purposes and goals of the Program. To achieve these purposes and goals, the Program will be overseen by a Steering Committee designed to ensure opportunities for participation and adequate representation of stakeholders. The Steering Committee will adopt procedures consistent with the MOA to ensure the Program includes, but is not limited to, the following procedural elements: an open process, advance public notice of meetings and proposed actions, opportunity for stakeholder participation, open communication, and consensus-based decision-making.

Section 4.2. Senate Bill 3 established the composition of an initial Steering Committee. Senate Bill 3 also allows, upon execution of this MOA, the initial Steering Committee to vote to add Members and to change the composition of the Steering Committee. In order to ensure adequate stakeholder representation on the Steering Committee, the signatories of this MOA recommend that the Steering Committee, at its earliest opportunity, add to the Steering Committee five other persons in the following categories:

(a) A representative of a holder of an Edwards Aquifer Authority initial regular permit issued to a small municipality (population under 50,000) located east of San Antonio,
(b) A representative of Edwards Aquifer region municipal ratepayers/general public,
(c) A representative of Guadalupe River Basin municipal ratepayers/general public,
(d) A representative of a conservation organization, and
(e) A representative of the Nueces River Authority.

Section 4.3. The Steering Committee will adopt procedures for the designation of primary, alternate, and replacement members of the Steering Committee. When changing or adding members, including members in addition to those listed in Section 4.2, the Steering Committee shall seek to maintain the balance of interests represented in the initial Steering Committee as set out in Senate Bill 3.

Section 4.4. In accordance with Senate Bill 3, the Steering Committee shall appoint an Edwards Aquifer area expert science subcommittee no later than December 31, 2007. As soon as reasonably possible, the Steering Committee shall establish a recharge facility feasibility subcommittee; other subcommittees shall be established as the Steering Committee determines appropriate. The Steering Committee shall ensure procedural elements are adopted to ensure an open process, advance public notice of meetings and proposed actions, opportunity for

stakeholder participation, open communication, and consensus-based decision-making are followed in subcommittees.

Article 5. Governance

Section 5.1. In addition to the responsibilities expressed in Senate Bill 3, the Steering Committee will adopt procedures to: address employment of a Program Manager and determine the Program Manager's role in the Program; establish appropriate Program subcommittee processes, to include membership, responsibilities, and decision-making recommendations; obtain funding for the Program ; adopt or amend Program Operational Rules; and other matters for which the Steering Committee determines procedures are necessary.

Section 5.2. The goal of the Steering Committee is to achieve consensus-based decision-making. Consensus is reached when no Member of the Steering Committee is opposed to a proposal. It is understood and accepted that in order to achieve a consensus on the Steering Committee, each Member will be open to pursuing "win-win" alternatives and to considering variations on the proposal that he or she might initially prefer. In its deliberations, the Steering Committee shall seek to exhaust every reasonable and practicable effort to reach consensus.

Section 5.3. In furtherance of consensus-based decision-making, when a proposal to the Steering Committee involving a Tier 1 decision (as set out in Section 5.5) does not achieve consensus, the Steering Committee will adopt a process which requires further deliberation and development of the proposal by an Issue Team. The Issue Team will be a smaller team of stakeholders as appointed by the Steering Committee and will include, to the extent practicable, participants representing all different viewpoints on the proposal, which may include participants who are not members of the Steering Committee. The Issue Team process will provide an opportunity for input from other stakeholders. The goal of the Issue Team is to achieve consensus on the proposal, or to develop a restatement of the proposal that may better achieve consensus of the Steering Committee. If after resubmission to the Steering Committee, or restatement of the proposal and resubmission to the Steering Committee, consensus has not been achieved, the Steering Committee will then vote on the proposal. A resubmitted or restated proposal will be deemed to have been approved by the Steering Committee when at least 75 percent of the entire Steering Committee has voted in favor of the proposal in accordance with voting procedures to be adopted by the Steering Committee.

Section 5.4. The Steering Committee will adopt procedures for appointment of Issue Teams, time requirements for resubmission and restatement of proposals, flexibility to continue to pursue consensus, an allowance for a minority report to be included with Tier 1 decisions, and voting procedures. These procedures to be adopted by the Steering Committee will apply to all Tier 1 decisions.

Section 5.5. The following types of decisions are considered to be Tier 1 decisions:

(a) Hiring or terminating of Program Manager;
(b) Approval of annual budget;
(c) Formal Recommendations to the EAA;

(d) Recommendations or Reports to the Legislature;
(e) Membership, responsibilities, and procedures of subcommittees;
(f) Changes to the membership of the Steering Committee beyond initial changes set out in Section 4.2 above;
(g) Adoption and amendment of the decision process of the Steering Committee;
(h) Decisions related to adoption or amendment of any Program agreements including, but not limited to the Memorandum of Agreement, the Implementing Agreement, the Cooperative Agreement, and the Program Document;
(i) Adoption or amendment of Program Operational Rules; and
(j) Any significant action determined by the Steering Committee to require Tier 1 decision-making in accordance with procedures to be developed.

Section 5.6. The Steering Committee will adopt simplified procedures for all other decisions of the Steering Committee. For those decisions other than Tier 1 decisions, a decision will be deemed to have been approved by the Steering Committee when a majority of the entire Steering Committee has voted in favor of the proposal in accordance with voting procedures adopted by the Steering Committee. Non-Tier 1 decisions are not subject to the Issue Team process described in Section 5.3.

Article 6. General Provisions

Section 6.1. This MOA shall remain in effect until the earlier of September 1, 2012 or the execution of a program document in compliance with the requirements of Senate Bill 3 and the Endangered Species Act. However, any signatory retains the ability to withdraw from the Program at any time by providing written notice of withdrawal to the Steering Committee. This MOA, including the term of the MOA, may be amended by action of the Parties in accordance with Senate Bill 3 and the decision processes established by the Steering Committee.

Section 6.2. Nothing herein shall constitute, nor be deemed to constitute, an obligation of future appropriations by the signatories to this MOA where creating such an obligation would be inconsistent with applicable federal, state, or local laws. Funding commitments made under this MOA by the signatories are understood to be contingent on obtaining approval and appropriations by the applicable local, state, or federal regulatory or legislative bodies. This MOA does not create an exclusive arrangement between the United States Fish and Wildlife Service (Service) or the Department of the Interior and the Parties to this agreement or commit the Service or the Department of the Interior to enter into any contract or other binding obligation. By entering into this MOA, no Party is obligated to enter into any contract or other binding obligation. This MOA is subject to and is intended to be consistent with all applicable federal, state, and local laws.

Section 6.3. All signatories to this MOA recognize that various parties have statutory responsibilities that cannot be delegated. Nothing in this MOA shall be construed to abrogate any of the statutory responsibilities of any signatory of the MOA, including:

(1) responsibilities that relate to implementing specific strategies included in the Program Document;

(2) authority to decide whether to approve any document, or amendment thereto, specifically required to be entered into by the parties under Senate Bill 3; or

(3) the Service's statutory authority under the Endangered Species Act.

Section 6.4. This MOA is effective on the date fully signed as described in the Definition of Effective Date. The MOA may be signed by additional stakeholders, including other appropriate federal agencies, following the Effective Date of the MOA.

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

Unless otherwise indicated within the signature blocks below, a person signs this Memorandum of Agreement for Edwards Aquifer Recovery Implementation Program in his/her individual capacity.

Edwards Aquifer Authority

By: _____ Date: 1/9/08

Velma R. Danielson, General Manager, Edwards Aquifer Authority

_____

Attested by: Jennifer Wong-Esparza, Administrative Assistant

United States Fish and Wildlife Service

By: _____ Date: _____

Benjamin N. Tuggle, Ph.D., Regional Director, Region 2

Texas Commission on Environmental Quality

By: _____ Date: _____

_____

Texas Parks and Wildlife Department

By: _____ Date: _____

Scott Boruff, Deputy Executive Director of Operations, Texas Parks and Wildlife Department

Texas Department of Agriculture

By: _____ Date: _____

_____

Texas Water Development Board

By: _____ Date: _____

J. Kevin Ward, Executive Administrator, Texas Water Development Board

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

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Edwards Aquifer Authority

By:_____ Date:_____

United States Fish and Wildlife Service

By:_____ Date: 12/21/07
Benjamin N. Tuggle, Ph.D.
Regional Director, Region 2

Texas Commission on Environmental Quality

By:_____ Date:_____

Texas Parks and Wildlife Department

By:_____ Date:_____
Scott Boruff, Deputy Executive Director of Operations
Texas Parks and Wildlife Department

Texas Department of Agriculture

By:_____ Date:_____

Texas Water Development Board

By:_____ Date:_____
J. Kevin Ward, Executive Administrator
Texas Water Development Board

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Edwards Aquifer Authority

By:_____ Date:_____

United States Fish and Wildlife Service

By:_____ Date:_____
Benjamin N. Tuggle, Ph.D., Regional Director, Region 2

Texas Commission on Environmental Quality

By:_____ Date: 1-9-08
Mark R. Vickery, P.G., Deputy Executive Director, for Texas Commission on Environmental Quality

Texas Parks and Wildlife Department

By:_____ Date:_____
Scott Boruff, Deputy Executive Director of Operations, Texas Parks and Wildlife Department

Texas Department of Agriculture

By:_____ Date:_____

Texas Water Development Board

By:_____ Date:_____
J. Kevin Ward, Executive Administrator, Texas Water Development Board

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Edwards Aquifer Authority

By:_____ Date:_____

_____

United States Fish and Wildlife Service

By:_____ Date:_____
Benjamin N. Tuggle, Ph.D., Regional Director, Region 2

Texas Commission on Environmental Quality

By:_____ Date:_____

_____

Texas Parks and Wildlife Department

By: Scott Boruff Date: 12-31-07
Scott Boruff, Deputy Executive Director of Operations, Texas Parks and Wildlife Department

Texas Department of Agriculture

By:_____ Date:_____

_____

Texas Water Development Board

By:_____ Date:_____
J. Kevin Ward, Executive Administrator, Texas Water Development Board

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

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Edwards Aquifer Authority

By:_____ Date:_____

United States Fish and Wildlife Service

By:_____ Date:_____
Benjamin N. Tuggle, Ph.D., Regional Director, Region 2

Texas Commission on Environmental Quality

By:_____ Date:_____

Texas Parks and Wildlife Department

By:_____ Date:_____
Scott Boruff, Deputy Executive Director of Operations, Texas Parks and Wildlife Department

Texas Department of Agriculture

By:_____ Date: 1-8-08

Drew DeBerry, Deputy Commissioner, Texas Department of Agriculture

Texas Water Development Board

By:_____ Date:_____
J. Kevin Ward, Executive Administrator, Texas Water Development Board

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

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Edwards Aquifer Authority

By:_____ Date:_____

_____

United States Fish and Wildlife Service

By:_____ Date:_____
Benjamin N. Tuggle, Ph.D., Regional Director, Region 2

Texas Commission on Environmental Quality

By:_____ Date:_____

_____

Texas Parks and Wildlife Department

By:_____ Date:_____
Scott Boruff, Deputy Executive Director of Operations, Texas Parks and Wildlife Department

Texas Department of Agriculture

By:_____ Date:_____

_____

Texas Water Development Board

By:_____ Date: 12/20/07
J. Kevin Ward, Executive Administrator, Texas Water Development Board

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

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San Antonio Water System

By: David E. Chardavoyne Date: 24 January 2008

David E. Chardavoyne, President/Chief Executive Officer, SAWS

Guadalupe-Blanco River Authority

By:_____ Date:_____

San Antonio River Authority

By:_____ Date:_____

South Central Texas Water Advisory Committee

By:_____ Date:_____

Bexar County

By:_____ Date:_____

CPS Energy

By:_____ Date:_____

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

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San Antonio Water System

By:_____ Date:_____

Guadalupe-Blanco River Authority

By:_____ Date: December 19, 2007

W. E. West, Jr.
General Manager

San Antonio River Authority

By:_____ Date:_____

South Central Texas Water Advisory Committee

By:_____ Date:_____

Bexar County

By:_____ Date:_____

CPS Energy

By:_____ Date:_____

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

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San Antonio Water System

By:_____ Date:_____

Guadalupe-Blanco River Authority

By:_____ Date:_____

San Antonio River Authority

By: Suzanne B. Scott Date: 12/21/07
Suzanne B. Scott, General Manager

South Central Texas Water Advisory Committee

By:_____ Date:_____

Bexar County

By:_____ Date:_____

CPS Energy

By:_____ Date:_____

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

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San Antonio Water System

By:_____ Date:_____

_____

Guadalupe-Blanco River Authority

By:_____ Date:_____

_____

San Antonio River Authority

By:_____ Date:_____

_____

South Central Texas Water Advisory Committee

By: Gary Middleton Date: 1-16-2008

Chairman of South Central Texas Water Advisory Committee

Bexar County

By:_____ Date:_____

_____

CPS Energy

By:_____ Date:_____

_____

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San Antonio Water System

By:_____ Date:_____

_____

Guadalupe-Blanco River Authority

By:_____ Date:_____

_____

San Antonio River Authority

By:_____ Date:_____

_____

South Central Texas Water Advisory Committee

By:_____ Date:_____

_____

Bexar County

By:_____ Date: 1-08-08
Nelson W. Wolff, County Judge

_____

CPS Energy

By:_____ Date:_____

_____

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

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San Antonio Water System

By:_____ Date:_____

Guadalupe-Blanco River Authority

By:_____ Date:_____

San Antonio River Authority

By: Suzanne B. Scott Date: 12/21/07

Suzanne B. Scott, General Manager

South Central Texas Water Advisory Committee

By:_____ Date:_____

Bexar County

By:_____ Date:_____

CPS Energy

By: Milton B. Lee Date: 12-27-07

Milton B. Lee, General Manager & CEO

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

Unless otherwise indicated within the signature blocks below, a person signs this Memorandum of Agreement for Edwards Aquifer Recovery Implementation Program in his/her individual capacity.

Bexar Metropolitan Water District

By: [signature] F. Gilbert Williams Date: 12-15-07

Board Approved Dec 15, 2007

Representative of a holder of an initial regular permit issued to a retail public utility located west of Bexar County

By:_____ Date:_____

Representative of a holder of an initial regular permit issued by the EAA for industrial purposes

By:_____ Date:_____

Representative of a holder of an industrial surface water right in the Guadalupe River Basin

By:_____ Date:_____

Representative of a holder of a municipal surface water right in the Guadalupe River Basin

By:_____ Date:_____

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

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Bexar Metropolitan Water District

By:_____ Date:_____

Representative of a holder of an initial regular permit issued to a retail public utility located west of Bexar County

By:_____ Date: 1/10/08

City of Castroville

Representative of a holder of an initial regular permit issued by the EAA for industrial purposes

By:_____ Date:_____

Representative of a holder of an industrial surface water right in the Guadalupe River Basin

By:_____ Date:_____

Representative of a holder of a municipal surface water right in the Guadalupe River Basin

By:_____ Date:_____

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

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Bexar Metropolitan Water District

By:_____ Date:_____

_____

Representative of a holder of an initial regular permit issued to a retail public utility located west of Bexar County

By:_____ Date:_____

Representative of a holder of an initial regular permit issued by the EAA for industrial purposes

By:_____ Date: 1/18/2008

Devin "Buck" Benson, Attorney for Alamo Cement Company II, Ltd.
Alamo Concrete Products, Ltd., Alamo Park, Inc.

Representative of a holder of an industrial surface water right in the Guadalupe River Basin

By:_____ Date:_____

_____

Representative of a holder of a municipal surface water right in the Guadalupe River Basin

By:_____ Date:_____

_____

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

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Bexar Metropolitan Water District

By:_____ Date:_____

_____

Representative of a holder of an initial regular permit issued to a retail public utility located west of Bexar County

By:_____ Date:_____

_____

Representative of a holder of an initial regular permit issued by the EAA for industrial purposes

By:_____ Date:_____

_____

Representative of a holder of an industrial surface water right in the Guadalupe River Basin

By: Kristan A Soto Date: 12/28/2007

Kristan A. Soto, representative of Union Carbide Corporation

Representative of a holder of a municipal surface water right in the Guadalupe River Basin

By:_____ Date:_____

_____

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

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Bexar Metropolitan Water District

By:_____ Date:_____

_____

Representative of a holder of an initial regular permit issued to a retail public utility located west of Bexar County

By:_____ Date:_____

_____

Representative of a holder of an initial regular permit issued by the EAA for industrial purposes

By:_____ Date:_____

_____

Representative of a holder of an industrial surface water right in the Guadalupe River Basin

By:_____ Date:_____

_____

Representative of a holder of a municipal surface water right in the Guadalupe River Basin

By:_____ Date: 12/20/07

JERRY JAMES, DIRECTOR OF ENVIRONMENTAL SERVICES
CITY OF VICTORIA

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

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Representative of a retail public utility in whose service area the Comal Springs is located

By: Roger R. Biggers Date: Dec. 27, 2007

Roger R. Biggers, Executive Director of Water Services, New Braunfels Utilities

Representative of a holder of an initial regular permit issued by the EAA for irrigation

By:_____ Date:_____

Representative of an agricultural producer from the Edwards Aquifer region

By:_____ Date:_____

Representative of environmental interests from the Texas Living Waters Project

By:_____ Date:_____

Myron Hess, Manager of Texas Water Projects, National Wildlife Federation

Representative of recreational interests in the Guadalupe River Basin

By:_____ Date:_____

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

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Representative of a retail public utility in whose service area the Comal Springs is located

By:_____ Date:_____

Representative of a holder of an initial regular permit issued by the EAA for irrigation

By: Rader Gilleland Date: 1/8/08

Rader Gilleland, Representative for the holders of an initial regular permit for irrigation

Representative of an agricultural producer from the Edwards Aquifer region

By:_____ Date:_____

Representative of environmental interests from the Texas Living Waters Project

By:_____ Date:_____

Myron Hess, Manager of Texas Water Projects, National Wildlife Federation

Representative of recreational interests in the Guadalupe River Basin

By:_____ Date:_____

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

Unless otherwise indicated within the signature blocks below, a person signs this Memorandum of Agreement for Edwards Aquifer Recovery Implementation Program in his/her individual capacity.

Representative of a retail public utility in whose service area the Comal Springs is located

By:_____ Date:_____

_____

Representative of a holder of an initial regular permit issued by the EAA for irrigation

By:_____ Date:_____

_____

Representative of an agricultural producer from the Edwards Aquifer region

By: Ray Jay Pfannstiel Date: Jan 10, 2008

Guadalupe County Farm Bureau

Representative of environmental interests from the Texas Living Waters Project

By:_____ Date:_____

Myron Hess, Manager of Texas Water Projects, National Wildlife Federation

Representative of recreational interests in the Guadalupe River Basin

By: [illegible] Date: 1-10-08

Texas BASS Federation, Nation

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

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Representative of a retail public utility in whose service area the Comal Springs is located

By:_____ Date:_____

Representative of a holder of an initial regular permit issued by the EAA for irrigation

By:_____ Date:_____

Representative of an agricultural producer from the Edwards Aquifer region

By:_____ Date:_____

Representative of environmental interests from the Texas Living Waters Project

By: Myron J. Hess Date: 12/20/07
Myron Hess, Manager of Texas Water Projects, National Wildlife Federation

Representative of recreational interests in the Guadalupe River Basin

By:_____ Date:_____

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

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Persons Representing Other Interests:

By: _____ Date: 1/7/08

CHAIR: GUADALUPE BASIN COALITION

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

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Persons Representing Other Interests:

By: _____ Date: 12/31/07

(STAKEHOLDER) REAGAN FREILING, PRESIDENT, SOUTH TEXAS FARM AND RANCH CLUB

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

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Persons Representing Other Interests:

By:_____ Date: 1/8/08

Interim City Manager, City of San Marcos, Texas

By:_____ Date:_____

By:_____ Date:_____

By:_____ Date:_____

By:_____ Date:_____

By:_____ Date:_____

By:_____ Date:_____

By:_____ Date:_____

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

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Persons Representing Other Interests:

By: Kirk Patterson Date: 1/20/08

KIRK PATTERSON, PRESIDENT, REGIONAL CLEAN AIR AND WATER ASSOCIATION

By:_____ Date:_____

By:_____ Date:_____

By:_____ Date:_____

By:_____ Date:_____

By:_____ Date:_____

By:_____ Date:_____

By:_____ Date:_____

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Persons Representing Other Interests:

By: _____ Date: 12-20-07

Ex. VP, TEXAS WILDLIFE ASSOCIATION

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

Unless otherwise indicated within the signature blocks below, a person signs this Memorandum of Agreement for Edwards Aquifer Recovery Implementation Program in his/her individual capacity.

Persons Representing Other Interests:

By: Hoffmann Date: Jan. 10, 2008

Personal

By: Date: 1/10/08

GEORGE RIOS FOR AGUA

By: Date: 1/10/08

ANNALISA PEACE FOR GREATER EDWARDS AQUIFER ALLIANCE

By: Date:

By: Date:

By: Date:

By: Date:

By: Date:

Persons Representing Other Interests

By: _____ Date: May 7, 2008

On behalf of the Greater San Antonio

Chamber Of Commerce

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (DECEMBER 13,2007)

Unless otherwise indicated within the signature blocks below, a person signs this Memorandum of Agreement for the Edwards Aquifer Recovery Implementation Program in his/her individual capacity.

Dianne H. Wassenich Date: 5-8-2008

Dianne H. Wassenich, Executive Director
San Marcos River Foundation

Persons Representing Other Interests:

By: _____ Date: February 13, 2008

John M. Donahue, Ph.D.

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

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Persons Representing Other Interests:

By: [signature] Date: 1/7/08

CHAIR: GUADALUPE BASIN COALITION

By: _____ Date: _____

By: [signature] Date: 2/14/08

City of Garden Ridge

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

Unless otherwise indicated within the signature blocks below, a person signs this Memorandum of Agreement for Edwards Aquifer Recovery Implementation Program in his/her individual capacity.

City of New Braunfels:

By: _____ Date: 2/15/08
Michael Morrison, City Manager

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

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Persons Representing Other Interests:

By: Jay Millikin Date: 12 June 08

Comal County Commissioners Court

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

By: _____ Date: _____

Persons Representing Other Interests

By: Carol G. Patterson Date April 17, 2008

Carol G. Patterson

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

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Persons Representing Other Interests:

By:_____ Date: March 10, 2008
Con Mims
Representing Nueces River Authority

By:_____ Date:_____

_____

By:_____ Date:_____

_____

By:_____ Date:_____

_____

By:_____ Date:_____

_____

By:_____ Date:_____

_____

By:_____ Date:_____

_____

By:_____ Date:_____

_____

SIGNATURE PAGES FOR MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM (December 13, 2007)

Unless otherwise indicated within the signature blocks below, a person signs this Memorandum of Agreement for Edwards Aquifer Recovery Implementation Program in his/her individual capacity.

Edwards Aquifer Authority

By: Mary Q. Kelly Date: August 11, 2008

Mary Q. Kelly - Individual

United States Fish and Wildlife Service

By:_____ Date:_____

Benjamin N. Tuggle, Ph.D., Regional Director, Region 2

Texas Commission on Environmental Quality

By:_____ Date:_____

Texas Parks and Wildlife Department

By:_____ Date:_____

Scott Boruff, Deputy Executive Director of Operations, Texas Parks and Wildlife Department

Texas Department of Agriculture

By:_____ Date:_____

Texas Water Development Board

By:_____ Date:_____

J. Kevin Ward, Executive Administrator, Texas Water Development Board

DAN R LAROE JR.
Persons Representing Other Interests

By: Dan R LaRoe Jr. Date: August 27, 2010

On behalf of Self

Persons Representing Other Interests

David DeViney, President

By: David DeViney Date: 5-21-09

On behalf of Preserve Lake Dunlap Association

APPENDIX B:

REPORT OF THE EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM SCIENCE SUBCOMMITTEE, "EVALUATION OF DESIGNATING A SAN MARCOS POOL, MAINTAINING MINIMUM SPRING FLOWS AT COMAL AND SAN MARCOS SPRINGS, AND ADJUSTING THE CRITICAL PERIOD MANAGEMENT TRIGGERS FOR THE SAN MARCOS SPRINGS," NOVEMBER 13, 2008

Evaluation of Designating a San Marcos Pool, Maintaining Minimum Spring Flows at Comal and San Marcos Springs, and Adjusting the Critical Period Management Triggers for San Marcos Springs

Report to the Steering Committee
for the Edwards Aquifer Recovery Implementation Program

The Edwards Aquifer Area Expert Science Subcommittee
for the Edwards Aquifer Recovery Implementation Program

November 13, 2008

The photograph on the preceding page is of Texas wild-rice in Spring Lake at San Marcos Springs (photo by John Thomaides).

November 13, 2008

To: The Steering Committee for the Edwards Aquifer Recovery Implementation Program

From: The Edwards Aquifer Area Expert Science Subcommittee

Attached please find a final report titled *Evaluation of Designating a San Marcos Pool, Maintaining Minimum Spring Flows at Comal and San Marcos Springs, and Adjusting the Critical Period Management Triggers for San Marcos Springs.* This report meets the requirements of Article 12, Senate Bill 3, Regular Session, 80th Texas Legislature, Section 1.26A(k), and the requirements of your charges to us. This is a consensus report.

If you have any questions, please do not hesitate to contact Ms. Susan Aragon-Long with the U.S. Geological Survey.

Evaluation of Designating a San Marcos Pool, Maintaining Minimum Spring Flows at Comal and San Marcos Springs, and Adjusting the Critical Period Management Triggers for San Marcos Springs

Report to the Steering Committee
for the Edwards Aquifer Recovery Implementation Program

The Edwards Aquifer Area Expert Science Subcommittee
for the Edwards Aquifer Recovery Implementation Program

November 13, 2008

The Edwards Aquifer Recovery Implementation Program
Edwards Aquifer Area Expert Science Subcommittee

Chair

Susan Aragon-Long, U.S. Geological Survey (non-voting)

Members

Rene Barker, P.G., Texas State University

Norman Boyd, Texas Parks and Wildlife Department

Thomas Brandt, Ph.D., U.S. Fish & Wildlife Service

Alan Dutton, Ph.D., P.G., The University of Texas at San Antonio

Michael Gonzales, San Antonio River Authority

Ron Green, Ph.D., P.G., Southwest Research Institute

Charles Kreitler, Ph.D., P.G., LBG-Guyton Associates (non-voting)

Glenn Longley, Ph.D., Texas State University

Robert E. Mace, Ph.D., P.G., Texas Water Development Board

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Texas wild-rice (photo by John Thomaides)

Executive Summary

In 2007, the 80th Texas Legislature passed Senate Bill 3 which, among other items, formalized the Edwards Aquifer Recovery Implementation Program. The legislation requires a group of stakeholders in a Steering Committee to develop a Program Document. The Program Document provides recommendations for withdrawal adjustments to protect threatened and endangered species at all times and includes provisions to pursue funding for programs to achieve that goal.

The Steering Committee is served by several subcommittees, one of which is the Edwards Aquifer Area Expert Science Subcommittee. Senate Bill 3 requires the formation of the Expert Science Subcommittee, its members appointed by the Steering Committee. The Expert Science Subcommittee's initial primary charges from the Steering Committee were to (1) evaluate designating a San Marcos Pool, (2) evaluate the necessity of maintaining minimum spring flows, and (3) evaluate whether adjustments to drought triggers for San Marcos Springs should be made. The Steering Committee, in a memo dated February 21, 2008, provided additional guidance and clarifications of the initial three charges.

Regarding the first charge, to evaluate designating a San Marcos Pool, the subcommittee was specifically asked to evaluate the option of designating a separate San Marcos Pool, how such a designation would affect existing pools, and the need for an additional well(s) to measure the San Marcos Pool (if designated). We do not believe that there are sufficient data at this time to support the designation of a separate San Marcos Pool or to define its boundaries.

To reach these conclusions, we first identified what data and modeling currently exist and if there was enough detailed information to designate a separate San Marcos Pool. We considered the importance of hydrogeologic conceptualization, flowpath considerations, recharge assessments, water-balance estimates, water-chemistry analyses, and hydraulic

correlation analyses on the designation of a separate San Marcos Pool in the San Antonio Segment of the Edwards Aquifer. We further evaluated the hydrogeology of the study area using results from existing numerical models and assessed the data and analyses to identify data gaps.

Hydrogeological conceptualizations, defined and inferred flowpaths, and water balance calculations of the Edwards Aquifer have been developed by multiple researchers. Though complex and sometimes conflicting, these studies generally indicate that portions of the Edwards Aquifer contributing significantly to San Marcos Springs extend beyond Hays and Comal counties. San Marcos Springs is more reliant on distant, rather than local, water sources within the aquifer to sustain springflow during drought. Water-chemistry analyses of discharges from multiple San Marcos Springs orifices indicate contributions from both recent, local recharge and older, regional recharge. Hydraulic correlation analyses show Comal Springs discharges are highly correlated with water levels in the Bexar County Index Well (J-17) and that San Marcos Springs discharges are correlated with Comal Springs discharges, despite some temporal anomalies at San Marcos Springs, likely caused by differences in local and regional recharge and storage recovery rates during the drought of 2006 and other droughts.

In short, the "unknowns" significantly outnumber the "knowns" when it comes to understanding the recognized hydrogeologic features and effects—much less the unrecognized controls—on groundwater levels and springflow associated with San Marcos Springs. From a scientific standpoint, we felt that at this time, we could not recommend segregation of the larger San Antonio Pool until the relationships among rainfall, recharge, and downgradient water levels and springflow become more predictable. In other words, a more complete understanding is required of the various elements of the hydrogeologic framework that control the flow and storage of groundwater in different segments of the Edwards aquifer. To improve this understanding, the subcommittee recommends several studies on hydrogeology and modeling.

On the second charge regarding the necessity of maintaining minimum spring flows, we believe that minimum spring flows are required within the context of a system flow regime for the survival and recovery of each species listed under the Endangered Species Act identified in Section 3.2 of the Edwards Aquifer Recovery Implementation Program Memorandum of Agreement. A system flow regime includes low flows, normal flows, and higher flows, each of which supports key ecological functions. We contend that minimum spring flows within the context of a system flow regime are important to both survival and recovery of these species. Minimum spring flows are vital to maintain conditions suitable for individuals of a species to continue to exist for some period (that is, survive). Minimum spring flows also play a role in genetic strengthening which serves a purpose in the recovery of a species.

To support this conclusion, we examined the available biological information for these species within the context of the hydrological regime present in the San Marcos and Comal rivers. These systems consist of relatively constant spring flow which provides unique, stable habitat within the aquifer and for some distance downstream. Flow has a direct effect on the amount of habitat available to these species. The hydraulic features of

flow (depth and velocity), along with channel, aquatic vegetation, and substrate, contribute directly to physical habitat features of these systems. The rate of spring flow is also an important factor in determining the longitudinal extent of suitable conditions for water temperature, carbon dioxide, nutrient distribution, and other water quality constituents. Additionally, the natural timing, frequency, duration, and magnitude of spring flows are important in controlling invasive and non-native species.

Secondly, we concluded that, at this time, no proven alternatives exist as a replacement for minimum flows (for example, something other than flow) as discussed in this report; however, potential management strategies involving flow have been proposed, and we recommend that these strategies be further evaluated. Potential management strategies involving flow, such as spring flow augmentation, recirculation, and artificial recharge, may be proven in the future to maintain or enhance minimum flows and thus maintain the biological community.

The use of refugia has been proposed by stakeholders and was characterized as an alternative for consideration in this report. However, we concluded that, although refugia play a vital role in the protection of threatened and endangered species, refugia are not viable or effective alternatives to maintaining minimum flows. Additionally, the policy regarding controlled propagation of species listed under the Endangered Species Act states that "Controlled propagation is not a substitute for addressing factors responsible for an endangered or threatened species' decline". As no alternatives were identified as a replacement for minimum flows, the additional studies evaluation focuses on ways to enhance ex-situ or captive propagation via applied research and to explore in-situ refugia within these spring systems.

Our third charge was to evaluate whether or not the critical period management triggers for San Marcos Springs for the San Antonio Pool should be adjusted. We believe that trigger levels for San Marcos Springs should not be adjusted at this time. In reaching this conclusion, we examined the critical period management triggers for San Marcos Spring in context with other triggers by evaluating data provided by the Edwards Aquifer Authority for San Marcos Springs flow from 1980 to 2007. The data was processed to isolate information for when flows in San Marcos Springs, water levels in Index Well J-17, and flows in Comal Springs hit their different critical period management triggers for declining and increasing water levels and springflows. Evaluating this data in context with triggers contained in Senate Bill 3, 80th Texas Legislative Session, show that the current trigger for flow at San Marcos Springs would occasionally precede the triggers for Index Well J-17 and Comal Springs going into critical period drought and would occasionally lag Index Well J-17 and Comal Springs when coming out of critical period drought. In addition, review of results from modeling done by others of the current critical period triggers indicate that the triggers do not prevent the cessation of flow at Comal Springs during a repeat of the drought of record; however, these triggers do preserve flow at San Marcos. Given that the triggers may be revisited as part of the recovery implementation program and our current lack of understanding of flow with respect to San Marcos Springs found under our first task, at this time we are not able to recommend an adjustment to the critical period management triggers for San Marcos Springs.

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Comal Springs in 2008 (photo by Steven Bereyso)

Introduction

The Edwards Aquifer is recognized as a vital water resource for a multitude of agricultural, environmental, industrial, municipal, and recreational uses. Several springs, namely Comal Springs and San Marcos Springs, provide habitat for a number of endangered species protected under the federal Endangered Species Act. After a lawsuit and the specter of federal control of the aquifer, the Texas Legislature created the Edwards Aquifer Authority to regulate pumping in the aquifer and to ensure that, by December 31, 2012, endangered and threatened species are protected.

In 2007, the Texas Legislature passed Senate Bill 3 which, among other items, formalized the Edwards Aquifer Recovery Implementation Program. The legislation requires a group of stakeholders in a Steering Committee to develop a Program Document. The Program Document provides recommendations for withdrawal adjustments to protect threatened and endangered species at all times and includes provisions to pursue funding for programs to achieve that goal. The document may be in the form of a Habitat Conservation Plan used in the issuance of an Incidental Take Permit. The Edwards Aquifer Authority, the Texas Commission on Environmental Quality, the Texas Water Development Board, and the U.S. Fish & Wildlife Service have to approve and execute the Program Document no later than September 30, 2012, with the document going into effect by December 31, 2012.

The Steering Committee is served by several subcommittees, one of which is the Edwards Aquifer Area Expert Science Subcommittee. Senate Bill 3 requires the formation of the Expert Science Subcommittee, its members appointed by the Steering

Committee (see **Appendix A** for information on the formation and operation of the subcommittee). The Expert Science Subcommittee's initial charges are to (1) evaluate designating a San Marcos Pool, (2) evaluate the necessity of maintaining minimum spring flows, (3) evaluate whether adjustments to flow triggers for San Marcos Springs should be made, and (4) submit the recommendations to the Steering Committee and all other stakeholders involved in the Recovery Implementation Program by December 31, 2008 (**Appendix B**). The Expert Science Subcommittee is also required, at a later date, to (1) analyze species requirements for spring flow and aquifer levels as a function of recharge and withdrawal levels and (2) develop recommendations for withdrawal reductions for critical period management.

The Steering Committee, in a memo dated February 21, 2008, charged the Expert Science Subcommittee with the initial charges listed above and provided additional guidance and clarifications of those initial charges (**Appendix C**). These charges, with minor editing to break them into subtasks, were:

Task 1: The option of designating a separate San Marcos Pool, of how such a designation would affect existing pools, and of the need for an additional well(s) to measure the San Marcos Pool (if designated).

1.1 Identify the data and modeling that exist regarding whether a separate San Marcos Pool should be designated.

1.2 Are the data sufficient to support the designation of a separate San Marcos Pool?

1.3 Provide an evaluation of the hydrogeological evidence and identify the data gaps.

1.4 If there are data to support the designation of such a pool, what should be the extent and boundaries of such pool?

1.5 To what extent is this pool hydrologically independent?

1.6 Is there a need for an additional well or additional wells to measure the San Marcos Pool, if one were designated? If so, what is the most effective location for such well(s)?

1.7 The evaluation of this issue should include consideration of information provided by the members of the Recovery Implementation Program.

Task 2: The necessity to maintain minimum spring flows, including a specific review of the necessity to maintain a flow to protect the federally threatened and endangered species.

2.1 Is a minimum spring flow required for the survival and recovery of each species listed under the Endangered Species Act identified in Section 3.2 of the Memorandum of Agreement for the Edwards Aquifer Recovery Implementation Program (**Appendix D**)?

2.2 If alternatives exist to minimum flows that may not reduce appreciably the likelihood of the survival and recovery in the wild

by reducing the reproduction, numbers, or distribution of each species listed under the Endangered Species Act identified in Section 3.2 of the Memorandum of Agreement for the Edwards Aquifer Recovery Implementation Program (**Appendix D**), identify and provide a preliminary evaluation of those alternatives to protect those federally listed species.

2.2.1 Your consideration of alternatives should include an evaluation of information provided by members of the Edwards Aquifer Recovery Implementation Program on this issue.

2.2.2 Your consideration of alternatives also should be mindful of impacts on protected species other than those species listed under the Endangered Species Act identified in Section 3.2 of the Memorandum of Agreement for the Edwards Aquifer Recovery Implementation Program (**Appendix D**).

2.3 Identify existing studies regarding the ability of each alternative other than maintaining minimum spring flows to protect federally threatened or endangered species. Identify additional studies or data needed to fully evaluate each of these alternatives, including an estimate of the time and cost to conduct such studies, and any different alternatives that might be explored in the future.

2.4 Investigate spring flow volume measurement methodologies currently in use and evaluate their accuracy. If any are deemed to be inadequate, suggest alternative measuring methods.

Task 3: Whether adjustments in the trigger levels for the San Marcos Springs flow for the San Antonio Pool should be made.

3.1 Should the trigger levels for the San Antonio Pool based on San Marcos spring flow be adjusted? Identify the existing data available to develop recommendations regarding such adjustments and what additional information will be necessary to make such recommendations.

3.2 Investigate spring flow volume measurement methodologies currently in use and evaluate their accuracy. If any are deemed to be inadequate, suggest alternative measuring methods.

The purpose of this document is to report on these initial charges.

This report is organized according to the tasks listed above. Under each subtask, we list our recommendation followed by our interpretation of the subtask, the information we considered, and our analysis. Supporting documentation is included in the appendices.

Spring Lake at San Marcos Springs in 1901 (from Taylor 1904)

Task 1: Are the data sufficient to designate a San Marcos Pool?

Recommendation: The Edwards Aquifer Area Expert Science Subcommittee does not believe that there are sufficient data at this time to support the scientific designation of a separate San Marcos Pool for aquifer management.

Our interpretation of the task

This task is focused on whether or not the current science and modeling is sufficient to designate a San Marcos Pool.

One of the key questions we had to answer was: What is a pool? "Pool" is not defined in the enabling act or the rules of the Edwards Aquifer Authority; however, pools are referred to in these documents. The authority's enabling legislation and rules refer to an Uvalde Pool and a San Antonio Pool, and the enabling act (Section 1.14(g)) states that "[t]he authority by rule may define other pools within the aquifer, in accordance with hydrogeologic research, and may establish index wells for any pool to monitor the level of the aquifer to aid the regulation of withdrawals from the pools."

Although the term "pool" is not explicitly defined in statute or rule, we can discern certain elements of what a pool is and what designation means through examining the

currently designated pools. Being designated as a pool does not infer hydrologic isolation from the rest of the aquifer as the Uvalde and San Antonio pools are hydrologically connected. The Uvalde Pool is defined as the part of the aquifer that underlies Uvalde County, and the San Antonio Pool is defined as the part of the aquifer that is within the bounds of the authority but outside of Uvalde County. The Knippa Gap, a hydrologic constriction in the groundwater flow from the western part of the aquifer to the eastern part, lies close to the line between Uvalde County and Medina County.

From a management perspective, a pool designation may affect permitting and critical period management, as seen in the statute and rules for the two existing pools. Therefore, we define a pool as a management construct supported by hydrogeologic data and descriptions that assist in managing the aquifer.

Why is this task important?

In 2006, after substantial rainfalls in some recharge basins, water levels in Index Well J-17 and flow from Comal Springs rebounded above their critical period management triggers while flow at San Marcos Springs remained below those triggers for an additional 125 days. Groundwater users in the San Antonio Pool were not allowed to reduce their pumping restrictions until Index Well J-17, Comal Springs, and San Marcos Springs all were above their respective triggers. This behavior in 2006 (**Figure 1**) as well as at other times in the past, has caused some to wonder whether or not a San Marcos Pool should be designated. A separate pool designation with separate triggers may allow some groundwater users outside of a San Marcos Pool to return to a lower, less restrictive, critical period withdrawal reduction stage while groundwater users within a San Marcos Pool area would remain at the higher withdrawal reduction stage until flow at San Marcos Springs exceeded a specified trigger level. A separate pool designation could also allow the Edwards Aquifer Authority to pass more stringent rules to protect the flow at San Marcos Springs.

Our approach for addressing the task

To address this task, we identified, reviewed, and discussed relevant literature and reports (noted below in the discussion) and listened to presentations by invited experts (**Appendix E**). Presentations relevant to our analysis included those by Geary Schindel of the Edwards Aquifer Authority on the Authority's report on the San Marcos Pool question; Charles Kreitler of LBG-Guyton Associates on his company's recent reports to the Authority on moving pumping locations to the east of Cibolo Creek and on augmenting spring flow; Rick Lindgren of the U.S. Geological Survey on his modeling work; Larry Land of HDR Engineering on recharge estimates and his work for the Guadalupe-Blanco River Authority on the effects on spring flow from the pumping of a power plant well near Comal Springs during the 1950s and the groundwater divide between San Marcos and Barton springs; and George Ozuna of the U.S. Geological Survey on spring flow measurements at Comal and San Marcos springs. The important

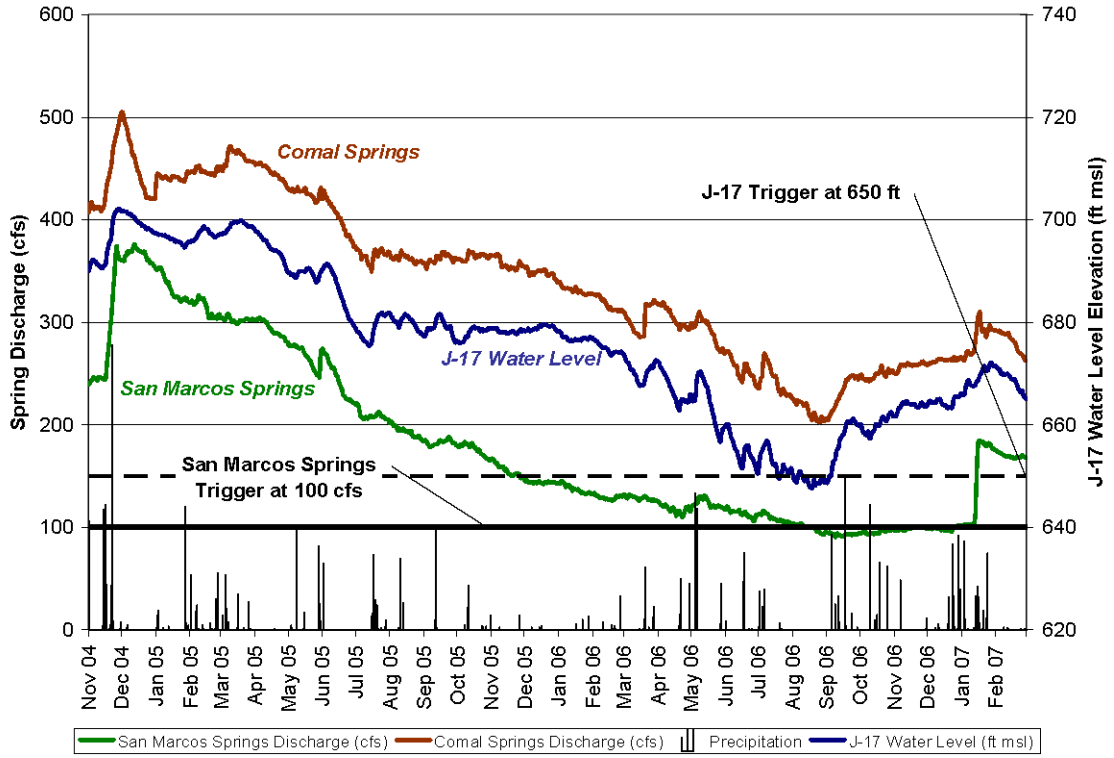


Figure 1: Comparison of Index Well J-17 water levels with Comal and San Marcos springflows for the period between November 2004 and February 2007 (from Johnson and Schindel 2008; cfs = cubic feet per second; ft msl = feet above mean sea level).

questions we sought to address were (1) Do we have a sufficient understanding of the geology and hydrodynamics of this part of the Edwards Aquifer to designate a separate pool for aquifer management? and (2) If we don't have enough information, what addition information is needed?

Task 1.1: Identify the data and modeling that exist regarding whether a separate San Marcos Pool should be designated

We used data and analyses from the following studies in our evaluation:

- DeCook (1963),
- Rose (1972);
- Pearson and others (1975),
- Guyton (1979),
- Maclay and Small (1984),

- Ogden and others (1986),
- Rothermel and Ogden (1986, 1987),
- Deike (1990),
- HDR Engineering (1991),
- HDR Engineering (1993),
- Hovorka and others (1993),
- Maclay (1995),
- Barker and Ardis (1996),
- Groschen (1996),
- Hovorka and others (1998),
- HDR Engineering (2002),
- Slade and others (2002),
- LBG-Guyton Associates (2004),
- LBG-Guyton Associates (2005),
- Otero (2007), and
- Johnson and Schindel (2008).

The most relevant modeling work that related to this task included:

- Klemt and others (1979),
- Maclay and Land (1988),
- Thorkildsen and McElhaney (1992),
- Lindgren and others (2004), and
- Lindgren (2006).

These studies are discussed under **Task 1.3**.

Task 1.2: Are the data sufficient to support the designation of a separate San Marcos Pool?

At this time, the Edwards Aquifer Area Expert Science Subcommittee does not believe that there are sufficient data to support the designation of a separate San Marcos Pool. The support for this recommendation is discussed in the following sections.

Task 1.3: Provide your evaluation of the hydrogeological evidence and identify the data gaps.

To address this task, we carefully reviewed the documents noted under **Task 1.1**. For data and analyses, we considered the importance of the following on the designation of a separate San Marcos pool in the San Antonio segment of the Edwards Aquifer:

- hydrogeologic conceptualization,
- flowpath considerations,
- recharge assessments,
- water-balance estimates,
- water-chemistry analyses, and
- hydraulic correlation analyses.

We further evaluated the hydrogeology of the study area using results from the numerical models. We then used a comprehensive assessment of these data and analyses to identify perceived data gaps.

Hydrogeologic conceptualization

The area within the Edwards Aquifer considered for a separate San Marcos Pool lies within an extensively faulted and highly anisotropic and heterogeneous portion of the aquifer known as the Balcones Fault Zone (Rose 1972; "anisotropic" means that the aquifer has different flow properties depending on the direction of flow). The Balcones Fault Zone is characterized by a network of en echelon, high-angle, mostly down-to-the-east normal faults along the northwestern margin of the Gulf Coastal Plain (Maclay and Small 1984; "en echelon" means parallel or subparallel, closely spaced, and overlapping). Within the roughly 200-mile-long (320-kilometer-long) Balcones Fault Zone structural corridor, the carbonate strata were vertically displaced, intensively fractured, and differentially rotated within a series of southwest-to-northeast trending fault blocks (Barker and Ardis 1996).

The groundwater flowpaths that converge toward and ultimately determine the conditions at Hueco, Comal, and San Marcos springs must traverse structurally controlled and diagenetically altered pathways (Deike, 1990; "diagenetically altered" means alterations to the rock after it was deposited; in the case, dissolution). Factors that determine the internal configurations of the flowpaths—such as matrix porosity and permeability (Hovorka and others 1993, 1998), fractures, and karst conduits (Worthington 2003)—result from depositional, structural, diagenetic, and hydrologic imprints that have evolved since the Cretaceous Period, over the last 80 million years of geologic time.

The effect of geologic structure on groundwater flow near Hueco, Comal, and San Marcos springs is not fully understood. The alternating sets of nearly vertical, en echelon faults have been assumed to act as barriers to flow in some places and as conduits that enhance flow in other locations (Guyton 1979, Maclay and Land 1988). Faults can focus flow along the fault zone, for example, where zones of greater porosity and permeability

are developed around the fault zones. Conversely, faults may provide the flowpath that allows groundwater to move vertically between aquifer members or from a confined aquifer to a spring at ground surface. Large-displacement faults at Comal Springs and San Marcos Springs are examples of groundwater flow along faults.

Faults could become barriers to flow, however, where groundwater is prevented from flowing perpendicular to the faults. The barrier might form where the fault offsets blocks of the aquifer. The aquifer becomes discontinuous across the fault because of vertical displacement of the fault.

In addition, conduits exist that cut across faults. Recent tracer studies by the Edwards Aquifer Authority in northern Bexar County (Johnson and others, in review) show that conduits can be superimposed on the structurally controlled fault blocks, and that flow can readily cross between fault-bounded blocks where conduits have developed. The mean velocity of flow in conduits in northern Bexar County is approximately 1,120 feet per day (341 meters per day), with a maximum measured apparent velocity of more than 15,000 feet per day (4,570 meters per day) (Johnson and others, in review), much higher than flow velocities in the matrix porosity of the aquifer.

As groundwater flows toward Comal, Hueco, and San Marcos springs, groundwater flow may be focused within fault-bounded blocks but the role of flow in conduits that cross between fault-bounded blocks of the aquifer is still being evaluated by tracer tests. Otero (2007) and Johnson and Schindel (2008) provide the most current conceptual models of the fault blocks as they affect groundwater flow. These two studies focus on slightly different geographical areas and use different nomenclature to define the fault blocks. Otero (2007) extended her study southwest to Leon Creek while Johnson and Schindel (2008) limited their evaluation to that portion of the San Antonio Segment of the Edwards Aquifer located northeast of Cibolo Creek.

Otero (2007) identified three fault blocks designated in terms of groundwater flow as the Northern, Central, and Southern Comal flowpaths (**Figure 2**). The Southern Comal Flowpath is bounded on the northwest by the Comal Springs Fault and on the southeast by a freshwater/saline-water interface (Schultz 1994), where the concentration of dissolved solids exceeds 1,000 milligrams per liter. Although the interface is not everywhere coincident with physical barriers to flow, a major effect of the Comal Springs Fault is a resistance to the encroachment of saline water from the southeast.

Johnson and Schindel (2008) identified four fault blocks—Bat Cave, Hueco Springs, Comal Springs, and Artesian fault blocks—in Hays and Comal counties (**Figure 3**). The Bat Cave Fault Block receives water both from vertical infiltration in the fault block and lateral groundwater flow from the Trinity Aquifer where the Bear Creek Fault (**Figure 2**) juxtaposes the Trinity Aquifer against the Edwards Aquifer (Otero 2007, Johnson and Schindel 2008). As only the basal part of the Edwards Aquifer is present in the Bat Cave Fault Block, the flow and storage of groundwater is relatively limited in this updip, unsaturated-to-thinly-saturated part of the aquifer ("updip" means the upper part of a slanted geologic bed; in this context, it means up toward the recharge zone).

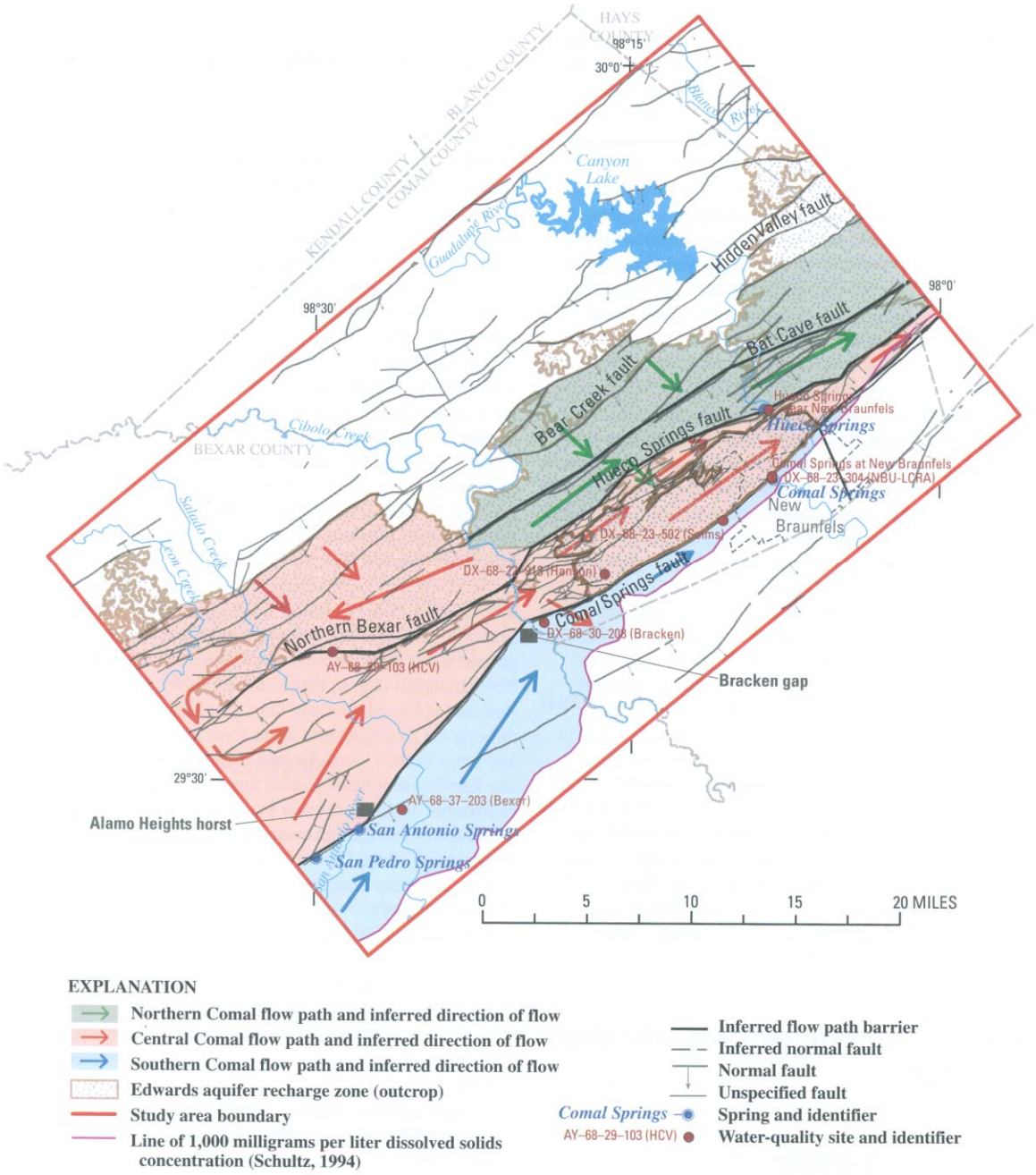


Figure 2: Locations of hypothesized groundwater flowpaths, northeastern Bexar and southern Comal counties, Texas (from Otero 2007).

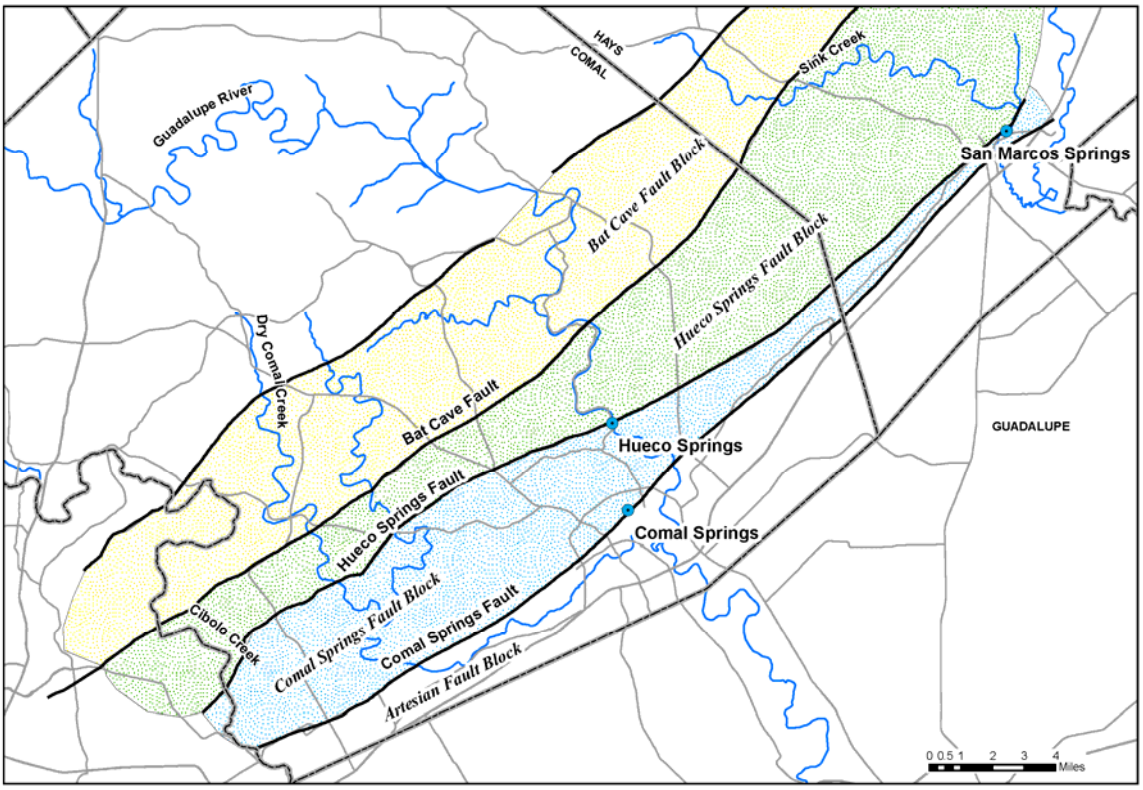


Figure 3. Locations of fault blocks in the Edwards Aquifer in Comal and southwestern Hays counties (from Johnson and Schindel 2008).

In addition to the Bat Cave Fault Block, the Edwards Aquifer recharge zone lies in large parts the Hueco Springs Fault Block and smaller parts of the Comal Springs Fault Block. Although saturated thicknesses in the Hueco Springs and Comal Springs fault blocks are highly variable, they generally are greater than a few tens of feet (a few meters), particularly during wet,high-stage periods. The Edwards Aquifer is fully saturated in the Artesian Fault Block, which comprises the hydraulically confined part of the Edwards Aquifer in this area (Johnson and Schindel 2008).

The distributions of recharge and discharge are overriding controls on the distribution of groundwater in the Edwards Aquifer (Puente 1978). Recharge areas occur where the Edwards Aquifer receives water, where the aquifer is receptive to the infiltration of precipitation, vertical leakage through streambeds, and/or cross-formational flow from adjacent aquifers. Discharge areas are characterized by places on or near the land surface where water escapes through springs, seeps, or base flow to streams or as a result of evaporation, transpiration, and/or pumping. Aquifers can also discharge water to other aquifers or aquitards via subsurface cross-formational flow (in this context, “aquitard” refers to geologic formations that transmit water much more slowly than the aquifer).

Most recharge to the aquifer occurs west of Bexar County in Kinney, Uvalde, and Medina counties where streams originating north of the aquifer lose most or all of their

discharge as they flow over the highly fractured, permeable outcrop of the Edwards Aquifer. Additional water from precipitation enters the aquifer through recharge areas in updip, unconfined parts of the aquifer in Bexar, Comal, and Hays counties. After recharge enters the aquifer, groundwater moves in a generally eastward direction toward points of discharge that consist mainly of natural springs and irrigation and municipal (water-supply) wells. As the freshwater flowpaths approach the updip edge of a freshwater-saline water interface (Schultz 1994), groundwater is diverted toward the northeast along the northwestern limits of freshwater (**Figure 4**). Water that does not discharge to springs or wells in Kinney, Uvalde, Medina, or Bexar counties continues generally northeastward through conduits or alongside northeast-trending faults toward discharge points in Comal and Hays counties, primarily Comal and San Marcos springs.

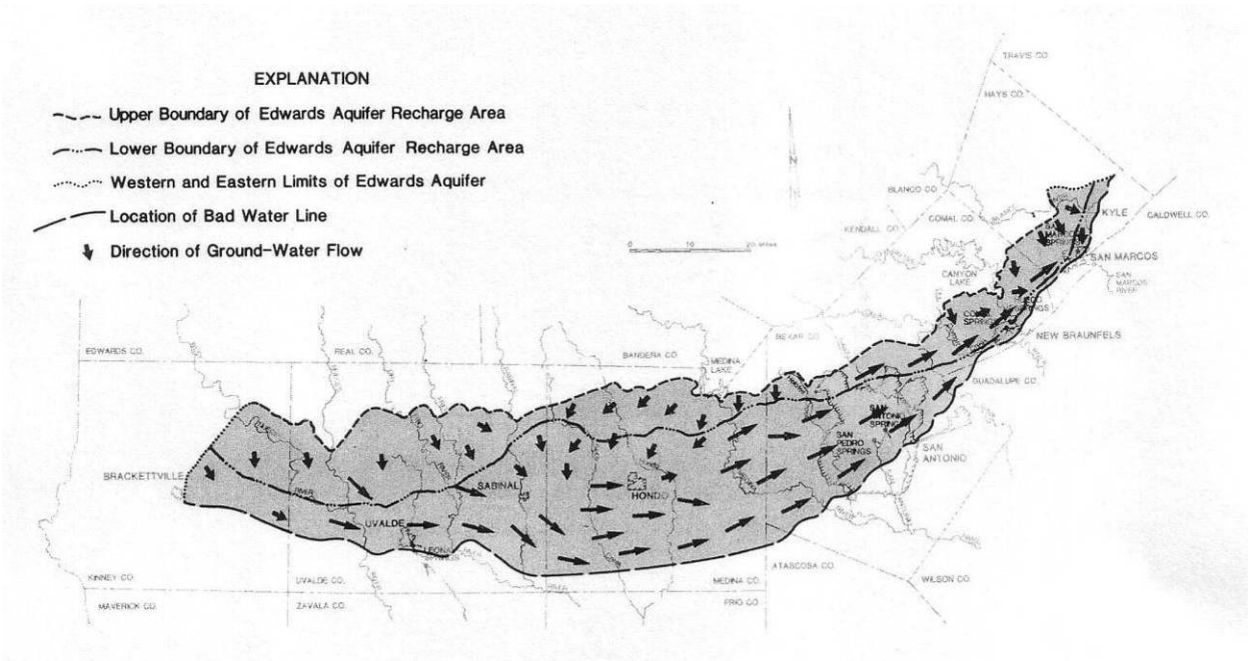


Figure 4: General directions of groundwater flow in the Edwards Aquifer between upgradient recharge areas and downgradient discharge areas (from Harden 1988, Figure 9).

A broad and changeable groundwater divide near Kyle (roughly 12 miles [19 kilometers] northeast of San Marcos Springs) is commonly used to separate the San Antonio Segment of the Edwards Aquifer from the Barton Springs Segment of the aquifer (LBG-Guyton Associates 1994, Scanlon and others 2002). However, the shifting nature of this groundwater "boundary" (Lindgren and others 2004) and its seemingly ephemeral existence during severe droughts (Land and Lemonds 2008) seems to preclude its use as a specific defining feature to distinguish between a separate San Marcos Pool and the Barton Springs Segment of the Edwards Aquifer.

Flowpath considerations

Groundwater flowpaths to Hueco, Comal, and San Marcos springs are significantly influenced by structural fault blocks as well as by conduits. An additional complexity is that these flowpaths may vary during high or low water level conditions. Otero (2007) combines flow in the Bat Cave and Hueco Springs fault blocks into the Northern Comal Flowpath. Flow in the Comal Springs Fault Block and flow to the southeast of the Comal Springs Fault are identified by Otero (2007) as the Central Comal and Southern Comal flowpaths, respectively. In comparison, Johnson and Schindel (2008) designate separate flowpaths for four fault blocks (the Bat Cave, Hueco Springs, Comal Springs, and Artesian fault blocks).

Johnson and Schindel (2008) interpret that groundwater flow is to the northeast in all four fault blocks (**Figure 3**). Conversely, Otero (2007) interprets groundwater flow in the southwestern end of the Central Comal Flowpath (designated as the Hueco Springs Fault Block by Johnson and Schindel [2008]) to be to the southwest. Elsewhere, Otero (2007) interprets that groundwater flow is to the northeast (**Figure 5**).

An unknown amount of water from the Northern Comal Flowpath is interpreted by Otero (2007) to migrate into the confined zones of the Central Comal Flowpath across the Hueco Springs Fault where it does not completely offset the Edwards Aquifer. Johnson and Schindel (2008) assert that much of the groundwater in the Bat Cave and Hueco Springs fault blocks likely discharges at Hueco Springs and that most of the water in the Comal Springs Fault Block discharges at San Marcos and Comal springs. Water in the Comal Springs Fault Block that does not discharge at either Hueco or Comal springs continues north-eastward toward San Marcos Springs. During low flow (low recharge) periods, Hueco Springs probably captures most of the water in the Hueco Springs Fault Block because water level elevations in the Hueco Springs Fault Block are lower than the elevation of San Marcos Springs.

Groundwater in the Artesian Fault Block flows to the northeast only as far as a point several miles (several kilometers) east of Comal Springs. LBG-Guyton Associates (2004) noted that the quality of water in the Artesian Fault Block has significantly higher total dissolved solids beyond this point. Otero (2007) attributes the change in water quality and direction of flow to a northwest trending fault that closes off northward flow within the Comal Springs Fault Block (**Figures 3 and 5**). Johnson and Schindel (2008) note that the water level in the Artesian Fault Block is mostly greater than in the Comal Springs Fault Block suggesting that groundwater flow is from the Artesian Fault Block to the Comal Springs Fault Block at this point (**Figure 6**). Johnson and Schindel (2008) state that the groundwater flow regime illustrated in **Figure 6** is active during both normal flow (200 to 300 cubic feet per second [5.7 to 8.5 cubic meters per second] discharge at Comal Springs) and low flow (less than 100 cubic feet per second [2.8 cubic meters per second] at Comal Springs) conditions.

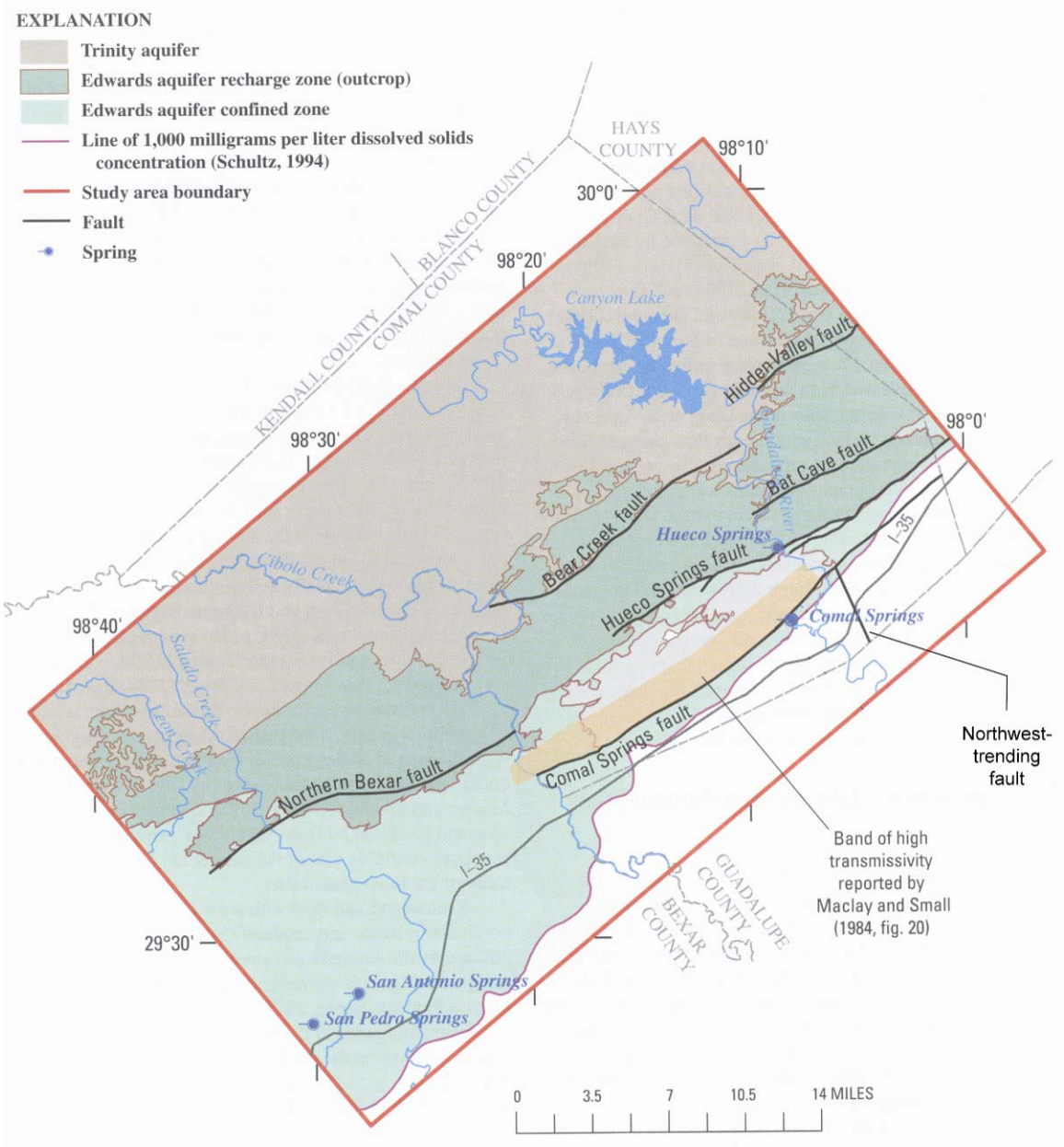


Figure 5: Main geologic structural features in the Comal Springs area including a northwest-trending fault located east of Comal Springs (modified from Otero 2007).

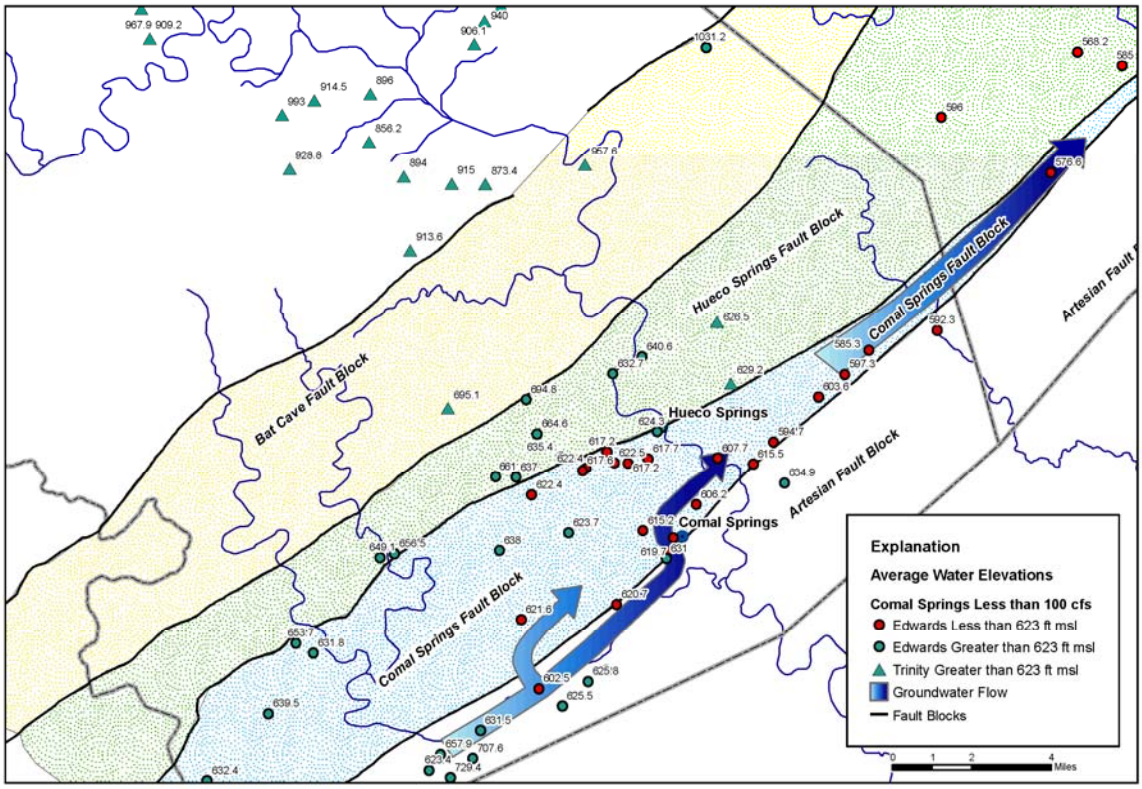


Figure 6: Groundwater flow in the Artesian and Comal Springs fault blocks (from Johnson and Schindel 2008; cfs = cubic feet per second; ft msl = feet above mean sea level).

Johnson and Schindel (2008) note that water from the Artesian Fault Block enters the Comal Springs Fault Block when Comal Springs discharge is less than 100 cubic feet per second (2.8 cubic meters per second), bypassing Comal Springs and flowing to San Marcos Springs. This conceptual model explains why San Marcos Springs continued to flow during the drought of 1956 although flow at Comal Springs ceased. Johnson and Schindel (2008) speculate that cross-formational flow from the Trinity Aquifer contributes to San Marcos Springs discharge during periods of low flow. There is probably also cross-formational flow from the Trinity Aquifer into the Edwards Aquifer during high flows (Mace and others 2000). During periods with high water levels (abundant recharge), groundwater flows to the northeast and discharges in some proportion to both Hueco Springs and San Marcos Springs (Johnson and Schindel 2008).

There are two primary sources of water that discharge from the numerous springs at Comal Springs (LBG-Guyton Associates 2004). Spring #1 (Main Spring), Spring #2 (Panther Canyon Spring), and Spring Run #3 discharge from the upthrown (or Comal Springs Fault) block. Much of the Comal Springs discharge, however, comes from the bottom of Landa Lake (LBG-Guyton Associates 2004). About 75 percent of the total spring flow from Comal Springs is from the downthrown (or Artesian Fault) block in the bottom of the lake.

During the drought of the 1950s, springs that issued from the upthrown (or Comal Springs Fault) block (Springs #1, #2, and #3) stopped flowing when water levels in the upthrown block dropped below the elevations of the individual spring orifices (LBG-Guyton Associates 2004). Interestingly, water levels in the downthrown (or Artesian Fault) block remained above the elevation of the springs as they went dry, again indicating that springs #1, #2, and #3 are sourced from the upthrown block.

The Lower Colorado River Authority well, also known as the Comal Plant #3 Well, was drilled into the downthrown block at a position less than half a mile (0.8 kilometer) south of Landa Lake. The Lower Colorado River Authority started pumping this well at about 5,000 gallons per minute (0.3 cubic meters per second) in June 1956. Water levels in Landa Lake quickly started dropping and the lake almost went dry during the summer (LBG-Guyton Associates 2004). Under such conditions, water levels in the Comal Springs Fault Block are lower than the elevation of the Comal Springs orifices for spring runs #1, #2, and #3. During periods of low flow, Comal Springs is fed entirely or mostly by water from the Artesian Fault Block (Southern Comal flowpath) (LBG-Guyton Associates 2004).

San Marcos Springs depends on several sources of recharge (Johnson and Schindel 2008, LBG-Guyton Associates 2004). A significant component comes from the southwest through the Comal Springs Fault Block (Johnson and Schindel 2008). According to Guyton (1979), between 55 and 60 percent of the water that discharges from San Marcos Springs is water that by-passed (did not discharge at) Comal Springs. Recharge assessments described in the following section indicate that a long-term average of 35 to 45 percent of the water that discharges from San Marcos Springs is water that by-passed Comal Springs. In drought years during which San Marcos Springs discharge averages less than 100 cubic feet per second (2.8 cubic meters per second), these recharge assessments indicate that 45 to 80 percent of the water that discharges from San Marcos Springs is water that by-passed Comal Springs. Johnson and Schindel (2008) concluded that, under high-flow conditions, water not discharging from Hueco Springs continues northeastward through the Hueco Springs Fault Block and that "any" water crossing the Hueco Springs Fault "probably flows northeast toward San Marcos Springs." San Marcos Springs is also sustained by water moving southeastward from the recharge area in southern Hays County (Maclay and Small 1984).

According to Johnson and Schindel (2008), local sources of recharge such as Purgatory Creek, York Creek, and the Blanco River may contribute up to 35 percent of the flow at San Marcos Springs. Recharge estimates from modeling efforts (LBG-Guyton Associates 2005) indicate that these specified local sources likely contribute between 60 to 70 percent of the long-term average discharge from San Marcos Springs.

The difference in hydrographs for Comal and San Marcos springs suggests the two springs are not fully correlated (LBG-Guyton Associates 2004). LBG-Guyton Associates (2004) interpreted this to indicate separate water sources: (1) a local source, which may be from the Blanco recharge basin, and (2) a more regional groundwater source, which may come from the major part of the aquifer located to the southwest of San Marcos. Additional sources of water discharged from San Marcos Springs may arrive as lateral

cross-formational flow from the Trinity Aquifer where the Bat Cave Fault juxtaposes the Trinity Aquifer against the Edwards Aquifer (**Figure 3**).

Recharge assessments

Recharge estimates have been calculated by the U.S. Geological Survey using methods developed in the late 1970s (Puente 1978) and published annually by the Edwards Aquifer Authority (2008). Estimates of recharge are reported for four recharge basins in the Nueces River Basin (**Figure 7**) and five recharge basins in the Guadalupe-San Antonio River Basin (**Figure 8**) (Puente 1978).

The Blanco and Guadalupe recharge basins are closest to San Marcos Springs. The Blanco Recharge Basin includes the Blanco River watershed as it traverses the Edwards Aquifer recharge zone located between streamflow gaging stations at Wimberley (USGS# 08117100) and Kyle (USGS# 081171300) and the ungaged watersheds of Sink, Purgatory, York, and Alligator creeks located on the recharge zone. The Guadalupe Recharge Basin includes the Guadalupe River watershed between the streamflow gaging station at Sattler (USGS# 08167700) and the City of New Braunfels.

The traditional recharge-estimation methodology relies on measured streamflow upstream and downstream of the outcrop of the Edwards Group with proportional estimates of potential runoff from the intervening subwatershed based on upstream or adjacent partner watersheds (Puente 1978). The traditional recharge-estimation method includes the components of recharge occurring in the primary streambed, smaller tributary water courses, and across the landscape. Recent studies (HDR Engineering, Inc., 2002, LBG-Guyton Associates 2005) suggest that recharge occurring in the primary streambed is variable and may be less than half of the calculated total recharge for some basins. Integration of all components of recharge, therefore, is important. Estimates from the traditional recharge-estimation method were used in calibration of the Texas Water Development Board's Ground Water Simulation Program, Version IV (GWSIM-IV) model of the Edwards Aquifer in the late 1970s (Klemt and others 1979) and early 1990s (Thorkildsen and McElhaney 1992).

An alternate method for estimating Edwards Aquifer recharge was developed by HDR Engineering in the course of studies sponsored by the Edwards Underground Water District (HDR Engineering 1993) and the Texas Water Development Board (HDR Engineering 1991). Like the traditional recharge-estimation method of the U.S. Geological Survey, the alternate-method uses a monthly time step. Key differences between the models include elimination of base flow curves and use of alternative procedures for calculating potential runoff over the Edwards Aquifer recharge zone by integrating a representation of soil cover (Soil Conservation Service 1972) and a selection of different partner watersheds (HDR Engineering 1993). As a part of the Trans-Texas Water Program, HDR Engineering updated its alternate-method estimates of recharge through 1996 and compared results of traditional and alternate methods (HDR Engineering 1998).

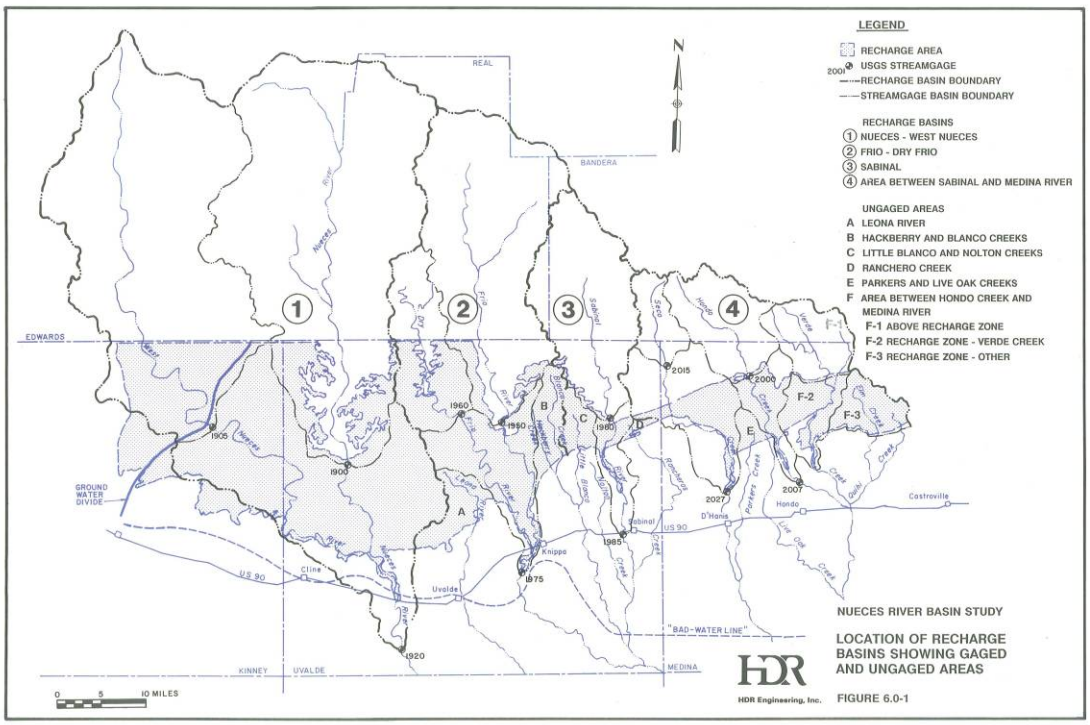


Figure 7: Recharge basins in the Nueces River Basin (from HDR Engineering 1991).

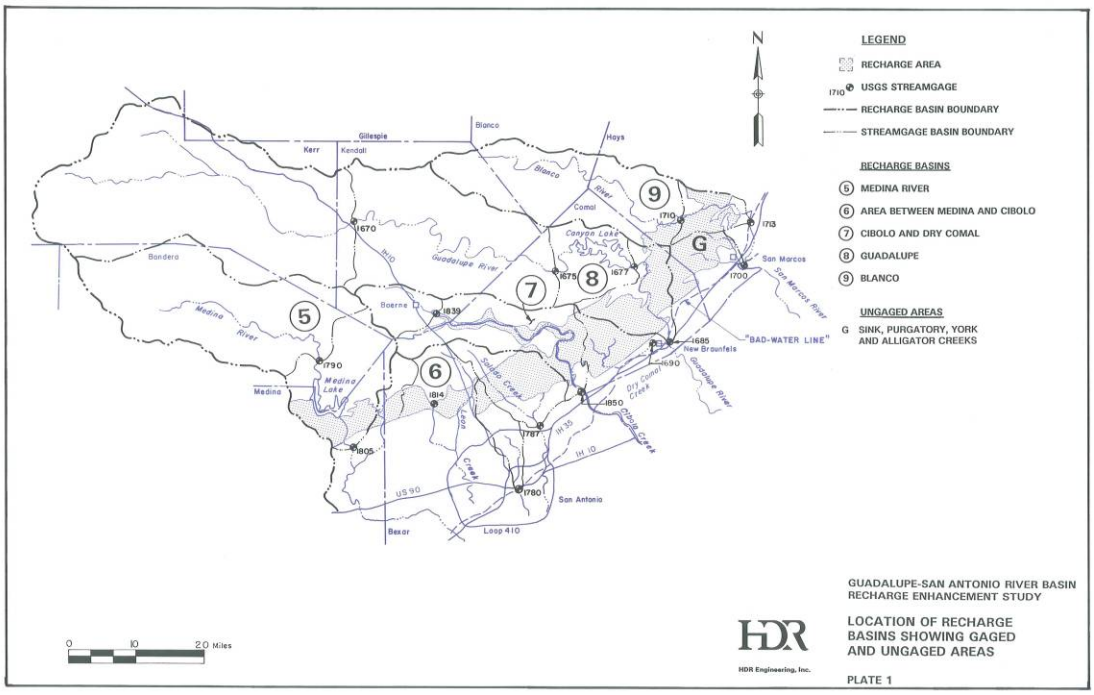


Figure 8: Recharge basins in the Guadalupe-San Antonio River Basin (from HDR Engineering 1993).

While overall estimates of long-term average recharge were quite similar, the geographic distribution proved significantly different. Recharge in the Blanco and Guadalupe watersheds, which are close to San Marcos Springs, was calculated to be greater by the alternate-method than by the traditional method. Differences in these two recharge estimates, in part, prompted additional research for selected recharge basins. Such research included an intensive, multi-year study of recharge in the Medina Lake System by the U.S. Geological Survey, a series of flow measurements to quantify losses and gains along the Guadalupe River between Canyon Dam and New Braunfels, and applications of Hydrologic Simulation Program-Fortran (HSPF) to estimate Edwards Aquifer recharge on a more refined time-step.

Pilot applications of HSPF for estimation of Edwards Aquifer recharge in the Nueces and Blanco recharge basins were completed in 2002 (HDR Engineering 2002), and comprehensive applications of HSPF for all recharge basins were completed in 2005 (LBG-Guyton Associates 2005). Models based on HSPF are thought to retain the strengths and overcome the weaknesses of either the traditional or alternate methods. Specific advantages of the HSPF models include (1) use of a water-balance approach integrating many relevant hydrologic parameters (such as measured streamflow at the upstream gaging station, precipitation, evaporation, diversions, soil type, antecedent moisture conditions, land use, interception, infiltration, and evapotranspiration) and (2) computation of recharge on a daily, rather than monthly, time step through direct simulation of watershed response to precipitation and streamflow inputs. Although review and refinement of historical recharge estimates based on the HSPF models are ongoing, it is likely that historical recharge in the Blanco and Guadalupe recharge basins was substantially greater than that estimated by the traditional U.S. Geological Survey method.

Lindgren and others (2004) specified recharge in their model using a modified version of the traditional U.S. Geological Survey recharge methodology. Modifications of the traditional estimates included estimation and consideration of recharge in the Guadalupe Recharge Basin at a long-term average of about 31,900 acre-feet per year (3,930 hectare-meters per year)(rather than zero) and reduction of recharge in the Blanco Recharge Basin in high flow years. The revised recharge estimates for the Blanco Recharge Basin give a long-term average of about 43,100 acre-feet per year (5,320 hectare-meters per year)(rather than about 46,200 acre-feet per year [5,700 hectare-meters per year]). Though individually quite different from the alternate-method and HSPF basin recharge estimates, the combined long-term average U.S. Geological Survey recharge estimates for these two basins were very similar to those reported by others.

For the drought period of 1950 through 1956, however, recharge for the Blanco and Guadalupe recharge basins by the modified-traditional method was less than half of the total reported by the other two methods. Nevertheless, San Marcos springflows simulated by the calibrated U.S. Geological Survey model match measured historical discharge reasonably well during this severe drought period.

Water-balance estimates

We reviewed comparisons of annual discharge from San Marcos Springs for the 1950 through 2000 historical period to the cumulative sums of annual recharge estimates for the Blanco (nearest), Guadalupe, Cibolo/Dry Comal, and Helotes/Salado recharge basins (respectively numbered 9, 8, 7, and 6 in **Figure 8)**. Annual recharge and springflow estimates used for these preliminary comparisons are those used by the U.S. Geological Survey for calibration of the 2004 Edwards Aquifer groundwater flow model (Lindgren and others 2004), in part because the HSPF recharge estimates are being refined at this time. Observations based on these comparisons include the following:

1. Discharge from San Marcos Springs exceeded estimated recharge in the Blanco Recharge Basin in every year.
2. Discharge from San Marcos Springs exceeded combined estimated recharge in the Blanco and Guadalupe recharge basins in 94 percent of the years considered.
3. Discharge from San Marcos Springs exceeded combined estimated recharge in the Blanco, Guadalupe, and Cibolo/Dry Comal recharge basins in 35 percent of the years considered.
4. In some of the most severe drought years, discharge from San Marcos Springs exceeded combined estimated recharge from all four of the recharge basins considered.
5. On a long-term average basis, 100 percent of estimated recharge in the Blanco and Guadalupe recharge basins together with 40 percent of that in the Cibolo/Dry Comal basin account for the discharge from San Marcos Springs.

These water balance estimates focusing on recharge and springflow provide some preliminary insights into portions of the Edwards Aquifer that contribute most directly to discharge from San Marcos Springs. In addition to conventional estimates of Edwards Aquifer recharge, San Marcos Springs may be sustained by depletion of aquifer storage and/or inter-formational flux from the Trinity Aquifer. Preliminary water balance assessments illustrate some of the technical difficulties associated with designating a separate San Marcos Pool when portions of the Edwards Aquifer contributing significantly to San Marcos Springs extend through Hays and Comal counties and likely extend into Bexar County.

Hydraulic correlation analyses

LBG-Guyton Associates (2004) and Schindel and Johnson (2008) correlated hydrographs for spring discharge (Hueco, Comal, and San Marcos springs), hydrographs for rivers and stream stages, and hydrographs of water levels for selected index wells. Correlations between index well water elevations and spring discharge rates show the hydraulic relationship between the aquifer at the well location and at the point of spring discharge. Correlations between river stage and spring discharge provide an indication of whether the rivers act as recharge to groundwater feeding the springs. Correlations between spring discharge hydrographs measure the hydraulic communication between the springs, either in terms of sharing similar recharge zones or in terms of discharging from the same

groundwater reservoir. It is important to realize that the relationships exhibited by these data may be dependent on aquifer stage. For example, correlations between index wells and spring discharge may differ during high stage relative to low stage.

Key index wells are:

- J-17 (Bexar County Index Well) documented to be strongly correlated with discharge at Comal Springs and weakly correlated with discharge at San Marcos Springs (**Figures 9 and 10**).
- 68-23-302 (Landa Park or Panther Canyon well) located in the Comal Springs Fault Block half a mile (0.8 kilometer) west of Comal Springs. Water elevations at Well 68-23-302 have a strong correlation with Comal Springs discharge (**Figure 11**).
- 67-09-110 (Southwest Texas Farms Wells) located in the Comal Springs Fault Block five miles southwest of San Marcos Springs. The water level in this 674 foot (205 meter) deep well is strongly correlated with San Marcos Springs discharge (**Figure 12**).
- 68-16-701 (Highway 306 Well) located in the Comal Springs Fault Block two miles (3.2 kilometers) east of Hueco Springs and approximately three miles (4.8 kilometers) north-northeast of Comal Springs. Water level measurements at this well strongly correlate with San Marcos Springs (**Figure 13**).

For several different time periods, discharge at San Marcos Springs did not correlate with discharge at Comal Springs or water levels at Index Well J-17 (**Figures 14 and 15**). Spring discharge from Comal Springs can be increasing while discharge from San Marcos Springs is decreasing due, in this particular time period, to the occurrence of significant local recharge proximate to and up-gradient of Comal Springs while below average recharge continued near San Marcos Springs Lake (LBG-Guyton Associates 2004). This suggests that the flow at Comal and San Marcos springs are influenced differently by the interaction of local and regional flow (LBG-Guyton Associates 2004). On the other hand, simple linear regression analyses of average discharges from Comal and San Marcos springs for each month during the 1956 through 1989 historical period shows a statistically significant correlation. More specifically, the coefficient of determination (r^2) is found to be 0.55 for a linear regression equation considering Comal Springs discharge as the sole independent variable for estimation of San Marcos Springs discharge. In other words, about 55 percent of the variations in San Marcos Springs discharge can be explained by a simple linear relationship with Comal Springs discharge.

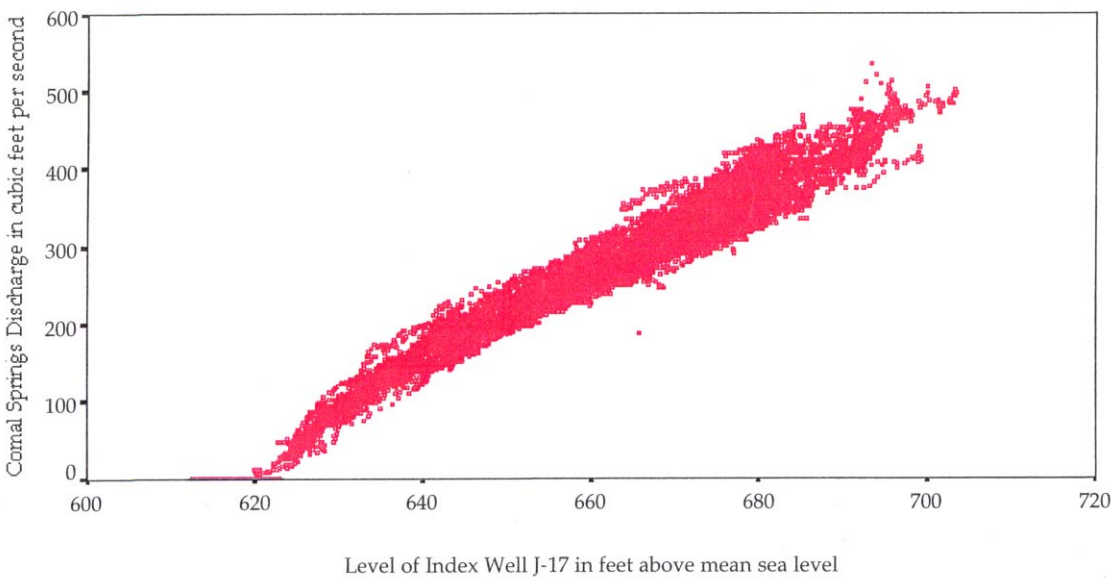


Figure 9: Relationship between (1) water level elevation at Index Well J-17 and (2) flow at Comal Springs (modified from Votteler 2000, Figure 14).

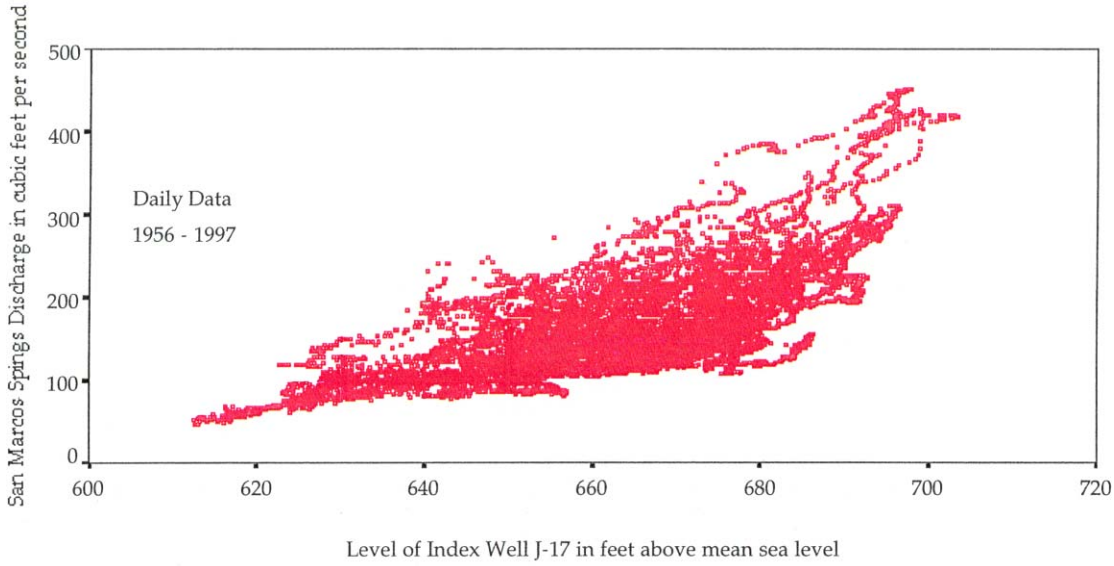


Figure 10: Relationship between (1) water level elevations at Index Well J-17 and (2) flow at San Marcos Springs (modified from Votteler 2000, Figure 17).

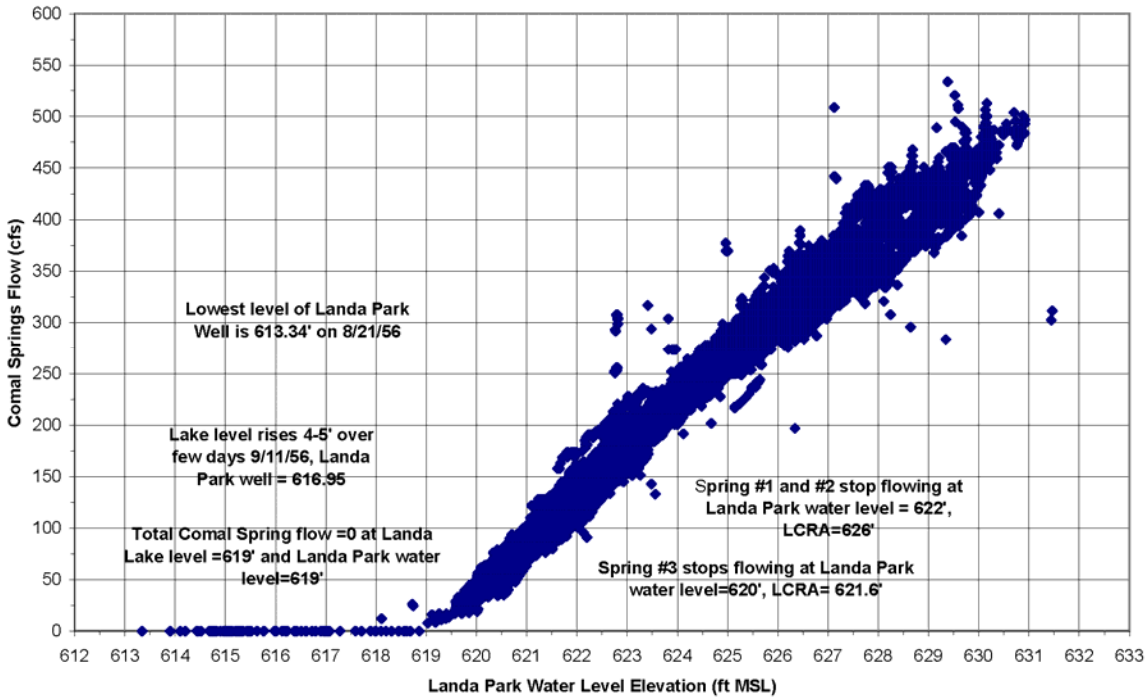


Figure 11: Relationship between (1) water level elevation at Well 68-23-302 (Landa Park or Panther Canyon well) located in the Comal Springs Fault Block half a mile (0.8 kilometer) west of Comal Springs and (2) flow at Comal Springs (from LBG-Guyton Associates 2004, Figure B-13; cfs = cubic feet per second, ft MSL = feet above mean sea level, ‘ = feet, LCRA = reference to a well operated by the Lower Colorado River Authority during the 1950s).

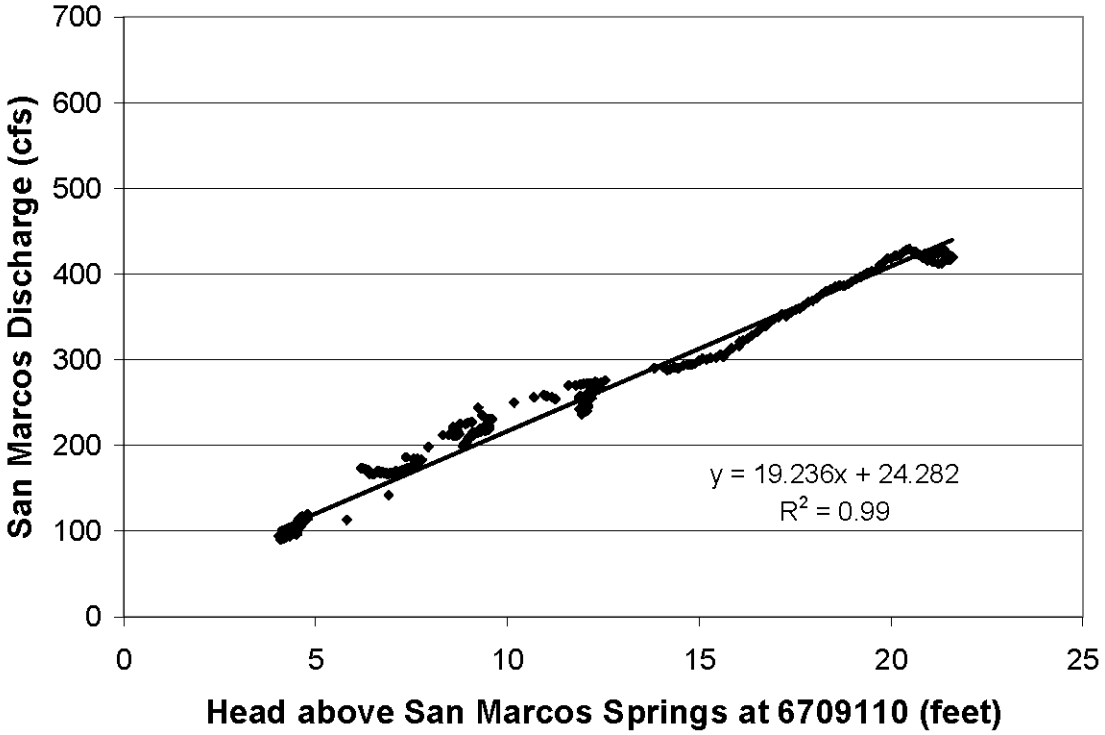


Figure 12: Relationship between (1) hydraulic head above San Marcos Springs at Well 67-09-110 (Landa Park or Panther Canyon well) located in the Comal Springs Fault Block five miles (eight kilometers) southwest of San Marcos Springs and (2) flow at San Marcos Springs (from Johnson and Schindel 2008, Figure 38; cfs = cubic feet per second).

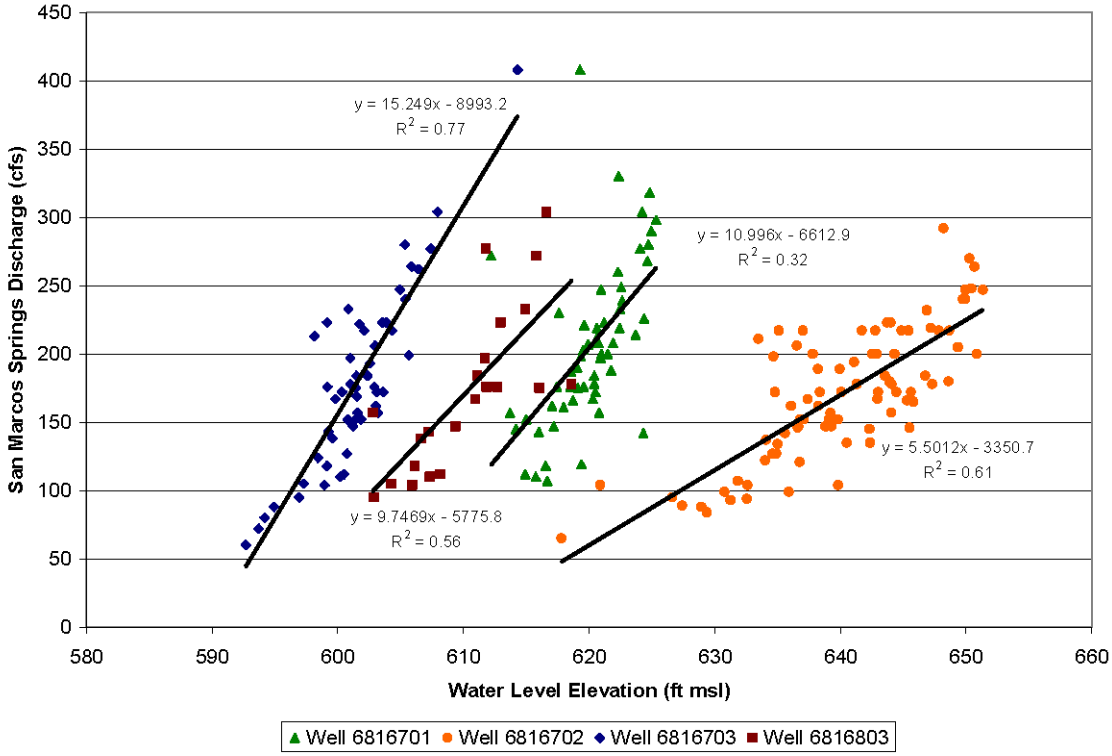


Figure 13: Relationship between (1) water level elevations at Well 68-16-701 (Highway 306 Well) located in the Comal Springs Fault Block two miles (three kilometers) east of Hueco Springs and approximately three miles (five kilometers) north-northeast of Comal Springs and wells 68-16-702, 68-16-703, and 68-16-803 and (2) flow at San Marcos Springs (from Johnson and Schindel 2008, Figure 12; cfs = cubic feet per second, ft msl = feet above mean sea level).

Figure 14: Flow at Comal and San Marcos springs for the period of 1988 to 1990 (modified from LBG-Guyton Associates 2004, Figure B-28; cfs = cubic feet per second).

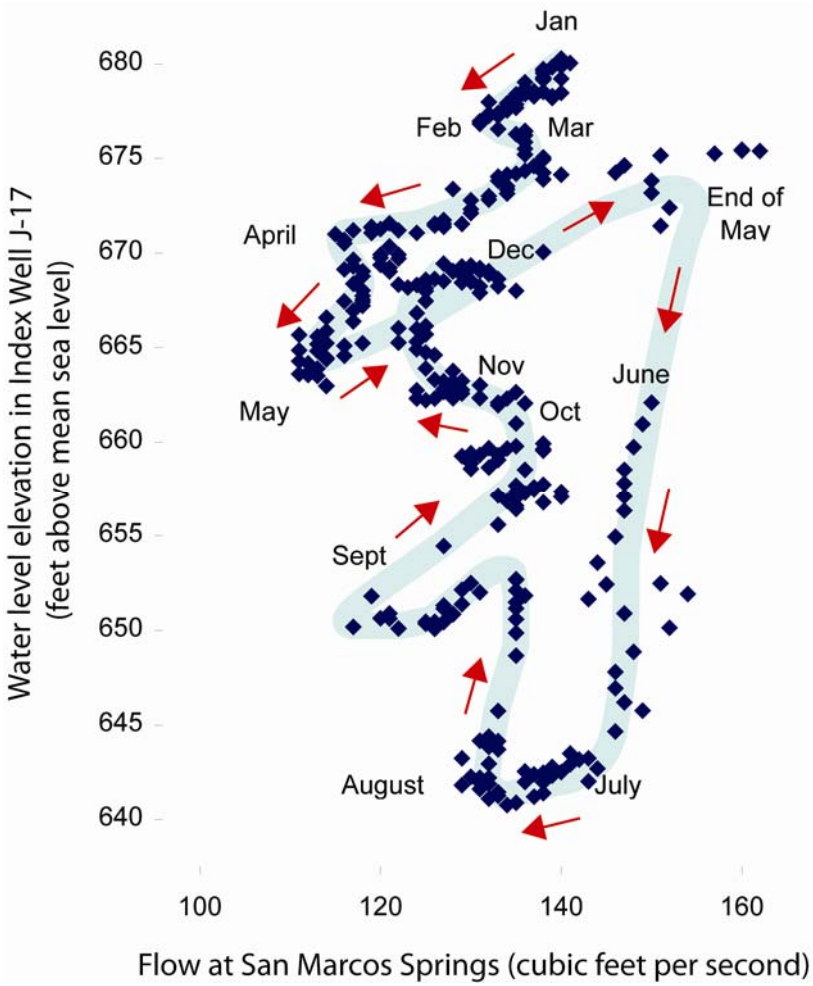


Figure 15: Water levels at Index Well J-17 versus flow at San Marcos Springs for 1980. The figure illustrates a complex pattern of changing spring flow and Index Well J-17 water levels.

Water chemistry analyses

Water quality indicators, including chemical composition and temperature, provide insight on different source areas and flow regimes. Ogden and others (1986) noted that tritium studies of Comal Springs by Pearson and others (1975) and time series analysis of fifteen water chemical parameters by Rothermel and Ogden (1986, 1987) demonstrated that Comal Springs receive very little local and recent recharge except during high water-table conditions. In contrast, tritium measurements of San Marcos Springs suggested that these springs generally receive a mixture of old and recent recharge (Pearson and others 1975). Hueco Springs has the highest tritium content and is believed to be composed of very recent groundwater from a local source.

Individual sampling of the San Marcos Springs orifices by divers (Ogden and others 1986) showed that, based on water chemistry, two seemingly hydrologically separate spring groups exist. Based on water chemistry, there are two different sets of springs—

the northern springs and the southern springs—discharging into Spring Lake (LBG-Guyton Associates 2004). The differences in water chemistries imply that different source areas are providing flow to the two spring groups. The northern springs may be discharging water from a more local source while the southern springs may be discharging water from a more regional flow system.

Numerical Models

Since 1979, more than a dozen groundwater models have been developed of the Edwards Aquifer. Several of these models have been used to simulate conditions of groundwater flow that appear to affect the San Marcos Springs flow regime. In regard to simulated results that most importantly influenced our evaluation of whether a separate pool for San Marcos Springs is appropriate, the most noteworthy of the Edwards Aquifer models are those by Klemt and others (1979), Maclay and Land (1988), Lindgren and others (2004), and Lindgren (2006). The major contributions of each of these models toward the current understanding of the San Marcos flow regime, and how their results influenced our decision as to whether the designation of a separate San Marcos Pool is justified, are summarized below. These models (and associated characteristics most related to conditions at San Marcos Springs) are discussed in order of their development.

Klemt and others (1979)

Klemt and others (1979) developed the first numerical model of the San Antonio Segment of the Edwards Aquifer. The associated investigation was directed primarily toward "quantitative aspects" of groundwater withdrawals, springflows, and aquifer characteristics. The purpose of this Texas Water Development Board model was to "determine the occurrence, availability, and dependability of the Edwards (Balcones Fault Zone) aquifer" and to "develop a groundwater resources management tool for use in a total water-resource management program."

Klemt and others (1979) used their model to simulate the effects of various management scenarios that began in 1972 and continued through 2049. All projected groundwater withdrawals "assumed that the present water quality of the aquifer would remain constant in time…and possible changes in water quality were not considered in sizing or in locating pumpage centers." The results of their simulations—based on projections of increased population growth, increased future water withdrawal, and climate—indicated that the aquifer was capable of meeting the projected demands. However, simulated discharge from San Marcos Springs showed "a declining trend" through the last year for which spring flow was simulated to occur, which was year 2009. Year 2000 was the first year for which spring flow was simulated to be less than the actual historical minimum, and water levels adjacent to San Marcos Springs showed "a downward trend similar to the trend observed for the water levels adjacent to Comal Springs." The results of even the most fundamental projections of future conditions indicated that the fate of San Marcos springflow was tied closely to upgradient conditions at Comal Springs.

Additional simulations were made to determine how artificial recharge might affect the Edwards Aquifer. The additional recharge was assumed to have come from "newly established and proposed reservoirs designed to increase recharge." The projections of

additional recharge indicated that both Comal and San Marcos springs would continue to flow for a longer period with the addition of artificial recharge.

Subsequent runs were made with the model to test whether San Marcos Springs might continue to flow at rates of at least 100 cubic feet per second (2.8 cubic meters per second), given assorted reductions in the projected rates of municipal and/or industrial pumpage. Under certain conditions, the simulated responses indicated that San Marcos Springs would continue to flow, albeit at rates far below average, through year 2002, but not without significant "joint" reductions in municipal and industrial pumpage. According to Klemt and others (1979), it was "important to note that the reduction in pumpage to maintain Comal Springs also resulted in continuous flow for San Marcos Springs."

Maclay and Land (1988)

Maclay and Land (1988) identified four hydrologic "storage units" and four associated "flow units" within the Edwards Aquifer. As forerunners to the relatively detailed "flowpath" and "fault-block" designations and associated explanations of more recent investigation and modeling, Maclay and Land (1988) based the calibration of their model on the premise that "four subareas of the unconfined zone tended to function as independent storage units because of faults." They explained that their division of such units was "strongly influenced by major faults, a narrowing of the recharge zone area, and a change from one stream basin to another." Maclay and Land (1988) defined flow units as

> "...an area of the aquifer that includes a storage unit and a zone in which water is transmitted from this storage unit to major points of discharge. Some interchange of ground water of the aquifer that includes a storage unit and a zone in which water is transmitted from this storage unit to major points of discharge. Some interchange of ground water from one flow unit to another probably occurs at different water-level conditions."

Maclay and Land's (1988) results advanced an appreciation of the need to simulate the hydraulic effects of structural compartmentalization on aquifer water levels and springflow. Despite the relatively large-scale nature of their model and its limited capacity to replicate historical water-level and springflow conditions, their contributions emphasized the need for future model studies to consider the effects of "ground-water storage and flow concepts." Their results provided a better appreciation of the effects faults impose on the movement and storage of groundwater and on the magnitude of aquifer properties that would be incorporated into subsequent models. Of particular relevance to the scope of this document, Maclay and Land's (1988) experience with this model left little doubt, in their opinion, that "Ground water in the unconfined zone of the aquifer in northwestern Bexar, Comal, and Hays counties is diverted by barrier faults toward San Marcos Springs."

Lindgren and others (2004) and Lindgren (2006)

Lindgren and others (2004) based the design of their finite-difference model on the conceptualization that most groundwater flow in the Edwards Aquifer occurs primarily through a finite number of elongated solution cavities (conduits) rather than through an expansive network of relatively small, but countless, openings. This design attempted to add a conduit flow component to the standard diffuse flow conceptualization. It was adopted with the premise that it would provide a plausible approach toward simulating the aquifer's relatively rapid response to short-term recharge (precipitation) events, including the associated increases in downgradient water levels and springflow. A key similarity shared with the design of past models was the objective of simulating the effects of barrier faults that tend to compartmentalize the storage and flow of groundwater within physically discrete fault blocks that, in places and in varying degrees, may be hydraulically linked.

The results of experimentation with this model (Figure 10 in Lindgren and others 2004), substantiate the importance of barrier faults, which appear to strongly influence the directions of groundwater flow by restricting it to preferential flowpaths within the fault-bounded blocks delineated earlier by Maclay and Land (1988). Although the fault blocks are not simulated as distinct entities (discrete partitions within the model) their presence is reflected by the concentration of simulated flow within a series of roughly parallel segments of the Edwards Aquifer. The preferential flowpaths are aligned, for the most part, with mapped barrier faults within the Balcones Fault Zone (Collins and Hovorka 1997).

Groschen (1996) postulated that the locations of most major springs in the Edwards Aquifer are structurally controlled. Groschen (1996) explained that springs tend to exist where confined water (under pressure) rises, through breaks in the overlying confining beds, to topographically low areas of the surface. The Lindgren and others (2004) model reflects this effect by simulating the movement of groundwater along specific conduits that "tend to facilitate" flow toward the springs, including Comal and San Marcos springs. Note that "conduits" are represented in the model as cells with high transmissivity and not as discrete features. The simulated rates of springflow in the Lindgren and others (2004) model were more dependent on the simulated orientation and hydraulic properties assigned to the conduits (based on regional structure and effects of karstification) than to the simulated elevations and spring-orifice properties of the springs themselves (due to local conditions).

By setting the model boundary at the Colorado River, Lindgren and others (2004, p. 73) were able to simulate the groundwater divide in the Edwards Aquifer near Kyle in south-central Hays County. From the location of this divide, groundwater flows northeastward toward Barton Springs or southwestward toward San Marcos Springs. The results of model simulations indicate that the position of this groundwater divide varies, depending on water-level conditions. For steady-state and above-normal rainfall and recharge conditions, the simulated position of the groundwater divide "is coincident with its commonly defined position near Kyle." However, during low-recharge drought conditions and given the assumed distribution of pumping in the model, the position of the simulated groundwater divide "shifts westward to near San Marcos Springs, and

recharge from the Blanco River moves eastward toward Barton Springs, rather than westward toward San Marcos Springs."

The conduit-dominated design of the Lindgren and others (2004) model was intended to allow a comparatively detailed account of the aquifer's relatively quick response to short-term recharge activity conveyed to the springs along flowpaths associated with mapped flow units and presumed locations of major conduits. However, this model remains "regional in nature and, therefore, is best suited to evaluate variations in spring discharge, regional water-level changes, and the comparison of regional water-management scenarios." Lindgren and others (2004) emphasized that the accuracy and applicability of the model decrease when "changing from the regional to the local scale." The authors explain that the model is not considered appropriate for local issues, such as water-level declines surrounding individual wells, because of the model's relatively coarse grid size (40-acre [16 hectare] grid cells). Other model limitations are related to an imperfect conceptualization of actual conditions, including having only approximated the locations and hydraulic properties of the conduits through which most of the groundwater-flow is simulated to occur.

Even before the conduit flow version of the Edwards Aquifer model (Lindgren and others 2004) was initiated, its basic design was questioned in that (1) the U.S. Geological Survey's Modular three-dimensional finite-difference ground-water Flow (MODFLOW) code (Harbaugh and others 2000) was not specifically formulated for the simulation of conduit flow, (2) the unknown degree to which conduits actually control prevailing, observable conditions in the Edwards Aquifer and, therefore, influence the most important regional aspects of groundwater flow, including spring discharge, and (3) the exact location and regional connections of the specified major conduits. To address some of this uncertainty, a diffuse-flow version of the former Edwards Aquifer model was developed (Lindgren 2006).

The objectives of this extended study and alternative model (Lindgren 2006) were to modify the hydraulic conductivity distributions of the conduit-flow model by replacing the simulated conduits with relatively broad zones of elevated hydraulic conductivity. The distribution of hydraulic conductivity in the non-conduit, diffuse-flow model emphasized the small-cavity, fracture-flow component rather than the pattern of large, interconnected conduits that dominates the former design. Revision of model properties for the diffuse-flow approach was limited to changes in the distribution of simulated hydraulic conductivity. All other aspects of the model are the same as those representing the conduit flow Edwards Aquifer model.

According to Lindgren and others (2004, p. 97–101) and Lindgren (2006, p. 30–32), both the conduit-flow and the diffuse-flow versions of the Edwards Aquifer (MODFLOW) model appear to provide a reasonably appropriate simulation of measured springflow and hydraulic heads over the relatively long transient-calibration period of 1947 to 2000. Both models better replicate the timing and rates of discharge for the Comal and San Marcos springs than for the smaller springs. Although the distributions of simulated springflow in both models are similar for all simulated springs, the conduit-flow model appears to provide a closer approximation of discharge for Comal Springs than for San Marcos Springs.

The slightly smaller total springflow simulated with the diffuse-flow model (relative to that with the conduit-flow model) is believed to result from the general pattern of somewhat lower water levels simulated with the diffuse-flow model. This, coupled with the observation that greater differences occur during the periods of greatest springflow, might indicate that the diffuse-flow model is "somewhat less responsive" to short-term recharge events than the conduit-flow model. Despite having been calibrated with different emphases on different aspects of the groundwater-flow regime, Lindgren believes that—on balance—no model stands out as the "better" of the two in terms of their capacities to simulate regional effects of alternative water-management scenarios (Rick Lindgren, U.S. Geological Survey hydrologist, verbal communication, 2008).

Summary

Evaluation of available hydrogeological evidence by the Edwards Aquifer Area Expert Science Subcommittee leads to the conclusion that there are insufficient data to support the designation of a separate San Marcos Pool or to define its boundaries at this time. On the basis of available hydrogeologic evidence, the Expert Science Subcommittee further concludes that aquifer levels, recharge, and pumpage in Comal and Bexar counties have sufficient effects on San Marcos Springs that management of a fully separate San Marcos Pool would be an administrative action rather than a scientifically-based decision.

Hydrogeological conceptualizations as well as defined and inferred flowpaths of the Edwards Aquifer set forth by multiple researchers, though complex and sometimes conflicting, all generally indicate that physical pathways for groundwater at least as far away as Bexar County contribute significantly to discharge at San Marcos Springs. Water balance estimates indicate that recharge occurring in Hays, Comal, and Bexar counties contribute significantly to discharge at San Marcos Springs.

Flowpaths, recharge, and water-balances considered together demonstrate that San Marcos Springs is more reliant on distant, rather than local, water sources within the aquifer to sustain springflow during drought. Water-chemistry analyses of discharges from multiple San Marcos Springs orifices indicate contributions from recent, local recharge and older, regional recharge. Hydraulic correlation analyses reveal that Comal Springs discharges are highly correlated with water levels in the Bexar County Index Well (J-17) and that San Marcos Springs discharges are correlated with Comal Springs discharges, despite some temporal anomalies at San Marcos Springs likely caused by differences in local and regional recharge and storage recovery rates during the drought of 2006 and other droughts.

Recommended Studies

The "unknowns" still significantly outnumber the "knowns" when it comes to understanding the recognized hydrogeologic features and effects—much less the unrecognized controls—on groundwater levels and springflow associated with San Marcos Springs. From a scientific standpoint, it seems unwise to recommend segregation of the larger San Antonio Pool until the relationships among rainfall, recharge, and downgradient water levels and springflow become more predictable. In other words, a more complete understanding is required of the various elements of the hydrogeologic

framework that control the flow and storage of groundwater in different segments of the Edwards Aquifer. To improve this understanding, the Expert Science Subcommittee recommends the following studies on hydrogeology and modeling.

Hydrogeology

- Develop a better understanding of recharge, flow, and water budget with respect to San Marcos Springs.
- Conduct a detailed baseflow study and analysis of the Guadalupe River as it flows over the Edwards Aquifer recharge zone.
- Study the relationship between San Marcos Springs and recharge from the Blanco and upper San Marcos river basins.
- Establish a water-level monitoring network in the San Marcos Springs area and try to correlate groundwater levels to flow at San Marcos Springs.
- Study the hydrogeology and water chemistry of the individual springs that make up San Marcos and Comal springs.
- Conduct more tracer studies to better understand flow paths near the springs.
- Conduct a basic hydrogeologic investigation of Fern Bank Springs.
- Understand why flow at San Marcos Springs at times does not correlate well with either Comal Springs discharge or water levels at Index Well J-17.
- Study possible connection to Barton Springs and the behavior of the groundwater divide.

Modeling

- Update the groundwater model to (1) reflect the most recent conceptualization of local groundwater flow regimes affecting Comal and San Marcos springs and (2) include the best available estimates of recharge.
- Improve model performance in the unconfined zone.
- Assess whether the model can be used to better evaluate San Marcos Springs hydrology and management scenarios.
- Study crossformational flow from the Trinity Aquifer to the Edwards Aquifer in the eastern part of aquifer and determine if this flow is accurately represented in the model.

Task 1.4: If there are data to support the designation of such a pool, what should be the extent and boundaries of such pool?

This task is not applicable because of our response to Task 1.2.

Task 1.5: To what extent is this pool hydrologically independent?

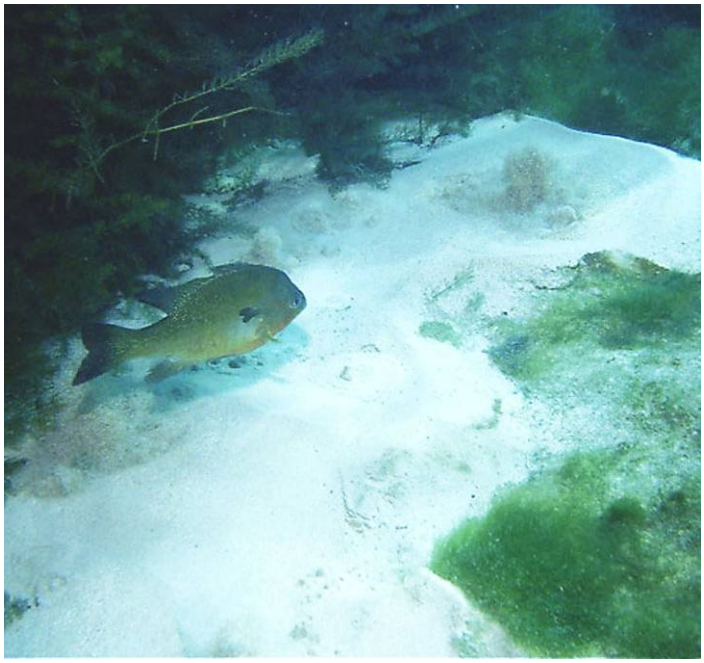
This task is not applicable because of our response to Task 1.2.

Task 1.6: Is there a need for an additional well or additional wells to measure the San Marcos pool, if one was designated. If so, what is the most effective location for such well(s)?

This task is not applicable because of our response to Task 1.2.

Task 1.7: The evaluation of this issue should include consideration of information provided by the members of the Recovery Implementation Program.

We have evaluated and taken into consideration the information provided by members of the Recovery Implementation Program. Position papers submitted by the members are included in **Appendix F**.



Cream of Wheat Springs in Spring Lake (photo by Bridget Lewin)

Task 2: Are minimum spring flows necessary?

Minimum flows are a necessary part of a flow regime of a given aquatic ecosystem for the protection of its component species. The state of instream flow science has evolved to the point that the maintenance of minimum flows alone is not considered sufficient to maintain a sound ecological environment (National Research Council 2005). The Texas Instream Flow Program has adopted an approach (Texas Commission on Environmental Quality and others 2008) that involves the identification of ecologically significant flow components for Texas' rivers and streams. Each of these components can be described by the timing, frequency of occurrence, flow magnitude, and duration of individual events. It is important to recognize that the ecology of an aquatic ecosystem is defined by extreme events on both the high- and low-flow end of the spectrum and that having occasional extremes supports populations of native species that have evolved life history strategies in response to the natural flow regime (Poff and Allan 1995, Poff and others 1997, Bunn and Arthington 2002). Experiencing these natural extremes puts stress on non-native species and promotes the survival of the native flora and faunal community (Poff and Allan 1995, Poff and others 1997, Bunn and Arthington 2002). However, the frequency and duration of these extreme events are of critical importance and, if extended beyond the natural tendency of the system, can be detrimental to the resident ecological community.

For this evaluation, minimum springflows are defined as flow events that occur infrequently, have a magnitude sufficient to maintain critical ecological functions (that is, water quality and minimal habitat conditions), and do not last long enough to stress the ecosystem beyond a point where it can recover naturally. Additionally, the ability of an aquatic community to endure stressful, low-flow events is largely related to its condition

at the onset. Consequently, assuring that flows are maintained at sufficient levels with appropriate inter- and intra-year variability during more normal (not extreme) conditions is also required to maintain a healthy community, thus inherently protecting the threatened and endangered species.

Task 2.1: Is a minimum springflow required for the survival and recovery of each species listed under the Endangered Species Act identified in Section 3.2 of the Edwards Aquifer Recovery Implementation Program Memorandum of Agreement?

Recommendation: At this time, the Edwards Aquifer Area Expert Science Subcommittee believes that minimum springflows are required within the context of a system flow regime for the survival and recovery of each species listed under the Endangered Species Act identified in Section 3.2 of the Edwards Aquifer Recovery Implementation Program Memorandum of Agreement. A system flow regime includes low flows which support the survival of individuals for limited periods of time, normal flows which support reproduction within the population, and higher flows that periodically rejuvenate the system.

Our interpretation of the task

While the term "required" might imply that a single minimum springflow would alone be sufficient, our interpretation is that minimum springflows are "necessary" within the context of a system flow regime. We do not feel that minimum springflows alone are sufficient for the survival and recovery of a threatened or endangered species. The question also implies that there may be a single minimum springflow that permits both survival and recovery. We contend that minimum springflows within the context of a system flow regime are important to both survival and recovery, but not in the same way nor at the same level of importance. Minimum springflows are vital to maintain conditions suitable for individuals of a species to continue to exist for some period (that is, survive). Minimum springflows also play a role in genetic strengthening which serves a purpose in the recovery of a species. Recovery is defined as "the process by which the decline of an endangered or threatened species is arrested or reversed, and threats removed or reduced so that the species' long-term survival in the wild can be ensured." The following sections document our rationale for this task.

Discussion

The species listed under the Endangered Species Act identified in Section 3.2 of the Edwards Aquifer Recovery Implementation Program Memorandum of Agreement (**Appendix D**) consist of eight threatened and endangered species found in the Comal and San Marcos springs ecosystems. These include two fish [fountain darter (*Etheostoma fonticola*) and San Marcos gambusia (*Gambusia georgei*)], two salamanders [Texas blind salamander (*Eurycea rathbuni*) and San Marcos salamander (*Eurycea nana*)], one plant [Texas wild-rice (*Zizania texana*)], and three invertebrates [Comal Springs dryopid beetle (*Stygoparnus comalensis*), Comal Springs riffle beetle (*Heterelmis comalensis*), and Peck's cave amphipod (*Stygobromus pecki*)]. Of these, only the San Marcos salamander is listed as threatened by the U.S. Fish & Wildlife Service; the rest are listed as endangered.

Each of these species has a restricted distribution limited to springs associated with the Edwards Aquifer, and several are found in either Comal Springs or San Marcos Springs, but not both. Originally, only the fountain darter was believed to occupy both spring ecosystems, but recent collections of the Comal Springs riffle beetle in Spring Lake at the headwaters of the San Marcos River (Gibson and others 2008) reveal that this species is also found in both ecosystems. Among the other species, San Marcos salamander and Texas wild-rice occur only in the San Marcos River, while the Texas blind salamander is found in the aquifer below San Marcos and nearby springs. Two of the three invertebrates, Comal Springs dryopid beetle and Peck's cave amphipod, are found only in Comal and nearby springs (that is, Hueco and Fern Bank springs). The San Marcos gambusia is considered extinct as no individuals have been collected since 1982, despite subsequent intensive surveys (U.S. Fish & Wildlife Service 1996).

Comal Springs, which consists of many spring openings, is the largest spring system in Texas. The clear, thermally constant water issues from the downthrown side of the Comal Springs Fault Block. Although Comal Springs reportedly has the greatest discharge of any springs in the Southwest, the flows can diminish rapidly during drought conditions. The springs completely ceased to flow for several months during the summer and fall of 1956 during the drought of record. Despite this fact, Comal Springs is home to several extremely rare, listed species. The San Marcos Springs complex represents the second largest spring system in Texas. It has historically exhibited the greatest flow dependability and environmental stability of any spring complex in the Southwest (U.S. Fish & Wildlife Service 1996). The springs have never been known to cease flowing, even in the drought of record. Clear, thermally constant water issues from the upthrown block of the San Marcos Springs Fault. Before being inundated by Spring Lake, the springs sent water three feet (one meter) above the water surface.

The simple answer to the question posed in **Task 2.1** is "Yes". Unlike most Texas rivers and streams, which have highly variable flow patterns, the San Marcos and Comal rivers are stable systems. The relatively constant springflow provides a unique, stable habitat within the aquifer and for some distance downstream. Flow has a direct effect on the amount of habitat available. The hydraulic features of flow (depth and velocity), along with channel, aquatic vegetation, and substrate, contribute directly to physical habitat features of a stream. The rate of springflow is also an important factor in determining the

longitudinal extent of suitable conditions for water temperature, carbon dioxide, nutrient distribution, and other water quality constituents. Additionally, the natural timing, frequency, duration, and magnitude of springflows are important in controlling invasive and non-native species. Many organisms have adapted to, and become reliant upon, this relative stability. In a warm, semi-arid climate such as central Texas, having a reliable flow of clear, clean, relatively cool, thermally constant water has led to the formation of a diverse, highly endemic, spring-dependent fauna and flora. For the surface-dwelling species, such as the fountain darter, San Marcos salamander, Texas wild-rice, and Comal Springs riffle beetle, some amount of springflow is necessary for survival and for recovery. A detailed examination of individual species requirements for springflow is presented below for the surface-dwelling species. For the aquifer-dwelling listed species such as the Texas blind salamander, Peck's cave amphipod, and Comal Springs dryopid beetle, a lack of discharge may not appear as critical; however, potential impacts are discussed following the individual species discussions.

Surface-dwelling species

(photo by Bridget Lewin)

Fountain darter

The fountain darter has been found to inhabit only the Comal and the upper San Marcos rivers where its density is influenced by the species of aquatic plants present (Schenck and Whiteside 1976; Linam and others 1993; Edwards Aquifer Authority 2007b). It only inhabits areas that are strongly influenced by the springs. Spring discharge level has an effect on water clarity, velocity, temperature, and carbon dioxide level. Each of these factors affects the aquatic plant species present and their abundance. As distance from the spring openings increases, plant species composition and fountain darter densities change in response to changes in water clarity, temperature, and carbon dioxide. In the Comal River, the fountain darter has access to the Guadalupe River but is not routinely found there. In the San Marcos River, the fountain darter is generally limited to portions of the river from the spring openings in Spring Lake to upstream of the outfall from the San Marcos wastewater treatment plant. The fountain darter has access to the river below the wastewater treatment plant but generally is not found there.

Both high- and low-flow events in the San Marcos and Comal rivers affect the fountain darter in various ways. While high-flow events rejuvenate the systems by causing

reduction of habitat-choking fine sediment and non-native snails (which consume native plants and harbor parasites), fountain darter numbers decrease in the immediate months following the flood event (Edwards Aquifer Authority 2007b). However, the typical response the following season is an increase in aquatic plant coverage and subsequent increase in fountain darter densities. It is evident that as aquatic plant coverage reestablishes, the invertebrates within the aquatic vegetation also rebound. This has repeatedly occurred during recent years in the Comal River in an area that extends from about 2,000 to 3,000 feet (600 to 900 meters) upstream from the confluence with the Guadalupe River. After floods in the San Marcos River, darter densities decline from about 500 to 900 feet (150 to 275 meters) downstream of the Cheatham Street bridge until the vegetation re-establishes itself (Thomas Brandt, U.S. Fish & Wildlife Service, personal observation). In the upper spring reach area of Landa Lake, when the springs in the area of the Blieder Creek confluence stop flowing and the bryophytes disappear, as happened in late 2000, the fountain darter density declined dramatically. The area affected extends from the confluence downstream to where other springs are still flowing just upstream of Spring Island. When springflows and the bryophytes return, darter densities subsequently increase. At some point, the carrying capacity of the system for aquatic vegetation is reached. The carrying capacity of the system is largely dependent on springflow. As spring flow deceases, water carbon dioxide levels decrease which causes a decrease in beneficial plants and a decrease in invertebrates and darters. The decreases in darter numbers first occur in the transition zone between suitable and unsuitable habitat. As springflow decreases, distances from spring openings that remain suitable habitat for fountain darters to reproduce decrease. Also, as springflow decreases, a flow will be reached where the number of darters being produced is less than the number dying. At this point, survival is still being maintained for some period, but recovery is compromised. When lack of springflow allows temperatures near the spring openings to rise above 84°F (29°C), fountain darter reproduction will likely cease. Between 84 and 90 °F (29 and 32°C) near the spring openings, mortality of some adults will likely occur.

Water clarity, velocity, temperature, and carbon dioxide level are important directly or indirectly to the fountain darter. Water clarity is important because the fountain darter is a sight feeder that consumes live invertebrates (Schenck and Whiteside 1977; Brandt and others 1993; Bergin 1996). As water clarity decreases, the ability of a fountain darter to detect and capture prey decreases. Also, as water clarity decreases, the ability of a fountain darter to detect a predator probably decreases. Fountain darters have definite water current preferences corresponding to their size. Adult fish are generally found in moderate to near zero currents. Juvenile darters occur in slower current than larger adults but, like adults, are found in areas with almost no current. It is assumed that current influences the ability of fountain darters to feed (as velocity increases the ability of the darter to maneuver and capture prey decreases) and to exchange gases across their gills (the stronger the current the less work the darter has to do to circulate water across the gills). Water temperature is known to affect fountain darter reproduction and survival (Brandt and others 1993, Bonner and others 1998, McDonald and others 2007). Fountain darter larval production significantly decreases at 77°F (25°C) and above (McDonald and others 2007). The upper temperature that will kill 50 percent of larval fountain darters after 24 hours is 89.4°F (31.9°C)(Bonner and others 1998).

While the direct effect of water carbon dioxide level on fountain darters is unknown, the effect of carbon dioxide level on some plants is known. For carbon dioxide obligates, such as Texas wild-rice (Power and Doyle 2004), a plant utilized by fountain darters (Catherine Phillips, U.S. Fish & Wildlife Service, personal observation), if carbon dioxide is not present in the water, photosynthesis by submersed leaves is probably limited. Aquatic plants provide fountain darters with cover, substrate that supports invertebrates, and spawning substrate.

Fountain darters populations have successfully been maintained only in flowing Edwards Aquifer water. In both the Comal and San Marcos rivers, the fountain darter densities decline when the beneficial effects of spring flow are negated by air temperature, loss of carbon dioxide to the atmosphere, and mixing with surface waters that cause changes in water clarity, water velocity, water temperature, and water carbon dioxide level. When Comal Springs stopped flowing in 1956, the fountain darter was eliminated from the Comal River. Fountain darters were restocked in the Comal River during the mid-1970s (Schenck and Whiteside 1976). A population exists today in the Comal River because of this re-introduction. The existence of the fountain darter requires springflows at levels that provide water clarity sufficient for detection and consumption of invertebrates, water temperatures that allow for survival and reproduction, and water velocities and carbon dioxide levels that support the growth of aquatic plants that provide the required cover and substrate needed for invertebrates and spawning.

Studies have shown that many fishes (especially species of a small size) have very similar food habitats (Hubbs and others 1978). If non-native species are added to the aquatic ecosystems, greater competition or overlap among species is possible. These non-native species may be able to acquire resources with greater efficiency than native species (U.S. Fish & Wildlife Service 1984). Suckermouth catfishes (Loricariidae) are a non-native fish species that have become established in the waters of Texas including the Comal and San Marcos rivers (Howells 2005). In particular, suckermouth catfishes that prefer to feed on periphyton and algae may be impacting fountain darter populations. The fountain darter lays eggs on algae and is believed to be threatened by the loss of spawning habitat and possibly egg predation (Hoover and others 2006). There is some concern that excessive numbers of suckermouth catfishes could directly displace or out compete fountain darters in the Comal and San Marcos rivers.

Two non-native gastropods [giant ramshorn snail (*Marisa cornuarietis)* and red-rimmed melania *(Melanoides tuberculata)*] also pose a threat to the ecosystem in the San Marcos and Comal rivers. The giant ramshorn snail, a species in the aquarium trade, was first discovered in the San Marcos River in 1983 and in Landa Lake in 1984 (McKinney and Sharp 1995). This snail grazes on aquatic plants and in the 1990s played a major role in reducing plant growth in Landa Lake. This snail prefers clear streams and pools with temperatures of at least 66°F (19°C). When exposed to lower temperatures, the snails withdraw into their shells and only survive for short periods. The warmest temperature that the giant ramshorn snail can withstand is 102°F (39°C). Although the population has diminished since the mid-1990s, the potential for future alteration of plant communities in these two ecosystems remains and could affect endangered species (McKinney and Sharp 1995, Edwards Aquifer Authority 2007b). The strong preference of fountain

darters for aquatic vegetation highlights the concern posed by the grazing activities of the giant ramshorn snail (Edwards Aquifer Authority 2004).

Another snail species that poses a potential threat to the Comal and San Marcos river ecosystems is the introduced red-rimmed melania. In 1990, a parasite (*Centrocestus formosanus*) was found in red-rimmed melania in Landa Lake (Knott and Murray 1991). The hosts for this parasite include fish-eating birds, red-rimmed melania, and fish. The parasite, a trematode which affects the gills of fountain darters, has been found at higher levels in fish from the Comal River than from the San Marcos River (Fuller and Brandt 1997). The trematode attacks the gills of the fountain darter causing reddening, swelling, and bleeding. The immune system of the fountain darter is sufficient to rid its body of the trematode, but not until the damage has already been done (Fuller and Brandt 1997, Bexar Metropolitan Water District 1998, Mitchell and others 2000; Mitchell and others 2005). Apparently the darters are not the normal hosts for the trematode since most of the larvae on the gills are encysted or dead (Fuller and Brandt 1997). Some of the concerns of the impact of this parasite are the increased stress, reduced ability to avoid predators, and reduced reproductive capabilities (BIO-WEST, Inc. 2002b). If snail and parasite numbers increase as springflows decrease, the parasite may cause greater harm to the fountain darter in the Comal River than deteriorating water quality. If not controlled, the parasite may cause the elimination of the fountain darter from the Comal River before spring flows drop to zero. The parasite is present in the San Marcos River but has remained at low levels and is not currently considered as a threat to the fountain darter. This level of threat may change if snail and parasite numbers in the San Marcos River increase.

(photo by John Thomaides)

Texas wild-rice

Texas wild-rice is an aquatic perennial grass that only occurs in the upper two miles (three kilometers) of the San Marcos River. The species grows in the swiftly flowing current of the river, rooted in the river bed. Texas wild-rice requires clear (turbidity usually less than 2.5 NTU [nephelometric turbidity units]), relatively cool, thermally constant (approximately 72°F [22°C]), flowing water (1.3 to 3.3 feet per second [0.4 to 1.0 meters per second]) at depths usually less than 3.3 feet (1 meter), and a substrate that is predominantly composed of sand and gravel (Poole and Bowles 1999). Stems are prostrate in the current and often root at the lower nodes. The long, ribbon-like leaves are

submersed in the water. Flowering occurs primarily spring through fall. The reproductive stems are lifted above the water surface with male and female flowers on separate parts of the stem. The species is wind-pollinated, and seeds are assumed to be water-dispersed. The flowering stem dies after the seeds are dispersed. Thus, under certain conditions, the plant may act as an annual, growing from seed, flowering, fruiting, and dying in one season.

The effects of low flow on Texas wild-rice have been documented via field investigations and laboratory studies. Texas wild-rice's requirement for some level of springflow is affected by physical habitat parameters (velocity, depth, substrate, and surrounding aquatic vegetation), water quality parameters (temperature and carbon dioxide), reproductive strategies, and non-native species. These components are intertwined and will be discussed holistically by necessity. For example, two water quality parameters that are considered important to Texas wild-rice growth are water temperature and carbon dioxide concentration. At lower flows, water temperature increases and carbon dioxide decreases, primarily as a function of springflow volume. In addition, at low-flow conditions the boundary layer through which gases and nutrients diffuse along the surface of aquatic plants is thicker, thus reducing the ability of the plant to uptake carbon dioxide and/or nutrients and potentially reducing plant growth and development (Crossley and others 2002). Swifter water flow increases nutrient and dissolved inorganic carbon uptake by plants (Stevens and Hurd 1997, Smith and Walker 1980) by reducing the unstirred boundary layer surrounding plant foliage (Chambers and others 1991). Depth and velocity affect reproductive success, as does herbivory (herbivory is the consumption of plants, algae, and photosynthesizing bacteria by herbivores).

Power (1996a, 2002) grew Texas wild-rice in three different current velocities (slow, moderate, and fast) in Spring Lake. The results of her investigations showed that Texas wild-rice had a better developed root system, produced more stems and overall biomass, and allocated more biomass to vegetative growth when grown in fast current (0.82 to 1.6 feet per second [0.25 to 0.49 meters per second]) as compared to plants grown in slow current (0 to 0.3 feet per second [0 to 0.1 meters per second]). Although slow current produced more reproductive stems, Power felt that it was at a cost of lower productivity and higher potential loss to herbivory. In still or shallow water, Texas wild-rice will send a flowering stalk above the water surface. In deeper, swifter water, the plant will remain submerged, and reproduce vegetatively by forming roots along the stem joints. Experimentation (Vaughan 1986) and observation has shown that Texas wild-rice will die in moist soil or even a few inches of water. The plant requires at least a foot of water flowing over its leaves and roots for survival.

Experimental work done by Power and Doyle (2004) indicated that Texas wild-rice is an obligate carbon dioxide user and that there is a positive relationship between current velocity and carbon dioxide. Faster-flowing water reduces the boundary layer thickness surrounding the leaves through which gases move primarily by diffusion. Still water or slower current leads to slower diffusion which in turn can limit photosynthesis. Texas wild-rice is carbon dioxide limited in slow flowing water, producing fewer submersed leaves and more reproductive growth (at the expense of less biomass overall, making the plant more subject to herbivory and reducing longevity).

BIO-WEST, Inc. (2004) also evaluated the response of Texas wild-rice to various levels of carbon dioxide in the water column. Texas wild-rice total and above-ground biomass varied substantially in the low carbon dioxide treatment. The large variation in the low treatment tanks may have been a result of Texas wild-rice leaves growing to the water surface before the end of the experiment (BIO-WEST, Inc. 2004). Since the below-ground biomass was significantly greater in the high carbon dioxide treatment than in the low carbon dioxide treatment, it appears that lower carbon dioxide conditions may cause Texas wild-rice to allocate more energy into above-ground growth and less into below-ground biomass to expedite reaching the water surface. Once plants reach the water surface, the leaves can draw carbon dioxide from the air which, in turn, would allow for increased plant growth. The Texas wild-rice plants used in the BIO-WEST, Inc. (2004) study were in the seedling/early growth stage where plants typically shift resources to below-ground biomass, presumably to exploit minerals needed for continued growth and to anchor the plant. Root biomass of plants in the high carbon dioxide treatment was significantly greater than low and moderate carbon dioxide treatments. This suggests that higher carbon dioxide tanks allowed higher photosynthetic rates to occur in submersed leaves and plants were able to shift the products of that photosynthesis to below ground biomass.

Water temperature affects the vegetative and reproductive growth of Texas wild-rice (Tolley-Jordan and Power 2007). Cool water (60°F [15.5°C]) slows vegetative growth and inhibits the formation of reproductive stems. In moderate temperate water (72.5°F [22.5°C]), biomass is first accumulated in vegetative parts and then shifted to reproductive growth later in the growing season. In warm water (83.3°F [28.5°C]) the shift of biomass from vegetative to reproductive growth is accelerated. Although reproduction is obviously necessary, the perennial habit allows accumulation of biomass from one growing season to the next. Also, because reproductive structures are lifted above the water, such parts are more vulnerable to herbivory.

One of the reasons that Texas wild-rice was listed as an endangered species was the lack of sexual reproduction in its natural habitat. In specific response to sexual reproduction, low flows have some benefit because lower depths and slower current velocity provide conditions that are conducive to sexual reproduction in Texas wild-rice. This is a specific case where some level of minimum flows with a limited frequency of occurrence can assist in the recovery of Texas wild-rice. However, relative to the survival of Texas wild-rice, if this was annually the condition, this growth form would make the plant more susceptible to herbivory and leave no vegetative growth to sustain the plant to the next growing season. Additionally, during lower flows, floating mats of vegetation catch on Texas wild-rice blocking sunlight and thus photosynthesis, shredding the leaves, interfering with reproductive culm emergence, and in some cases uprooting plants (Power 1996b). During low-flow events, lowered water depths combined with current velocity peel the root mats of Texas wild-rice off the substrate. This has been observed at both Sewell Park during low flows as well as within the large stands above the Interstate-35 bridge during the 2000 failure of Cape's Dam.

For the recovery of the species, the full range of the flow regime is necessary. Devastating floods or other extreme high flow events often temporarily reduce Texas wild-rice coverage. Plants are lost during floods due to the scouring action of the water

itself or from trees and debris scraping the river bottom. High flow events can also rip Texas wild-rice root mats from the substrate. Additionally, plants subjected to areas of low carbon dioxide are hypothesized to have limited root structure, thus potentially exacerbating the effect of floods and high-flow events in the lower reaches of the river. Perhaps this is reason for the almost total loss of Texas wild-rice below the Interstate-35 bridge following the 1998 flood as well as its lack of re-establishment (Poole 2002). However, such reduction in overall Texas wild-rice coverage is typically temporary, with these events rejuvenating the bulk of the population. Rapid responses in biomass have been observed following each flushing flow event in the past seven years (Edwards Aquifer Authority 2007b). Also, during higher flow conditions, floating mats of vegetation do not cling to the plants, blocking photosynthesis, hindering reproductive growth, and shredding the leaves. Faster flowing water increases root mass, stem number, and overall biomass.

As discussed above, the natural timing, frequency, duration, and magnitude of springflows are important in controlling invasive and non-native species. Similar to fountain darters, Texas wild-rice can also be affected during low-flow conditions directly and indirectly by non-native species. Lemke (1989) documented 31 species of aquatic macrophytes (plants large enough to see with the naked eye) in the upper San Marcos River. Of these, 23 were native. Increasing competition with non-native species and the resulting displacement of native species was noted. Three non-native plant species, hydrilla (*Hydrilla verticillata*), West Indian hygrophila (*Hygrophila polysperma*), and elephant ear *(Colocasia esculenta*), have significantly altered both the Comal and San Marcos ecosystems (LBG-Guyton Associates 2004). There is a concern that aggressive non-native plant species may gain a competitive advantage when conditions are sub-optimal for Texas wild-rice. Texas wild-rice is frequently found in areas of dense growth of the non-native macrophytes West Indian hygrophila and hydrilla (Poole and Bowles 1999). These and other non-native plants such as egeria (*Egeria densa*) have similar habitat requirements as Texas wild-rice and over the years have reduced the amount of suitable habitat for Texas wild-rice. All these non-native species occur at least in part in habitats that could be occupied by Texas wild-rice. While it is uncertain if Texas wild-rice ever occurred in abundance in the habitat currently occupied by elephant ears, it is possible that Texas wild-rice may have used the shallower, slower current areas near the river's edge as an area for the sexually reproductive, annual growth form.

A relatively new non-native species in the San Marcos Springs system is the water trumpet (*Cryptocoryne beckettii*) that has been observed forming colonies that extend from bank to bank excluding native plant species and threatening the habitats of Texas wild-rice and the fountain darter (Tu 2002). The invasion of the water trumpet has created a new and very serious threat to Texas wild-rice. Water trumpet is native to Southeast Asia and was introduced into the San Marcos River in 1993 (U.S. Fish & Wildlife Service 2003). The plant probably escaped into the river from a dumped aquarium as the plant is popular in the aquarium trade (Tu 2002). The plant has habitat preferences that are nearly identical to Texas wild-rice and had quickly established in the section of the San Marcos River from the A.E. Wood State Fish Hatchery to the confluence to the San Marcos and Blanco rivers, before extensive removal efforts were undertaken (U.S. Fish & Wildlife Service 2003).

The non-native suckermouth catfishes are believed to be impacting water quality and causing habitat degradation in areas where their numbers are not naturally controlled. Suckermouth catfishes reproduce by burrowing into banks and bottom sediments to create chambers for the females to lay eggs. When burrows are dense, erosion, sedimentation and elevated turbidity may result. Bank failure, shoreline collapse and terracing have been observed in rivers where suckermouth catfish populations are high (Hoover and others 2006). There is a growing concern that erosion, sedimentation, and elevated turbidity may be affecting Texas wild-rice populations, particularly during low-flow conditions that have the potential to magnify these effects.

Nutria (*Myocastor coypus*) is a large semi-aquatic rodent that is smaller than a beaver and larger than a muskrat with a round slightly haired tail. Nutria can breed year round and are extremely prolific. Nutria are well adapted for movement on land; however, they are more at home in the water. They are strict vegetarians and consume approximately 25 percent of their body weight daily, targeting plant stem bases and digging for roots and rhizomes. In the San Marcos River, herbivory by nutria is believed to be a significant factor in reducing the size and vigor of stands of Texas wild-rice (McKinney and Sharp 1995). During low-flow conditions, herbivory of Texas wild-rice has been shown to increase.

(photo by Joe Fries)

San Marcos salamander

San Marcos salamanders are found throughout Spring Lake (at the headwaters of the San Marcos River) where rocks are associated with spring openings and in rocky areas up to 500 feet (150 meters) below Spring Lake Dam (Nelson 1993). The San Marcos salamander is a small, neotenic form that retains gills throughout its life. It lacks a terrestrial phase, becoming sexually mature and breeding in the water. The primary concerns facing the San Marcos salamander are water temperature, available physical habitat, and water quality.

Temperature requirements are known only from research conducted to determine critical thermal maximum for the species: 96.4ºF and 99.1ºF (35.8ºC and 37.3ºC) for juveniles and adults, respectively (Berkhouse and Fries 1995). Temperatures at which sub-lethal effects, such as decreased fecundity and growth rates, begin to occur are unknown. Downstream of Spring Lake Dam there is a greater potential for water temperatures to increase; however, studies have shown that, typically, the temperature in this portion of the San Marcos salamander's range remains virtually unchanged from the temperature at the spring orifice (Groeger and others 1997). Extended low-flow or especially no flow

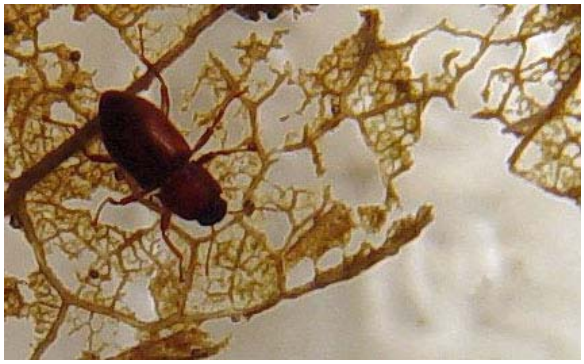
conditions during hot summer months may cause temperature conditions to exceed the tolerance requirements for the San Marcos salamander.

One of the habitat requirements of the San Marcos salamander is silt-free rocks around the spring openings within Spring Lake and downstream of the dam (Tupa and Davis 1976, Nelson 1993, Edwards Aquifer Authority 2007b). Because the rocks used by the salamanders are located adjacent to spring openings, they are kept silt-free as long as water is issuing from the springs. Rocks within the habitat downstream of the dam are more susceptible to being covered with detritus or silt that washes over the dam. No research is available to determine what discharge levels are necessary to prevent buildup of silt and detritus in this reach; however, some level of discharge is assumed. This area is close to the headwaters (Spring Lake); thus, very little silt enters the system before it reaches this section. In addition, flow is generally rapid (sufficient to prevent siltation) in this reach as water travels over the dam and through this relatively shallow region just downstream.

In addition to using silt-free rocks, the San Marcos salamanders are abundant in the filamentous algae found in the upper end or "hotel reach" section of Spring Lake (Tupa and Davis 1976, Nelson 1993, Edwards Aquifer Authority 2007b). Investigators hypothesize that San Marcos salamanders find abundant food in the algae as well as increased protection from predators. Because of the constancy of water temperature, dissolved oxygen, and nutrients found in Spring Lake (McKinney and Sharp 1995), algae remains abundant in this section of the lake. Within the period of record, changes in discharge from the springs have had very little affect on these water quality parameters. However, no springflow is assumed to cause major impacts to this preferred habitat type.

Wetted perimeter is another concern for the San Marcos salamander, though the relative constancy of the water level in Spring Lake, even with changes in discharge, minimizes this concern. Unlike habitat in the lake itself, portions of the San Marcos salamander's range found downstream of Spring Lake are subject to changes in wetted perimeter as discharge fluctuates.

Recreation is another factor that can impact the San Marcos salamander population in relation to springflow (Edwards Aquifer Authority 2007b). Recreation is regulated and generally prohibited on Spring Lake, although archeological excavations and other scientific investigations may disturb sites where San Marcos salamanders are found. Downstream of the dam, the river is open to the public and portions are heavily used for recreation especially during periods of lower springflow. During lower flow conditions, depth at the west spillway is reduced, and underwater hazards (the remains of an old dam at the east spillway) become visible, allowing safer use of this area, resulting in more recreational use.



(photo by Joe Fries)

Comal Springs riffle beetle

The Comal Springs riffle beetle (*Heterelmis comalensis*) was described by Bosse and others (1988) as having functional eyes, poor dispersal due to vestigial wings, and related to *H. glabra*, a winged species complex isolated in springs of west and central Texas (Gonzales 2008). The adults and larvae are primarily collected on cotton cloth lures and more rarely collected by hand and drift nets in springs, seeps, and upwellings of the spring runs, western shoreline, and Spring Island area of the Comal Springs system (but not in the headwater springs near Blieders Creek) and from a few springs and upwellings in the headwaters of the San Marcos River (Barr 1993, Fries and others 2004, Edwards Aquifer Authority 2007b, Gibson and others 2008).

Characteristic of the family, larvae have gills and are aquatic, often inhabiting similar habitat as adults, and subsisting on microorganisms and debris scraped from substrate (Brown 1987). The gills of elmid larvae can be expanded and contracted to increase ventilation when oxygen levels are lower (White and Roughley 2008). Typically, elmids pupate above the water line in moist soil, under rocks, or in rotting wood (White and Roughley 2008), but pupation requirements are not known for *H. comalensis*. In captivity at the National Fish Hatchery and Technology Center, hundreds of *H. comalensis* larvae have been produced, but successful pupation has rarely occurred.

Elmid adults (about 100 species, 27 genera in North America) are typically found in swifter portions of relatively clean rivers and streams (Brown 1987, White and Roughley 2008). The beetles are relatively slow moving, cannot swim, and respire through a plastron (gas film produced by an area of dense water-repelling hairs) which limits them to habitats with high dissolved oxygen (Brown 1987, Resh and others 2008, White and Roughley 2008). Elmids in the genus *Heterelmis* often occur on submerged wood (Brown 1976), presumably using it as a source of nutrition, and several species have been collected in large numbers from shoreline seeps and springs in Texas (Gonzales 2008). They likely feed on fungus and bacteria growing on roots, woody debris, and leaf litter within these areas. Thus, intact riparian areas with trees and shrubs are important (U.S. Fish & Wildlife Service 2007). Bowles and others (2003) and BIO-WEST, Inc. (2002a) found that the Comal Springs riffle beetles mainly occurred in areas with gravel and cobble and not in areas of high sedimentation. Reduction in springflow can cause areas to become unsuitable for the beetles by lowering dissolved oxygen and increasing sedimentation.

The Comal Springs riffle beetle appears to be strongly tied to surface spring habitat as opposed to the riverine species *H. vulnerata* which has been found on rocks and woody debris on the streambed surface just downstream of Landa Lake (Old Channel) and Spring Lake (East Dam). The Comal Springs riffle beetle has only been collected in or very near springs. When searching around upwellings within Landa Lake, they have not been observed outside of the spring openings in areas where water chemistry and substrate are very similar. They likely inhabit shallow subterranean areas within springs because this is a pigmented and eyed species that is collected in substantial numbers near the surface on cotton cloth lures (Edwards Aquifer Authority 2007b, Gibson and others 2008, Gonzales 2008) and is not morphologically adapted to subterranean life like the dryopid beetle (*Stygoparnus*). During drought conditions, the Comal Springs riffle beetle has similar constraints as *Stygoparnus* but is likely affected negatively to a greater extent than the dryopid beetle as the water table is reduced.

Recent mitochondrial DNA analysis indicated high levels of differentiation among most *H. comalensis* subpopulations (located at the three main spring runs, West Shoreline, and Spring Island at Comal Springs and the headwaters of San Marcos Springs). Populations of *H. comalensis* contained higher levels of genetic variation and exhibited greater differentiation than populations of the more widespread and common *H. vulnerata*. Populations of *H. comalensis* appear to be significantly isolated from each other despite relatively little geographic isolation and no obvious barriers to gene flow in most cases. However, *H. comalensis* populations do not appear to have suffered the loss of genetic variation expected with small population sizes. Instead, the West Shoreline, Spring Island and the San Marcos Springs *H. comalensis* populations contain surprising amounts of genetic variation, including several private haplotypes, which indicates that these localities probably support unexpectedly large populations. Within the Comal Springs system, the populations found in the higher elevation springs (spring runs 1, 2, and 3) contained the lowest amount of genetic variation and contained no unique haplotypes as compared to the West Shoreline and Spring Island populations. This and the fact that the beetles are not found in the higher elevation headwater springs (spring run 4 and 5 near Blieders Creek) could be the result of beetle population reductions (due to bottleneck effects) in these areas due to drought (Gonzales 2008).

Subterranean species

Given that we have a poor understanding of the range of the aquifer-dwelling species (Peck's cave amphipod, Comal Springs dryopid beetle, and Texas blind salamander), the question of minimum flows should be expanded to include sub-surface flows. For the aquifer-dwelling listed species, a lack of discharge may not only degrade habitat near the spring orifice, but lead to changes in the subterranean habitat such as water quality, siltation, and temperature changes, at least near the surface. Longley (1981) notes that there are at least 29 other species of invertebrates existing in the aquifer, most of these being endemic. The reason that these were not listed by agencies is primarily because it has been thought that listing one species from a community is sufficient to protect the community. In addition to the Texas blind salamander discussed later, there are at least four other vertebrate species that are found only in the aquifer and therefore are subject to the same issues affecting the Texas blind salamander. In recent years there have been

additional species discovered and all of these subterranean species are unique and in need of protection. Since the Federal Endangered Species Act is designed to protect the critical habitat of species, it has been thought that all of these species are afforded protection if one species from the ecosystem is listed. The following discussions provide some information on flow requirements for the listed species.

(photo by Joe Fries)

Comal Springs dryopid beetle

The Comal Springs dryopid beetle (*Stygoparnus comalensis*) described by Barr and Spangler (1992) is the only known subterranean adapted (vestigial eyes and wings and lacking pigment) beetle in the family Dryopidae. The adults and larvae have been rarely collected by hand, drift net, and cotton cloth lures in springs, seeps, and upwellings throughout the Comal Springs system. The species was also collected from Fern Bank Springs in 1992 (13 individuals from one of the small hillside seeps) and in 2003 (1 individual from a small spring outlet on the water's edge of the Blanco River) (Barr 1993, Fries and others 2004, Edwards Aquifer Authority 2007b, Gibson and others 2008). This species has not been found in wells or caves.

Characteristic of this small family, larvae do not have gills and are considered terrestrial, inhabiting moist soil along stream banks (Brown 1987). The larvae of two species of *Helichus* (the nearest relatives to *Stygoparnus*) were found up to 16 feet (5 meters) from stream edge (Ulrich 1986). Barr and Spangler (1992) presumed the microhabitat to be soil, roots, and debris exposed above the waterline on the ceilings of spring orifices. Adult dryopids are found in relatively clean rivers and streams feeding on biofilm scraped from surfaces such as rocks, wood, and vegetation (Brown 1987). They are relatively slow moving, cannot swim, and respire through a plastron which limits them to habitats with high dissolved oxygen (Brown 1987, Resh and others 2008). As springflow is reduced, dissolved oxygen may also be reduced. A reduction in dissolved oxygen would likely result in a reduction of suitable habitat available to *Stygoparnus*, thus potentially reducing population size.

Although adapted for subterranean life, the beetle appears to live near the surface due to the terrestrial larvae and a diet which likely includes decaying root matter supplied by the riparian area associated with the springs (U.S. Fish & Wildlife Service 2007). The species survived the drought of 1956 when Comal Springs ceased to flow. During drought conditions, the beetle can likely retreat into the aquifer, but reduction in population likely occurs as suitable habitat for the species becomes reduced as the water table drops. If the

water drops below the root line for an extended time, extinction could follow. As the water recedes, the slow moving beetle might find difficulty in moving through the smaller interstitial spaces as well as finding required habitat for survival, growth, egg deposition, and pupation (including nutrients, oxygen levels, moisture, and pupation sites as well as increased predation). Extended drought conditions could negatively affect the riparian habitat associated with the springs resulting in lowered nutrient input which can reduce beetle populations and slow the recovery of the beetle population as this area is re-established.

(photo by Joe Fries)

Peck's cave amphipod

Peck's cave amphipod (*Stygobromus pecki*) was first collected by Peck in 1964 and later described by Holsinger (1967). They are members of the *flagellatus* group of *Stygobromus* which is distinguished as having insular patterns of speciation, being greatly restricted in ranges, and occupying deeper groundwater niches. This group is composed of four described and maybe the same number of undescribed species all found in the Edwards Aquifer of central Texas (Holsinger 1967). The genus *Stygobromus* has around 100 species; all are subterranean and found primarily in North America with a few in Eastern Europe and Siberia (Holsinger 1994).

Peck's cave amphipods have been collected in springs, seeps, and upwellings throughout the Comal Springs system, Panther Canyon Well, and Hueco Springs (Barr 1993, Fries and others 2004, Edwards Aquifer Authority 2007b, Gibson and others 2008). They are found in gravel, rocks, and associated debris (leaves, roots, and wood) directly in or near springs or collected drifting out of spring orifices (Fries and others 2004, Edwards Aquifer Authority 2007b, Gibson and others 2008). They most likely are omnivores feeding on detritus and decomposing plant material, and scavenging or preying on other aquifer organisms (U.S. Fish & Wildlife Service 2007). They have been observed eating other invertebrates soon after capture from the wild (Fries and others 2004) and have been reared in captivity for at least 2.7 years with dried leaves as the primary nutrient source and rarely introduced tropical fish flakes as an additional source. At Comal Springs, Peck's Cave amphipods were relatively abundant and usually bright orange in color, as opposed to Hueco Springs where they were relatively rare and were the typical white color exhibited by most unpigmented cave organisms. The color of some

amphipods, and crustaceans in general, often is dependent on diet, which usually includes carotienoids produced by plants, algae, and probably some bacteria (Negre-Sadargues and others 2000, Fraser and Bramley 2004, Gaillard and others 2004). It is possible that the orange coloration found within the Comal Springs population is derived from food sources (that is, roots, woody debris, and leaf litter) that are scarce at Hueco Springs (Gibson and others 2008). The relative abundance of the Peck's cave amphipods near the surface at Comal Springs is likely due to a nutrient source supporting the population provided by the spring associated riparian area which could also be contributing to the orange color. This species appears to be restricted in range with the largest numbers supported in the shallow habitat of Comal Springs. During drought conditions, this species can likely inhabit deeper groundwater niches, but as the water recedes the nutrient base will be reduced and the population could be significantly affected. Population genetics of the Peck's cave amphipod has just begun at Texas State University by Dr. Chris Nice.

(photo from U.S.Fish & Wildlife Service)

Texas blind salamander

This neotenic (retention of some juvenile characteristics as adults) salamander is aquatic throughout life and lives in the water-filled cavernous areas of the Edwards Aquifer in the San Marcos area. The Texas blind salamander is probably stenothermal (capable of surviving over only a narrow range of temperatures) and restricted to water temperatures near 69.8ºF (21°C). It feeds on the biota of the aquifer including shrimp, amphipods, isopods, and other invertebrates. The Texas blind salamanders apparently sense the movements of their prey with specialized structures on their head region. These salamanders have been able to lay eggs and have them develop in the laboratory at the Cincinnati Zoo, the San Marcos National Fish Hatchery and Technology Center, the Fort Worth Zoo, the Dallas Zoo, and Texas State University.

Primary concerns to the Texas blind salamander are depth of the water table and water temperature. The latter is an assumption based on the constant temperatures of the water in which the species is found; more research is needed to address the effects of temperature changes to the species. Regardless, the temperature of the water stored in the aquifer is constant at approximately **69.8ºF (21°C)**, which is unaffected by temperatures aboveground or fluctuations in discharge from spring openings. Depth of the water table fluctuates depending on recharge to the aquifer and withdrawals made from it. Despite

concern for a decline in the water table, the springs feeding the San Marcos River (in Spring Lake) have not ceased flowing in recorded history.

Water quality beyond just temperature is another area of potential concern to the Texas blind salamander. Concerns with water quality include human activities in the recharge zone (that is, non-point source runoff, sewage leaks, and other chemical contamination) and lowered aquifer levels preventing adequate dilution to these contaminants. There is also concern with encroachment of saline water into spring areas during extended low-flow periods. This would result from the movement of the "Fresh Water/Saline Water interface," which is approximately 160 feet (50 meters) from some of the San Marcos Spring openings.

Task 2.2: ***If alternatives exist to minimum flows that may not reduce appreciably the likelihood of the survival and recovery in the wild by reducing the reproduction, numbers, or distribution of each species listed under the Endangered Species Act identified in Section 3.2 of the Edwards Aquifer Recovery Implementation Program Memorandum of Agreement, identify and provide a preliminary evaluation of those alternatives to protect those federally listed species.***

Recommendation: At this time, the Edwards Aquifer Area Expert Science Subcommittee believes that no proven alternatives exist as a replacement for minimum flows as discussed below; however, potential management strategies involving flow have been proposed and should be further evaluated.

Our interpretation of the task

Our interpretation of this task is that an "alternative" to minimum flows would be something other than "flow" (for example, a replacement for flow). The use of refugia has been proposed by stakeholders as one such alternative. As discussed below, although refugia play a vital role in the protection of threatened and endangered species, refugia are not viable or effective alternatives to maintaining minimum flows.

There are potential management strategies, such as springflow augmentation, recirculation, and artificial recharge, which may be proven in the future to maintain or enhance minimum springflows and thus maintain the biological community. However, our interpretation is that these strategies, if proved successful, may enhance minimum flows; thus, they are not considered "alternatives" to minimum flows.

We interpret "survival and recovery" in this task the same as we described in **Task 2.1**, with "survival" being the continued existence of individuals for some period of time and

"recovery" constituting the conservation and survival of a species. Finally, we interpret "in the wild" as in the physical environments of the spring, river, and/or aquifer in which the species currently exist.

Discussion

The use of ex-situ (off-site) or captive propagation as a protective measure for certain Edwards Aquifer aquatic species has been employed by the U.S. Fish & Wildlife Service since 1990. In-situ (a Latin phrase meaning "in the place") refugia, another type of refugia that has been discussed by stakeholders, refers to a subset of the available habitat in a given spring system that could be intensively managed to house a given species for some period. The goal of in-situ refugia would be to sustain species and habitat when conditions are poor, while also providing the opportunity for research in these areas when conditions are favorable. We agree that certain aspects of in-situ refugia have potential merit and should be evaluated. However, we believe that in-situ refugia are unproven for the Comal and San Marcos springs systems at this time. Therefore, our discussion in this section focuses solely on ex-situ refugia, with in-situ refugia discussed further in **Task 2.3** (identification of additional studies).

The Policy Regarding Controlled Propagation of Species Listed under the Endangered Species Act states that "Controlled propagation is not a substitute for addressing factors responsible for an endangered or threatened species' decline" (U.S. Fish & Wildlife Service and National Oceanic and Atmospheric Administration 2000). The policy supports controlled propagation associated research, the establishment of refugia, the production of plants and animals for restocking, and conservation of species to prevent extinction. The policy requires that a controlled propagation plan include the evaluation of the following risks: effects of removing individuals from the wild, effects of losing some or all of the individuals being maintained in captivity, genetic changes that controlled propagation individuals could convey to wild populations, and the effects of diseases that controlled propagation individuals could introduce to wild populations (U.S. Fish & Wildlife Service and National Oceanic and Atmospheric Administration 2000).

All risks associated with controlled propagation are greatly compounded when recovery of a species is solely reliant on a refugium to prevent extinction. Before Lake Amistad was filled, *Gambusia amistadensis* was collected from Goodenough Springs and placed in a refugium. The habitat utilized by *G. amistadensis* was destroyed when Lake Amistad was filled. It is assumed that *G. affinis* was unintentionally collected when *G. amistadensis* was collected. *Gambusia affinis* out competed *G. amistadensis* while they both were being held in the refugium, and *G. amistadensis* was lost and became extinct (Hubbs 1984).

Currently, there are only two Edwards Aquifer Recovery Implementation Program aquatic species (fountain darters and Texas wild-rice) that have been successfully propagated in captivity; however, it is unproven that both species can be maintained in captivity for multiple generations. The other five species (excluding the San Marcos gambusia, which is thought to be extinct) would thus lack protection. Captive propagation techniques for the San Marcos salamanders have not been fully developed. San Marcos salamander techniques have been developed to hatch eggs, feed the larvae,

feed juveniles, and feed adults. San Marcos salamander reproduction routinely occurs at the San Marcos National Fish Hatchery and Technology Center, but reproduction cannot be induced or predicted. Over 10 years have been invested in studying San Marcos salamander reproduction, yet the controlling factors have not been identified. Genetic manipulation of the species through the mating of given individuals is not currently possible. Without this ability, the genetic diversity of the salamanders used for restocking the native habitat cannot be assured. Over the years, the San Antonio Zoo, the Dallas Aquarium, the Cincinnati Zoo, the Detroit Zoological Institute, the National Aquarium in Washington, D.C., and the National Aquarium in Baltimore have maintained one or more salamander species associated with the Edwards Aquifer (San Marcos salamander and Texas blind salamander), but none of the facilities have maintained the number of salamanders that are routinely maintained at the San Marcos National Fish Hatchery and Technology Center. The zoos are viewed as research collaborators but not as refugia.

Comal Springs riffle beetles are being maintained at the San Marcos National Fish Hatchery and Technology Center, but captive propagation techniques require further improvement. Adult riffle beetles have been collected from the wild and have been successfully reared and reproduced. Eggs have hatched, and thousands of larvae reared. However, only a few larvae have pupated to the adult stage. Thus, adults could not be produced for restocking purposes. Only the San Marcos National Fish Hatchery and Technology Center is maintaining live Comal Springs riffle beetles in captivity.

The development of captive propagation techniques for the Peck's cave amphipod is in its infancy. The San Marcos National Fish Hatchery and Technology Center is maintaining less than 100 individuals in captivity. Over a three year period, adults collected from the wild successfully reproduced, and a few offspring survived to adulthood and produced young. This species developed slowly in captivity and has been observed to be cannibalistic which can be problematic for culture. The Comal Springs dryopid beetle is rare; less than 20 beetles are collected annually. Until the availability of the Comal Springs dryopid beetle increases, it is unlikely that the San Marcos National Fish Hatchery and Technology Center will actively pursue the development of captive propagation techniques for this species. No facility is maintaining live Comal Springs dryopid beetles in captivity.

Even though fountain darters and Texas wild-rice could likely be maintained in refugia for several generations, potential problems exist. Captive populations are too easily lost for the existence of a species to be solely dependent on that technique. The two existing fountain darter refugia, San Marcos National Fish Hatchery and Technology Center and the Uvalde National Fish Hatchery, maintain only wild-captured fish. Fountain darters from the Comal and San Marcos rivers are collected generally in the spring and fall to replace darter losses that occurred during the preceding six months. Neither facility is designed to maintain captive populations that do not rely on a wild source of fish to produce offspring for stocking purposes. Existing facilities would not permit sufficient numbers of fountain darters and Texas wild-rice to be produced to assure that a re-introduced population would be genetically reflective of the natural population. Fountain darters are a short-lived species, 18 months in the wild (Schenck and Whiteside 1976). Texas wild-rice seeds cannot typically be stored longer than nine months. The longer the

species are held in refugia and the older the brood stock used to produce the fish and plants for stocking, the lower the probability of successful re-establishment.

Another component of maintaining a population for reintroduction is the probability of success that a given species can reestablish self-sustaining populations. Although not an example of a reintroduction from a refugium, a case study presented itself when the Comal Springs stopped flowing in 1956 and the fountain darter was subsequently eliminated from the Comal River. Fountain darters from the San Marcos Springs system were stocked into the Comal River during the mid 1970s, and a population exists in the Comal River today because of this reintroduction (Schenck and Whiteside 1976). It is currently unknown if a similar reintroduction and corresponding success could be achieved with just refugium populations. A major problem to successful reintroduction is whether or not the springs will be flowing at a sufficient level to permit the population to rapidly recover. The re-introduction of the existing aquatic invasive species (specifically the gill parasite *Centrocestus formosanus*) and new invasive species also have the potential to negatively effect the re-establishment of the fountain darter.

As with the fountain darter, the amount of Texas wild-rice in ex-situ refugia represents a small proportion of its wild population. Refugium populations are similar to small wild populations and face some of the same threats. Catastrophic stochastic events such as pests, pathogens, power loss, and contamination can wipe out refugium stocks as easily as a wild population. The genetic composition of a refugia population may change relative to a wild population through genetic drift (random loss of alleles or change of allele frequencies leading to fixation of alleles and loss of genetic diversity), artificial selection (adaptation to cultivation conditions such as nutrient, light, water, temperature and competitive regimes), mutation accumulations (less strenuous growing conditions can lead to the survivorship of less fit individuals), inbreeding depression (self-fertilization or breeding between closely related individuals can lead to a reduction in the fitness of the offspring), and outbreeding depression (individuals from widely separated populations may have unique genetic adaptations for their local environment; the breeding of such individuals may result in offspring that are poorly adapted to either parental environment). Additionally, the seeds for Texas wild-rice cannot typically be stored for longer than nine months (Power and Fonteyn 1995). Refugia also assume eventual reintroduction. Reintroduction, especially that of an entire community, is an extremely difficult, time-consuming, and expensive process.

The success of planting Texas wild-rice into the San Marcos River and other spring systems has not been good. Using plants grown in raceways on the campus of Southwest Texas State University, W.H.P. Emery, professor at Southwest Texas State University, tried to reintroduce Texas wild-rice into the San Marcos River in the 1970s (Power 1996c). Some of the transplants did survive, but their reason for success is not known (Power 1996c). An attempt was made to introduce the species outside of its historic range to Salado Creek in Bell County, Texas (Beaty 1976). The introduction was unsuccessful due to local recreation pressure and periodic vegetation removal from the creek. Terrell and others (1978) attempted to grow Texas wild-rice in a laboratory in Beltsville, Maryland. Although one plant flowered, all plants eventually succumbed to mites. In the late 1980s Fonteyn and Power (1989) removed elephant ears from along the banks of the San Marcos River and transplanted Texas wild-rice in its place. Despite a second planting

after a flood swept away all the original transplants, only one plant out of several hundred survived; it flowered and then died.

In 1992 to 1994, Power transplanted almost 700 young plants into Spring Lake in five different habitats defined by depth and current velocity (Rose and Power 1992, 1994; Power 1996a, 1996c). Although water depth did not appear to be limiting, velocity was. Plants in still or slow water (less than 0.13 feet per second [0.04 meters per second]) were gone within three years. The other transplants have maintained moderate-sized stands as of 2008. Power also transplanted Texas wild-rice above the Interstate-35 bridge and in the river between the state fish hatchery and the wastewater treatment plant. Some of these transplants were also alive as of 2008. During the breach of Cape's Dam in early 2000, plants were either moved immediately and replanted in deeper water or were taken to the San Marcos National Fish Hatchery and Technology Center. After plants were removed from the area of Clear Springs Apartments in summer 2006, Mara Alexander and other U.S. Fish & Wildlife Service staff replanted the area. Flooding washed away some of the transplants, but some remain as of 2008. Alexander also began a study planting seeds in degradable cloth bags to determine if seeds would be a more reliable and less resource-consuming method of establishing wild-rice than transplants.

The problems associated with how and where to plant Texas wild-rice in the San Marcos River are compounded by non-native plants out competing Texas wild-rice. After flood events, the gains made by wild-rice are small compared to the gains made by elephant ear, hydrilla, and water trumpet. It is safe to assume that other non-native plants that out compete Texas wild-rice will be introduced into the San Marcos River in the future. In conclusion, reintroduction of Texas wild-rice is still not an assured science. Although some reintroductions of Texas wild-rice appear to be successful, reintroduction or even restoration of the entire San Marcos ecosystem has not been attempted.

Task 2.2.1: Your consideration of alternatives should include an evaluation of information provided by Recovery Implementation Program members on this issue.

We have evaluated and taken into consideration the information provided by members of the Recovery Implementation Program. Position papers submitted by the members are included in **Appendix F**.

Task 2.2.2: Your consideration of alternatives also should be mindful of impacts on protected species other than those species listed under the Endangered Species Act identified in Section 3.2 of the Edwards Aquifer Recovery Implementation Program Memorandum of Agreement.

During the evaluation, we considered protected species (for example, subterranean species, Cagle's map turtle, and whooping crane) other than the Edwards Aquifer Recovery Implementation Program species. The Edwards Aquifer Recovery Implementation Program species are members of complex biological communities that include many species that coexist in these specific environments. The goal of protecting

the listed species is to protect the ecosystem as a whole, which in turn offers protection to the full suite of organisms. However, as no alternative was identified as a replacement for minimum flows, no detailed response was necessary.

Task 2.3: Identify existing studies regarding the ability of each alternative other than maintaining minimum springflows to protect federally threatened or endangered species. Identify additional studies or data needed to fully evaluate each of these alternatives, including an estimate of the time and cost to conduct such studies and any different alternatives that might be explored in the future.

As no alternative was identified as a replacement for minimum flows, no response is necessary. However, we felt that some additional information on additional studies or data gaps relative to refugia would be informative. Therefore, we discuss both ex-situ refugia and in-situ refugia below.

Discussion

The establishment of fountain darter and Texas wild-rice refugia and the research associated with these refugia has led to the determination of the requirements needed to rear and reproduce these species in captivity. Similar research has been conducted for the other Edwards Aquifer Recovery Implementation Program species, and progress is being made to determine their respective requirements. As discussed under **Task 2.2**, life history information for the endangered invertebrates is extremely limited. The literature cited and additional references provided (**Appendix G**) include numerous studies that have been conducted over the years to improve the understanding of the Edwards Aquifer Recovery Implementation Program species. Goals for additional studies relative to the invertebrates would be to, first, gain a better understanding of the general life history requirements of these species and to, second, use that knowledge to develop protocols to rear and reproduce these species in captivity. These efforts have been initiated at the San Marcos National Fish Hatchery and Technology Center but will require substantial resources beyond what is currently available for any real chance of meeting these goals. Finally, should these goals be achieved, the vital component of reintroduction would need to be addressed. These additional studies would enhance the knowledge of species requirements and likely improve efficiency and effectiveness of ex-situ refugia. However, even with improvements to our understanding of life history requirements, plus technology advancements over time, we believe that ex-situ refugia will continue to provide only short-term protection from species extinction, and should not be considered an alternative to minimum flows.

In-situ refugia have only been evaluated for the Comal and San Marcos springs systems in a conceptual framework (LBG-Guyton Associates 2004). There are two aspects of in-situ refugia that warrant further investigation: (1) the redirection of springflow within either the San Marcos or Comal springs system during times of limited springflow and (2) the establishment of specific in-situ refugia areas for constant protection and potential

environmental research. It is most logical to focus these activities on surface-dwelling species. Additionally, it is probably most logical to focus on the fountain darter and Texas wild-rice because of the knowledge base already established. Several major questions would need to be addressed, including (1) Would in-situ activities be effective in maintaining survival for periods of time in the wild? and (2) Would the gain from protecting smaller areas in the systems outweigh the impacts required to sacrifice water to make this feasible? There are a host of other questions to be addressed including the physical possibility of constructing such areas or diversion devices, the cost, the length of effectiveness, species to be included, and other potential considerations.

One potential study would be to evaluate the use of existing structures or temporary dams to divert water from lower quality habitat to maintain acceptable quality habitat longer in other areas. Elevation of the upstream-most dam in the Comal River New Channel would permit maintenance of higher quality habitat in the Old Channel for a longer period of time. This is also true if the height of boards controlling the chute opening on the western spillway of Spring Lake dam was raised to divert all water over the eastern spillway. The use of inflatable dams in Spring Lake and Landa Lake to concentrate the flow of spring discharge across the best fountain darter and Texas wild-rice habitats while eliminating areas of low habitat quality has merit. In Spring Lake, an inflatable dam has been proposed to block off water flow into the slough (Sink Creek confluence area) portion of the lake. In Landa Lake, inflatable dams would be used to quarantine off the large *Vallisneria* sp. beds that support low densities of fountain darter. As with the use of re-circulated water, an evaluation needs to be done to determine if the benefits to populations in the proposed enhanced areas will exceed the damage done to the populations in the dammed off areas.

Another potential opportunity would be to explore environmental restoration and research feasibility within either the Comal or San Marcos springs systems. An area that is well suited for this type of activity is the Old Channel within the Comal system. The Old Channel has been overrun with non-native vegetation and is not the high quality habitat that it was merely five years ago (Edwards Aquifer Authority 2007b). A proposal to examine the effectiveness of an Intensively Managed Area at Comal Springs could be tested in the field. The goal of the Intensively Managed Area would be to provide in-situ refugia for species when conditions are poor, while also providing the opportunity for research when conditions are favorable. Conducting in-situ experiments to evaluate low discharge responses of fountain darters and their habitats (with a focus on aquatic vegetation) would assist in providing insight into habitat responses during low-flow conditions in the wild.

At this time, a companion strategy to an Intensively Managed Area pilot study would be to restore the higher quality (native) vegetative habitat for fountain darters within the Old Channel reach in the Comal Springs system. One proposed area would be between the culvert that directs flow from Landa Lake into the Old Channel and the low-water golf course road. The length of this segment of river is approximately 900 feet (275 meters). Flow enters the proposed study reach through two culverts, which are both controlled by the City of New Braunfels along with the U.S. Fish & Wildlife Service. In addition to the culvert that directs flow from Landa Lake into the head of the Old Channel, there is another culvert that directs water from the lake into the city swimming pool area and then

into the Old Channel about 575 feet (175 meters) downstream from the first culvert. The majority of the proposed Intensively Managed Area would be within the downstream-most 300 feet (100 meters) of this reach.

The basic conceptual design of the project is to install a diversion structure and pipeline to re-circulate a portion of the flow in the Old Channel from a point near the golf course road back up to a point near where the flow-through swimming pool water enters the channel. This could potentially provide higher discharge through the immediate project area during periods of limited recharge. It is anticipated that water chemistry conditions would not change substantively using this re-circulation design, but that component would also need to be evaluated prior to implementation. In addition to re-circulation, the pipeline would allow the transfer of water in both directions so that during normal to high flow periods a portion of the flow could be directed around the project area. The ability to lower discharge through the project area, without affecting the total flow available to downstream users, would provide an ideal situation for experimentation of the impacts of different streamflow conditions.

Although Intensively Managed Areas might have merit, there are a number of factors that would need to be studied in detail. Re-circulation of water to maintain fountain darter or Texas wild-rice habitat should be further evaluated before it is recommended. The effect of increased water temperature and total dissolved gas levels on fountain darter reproduction and health and the effect of increased water temperature and concomitant decreased carbon dioxide level on Texas wild-rice (and other native aquatic plants) growth are the factors that should receive priority attention. The effect of increased water temperature on darters in the area where the pumped water is discharged and the area below where the water is picked up and pumped upstream would need to be conducted. If the benefits to the populations in the re-circulated water area do not exceed the damage done by re-circulation to the habitat downstream of the re-circulated water area, water re-circulation should not be done. If the water temperature exceeds 77°F (25°C), a significant decrease in fountain darter fry production will probably occur (McDonald and others 2007). As water temperature increases, the ability of water to hold gases in solution decreases. As carbon dioxide levels decrease in the water, the quality of the habitat to support Texas wild-rice decreases (BIO-WEST, Inc. 2004). If the water temperature exceeds 84°F (29°C), Texas wild-rice would shift to an annual sexual reproductive mode (Tolley-Jordan and Power 2007). This could be detrimental to wild-rice as the annual sexual phase leaves no vegetative material behind as well as being more vulnerable to herbivory. Beyond this temperature, the effects on Texas wild-rice are unknown and should be studied. However, the two former concerns are more pertinent to recovery of species rather than survival. The latter concern could affect survival of Texas wild-rice. It is acknowledged that during extremely low-flow conditions (whether experienced naturally or artificially) fountain darter reproduction and Texas wild-rice growth may actually be non-existent for short periods of time.

To demonstrate the complexity of any ecological evaluation regarding threatened and endangered species we need only to examine a few of the obstacles involved in any Intensively Managed Area feasibility study or pilot project. Re-circulated water has been used for years to rear fountain darters at the San Marcos National Fish Hatchery and Technology Center. Chillers are used at the hatchery to maintain the re-circulated water

temperature below 73°F (23°C). During the summer months, moving water through uninsulated pipes causes an increase in water temperature. As water temperatures rise, the solubility of gases in water decreases. A rise of only a few degrees can cause unsaturated water to become saturated when the water is contained within a pipe. Minute gas bubbles form in saturated water, and these gas bubbles can pass through the gills into the blood stream of both salamanders and fishes. The bubbles can be fatal. As total gas saturation level increases above 100 percent, the mortality rate of both fountain darters and San Marcos salamanders increases (Schaefer 2000). Total dissolved gas levels in the re-circulated water at the hatchery are routinely monitored, and adjustments are made to keep total dissolved gas levels below saturation. If water is to be pumped and circulated within the Comal and San Marcos rivers, total dissolved gas levels within the water will need to be monitored, and mechanisms must be present that allow for total dissolved gas level adjustments to be made. Damage done to listed and unlisted organisms that pass through the pumps needs to be considered. It is assumed that fountain darters, San Marcos salamanders, and the invertebrates they consume will all pass through the pumps. Texas wild-rice tillers also break free from parent plants and drift down the river. The effect of the tillers passing through the pumps needs to be considered. The above are only a few of the ecological factors, and not the permitting, political, and economic considerations, that these types of efforts will no doubt entail.

In summary, additional studies would be required before a determination of the potential of in-situ refugia as a supplement to minimum flows could be adequately made.

Task 2.4: Investigate spring flow volume measurement methodologies currently in use and evaluate their accuracy. If any are deemed to be inadequate, suggest alternative measuring methods.

Recommendation: The Edwards Aquifer Area Expert Science Subcommittee recommends that

- the accuracy of the stage-discharge relationships be reassessed whenever it appears spring flows are approaching the critical period management triggers and
- a concrete low-flow control section be installed in the San Marcos River at a location minimizing disturbance of endangered species and maximizing accuracy of continuous measurements.

Spring flow measurements are important for understanding the magnitude and variability of flow as it relates to endangered species and critical period management triggers. Because the U.S. Geological Survey estimates spring flows at San Marcos and Comal springs, under contract with the Edwards Aquifer Authority, we invited George Ozuna of the survey to give us a presentation about measurements of flow at the springs. Note that we did not consider measurements of flow at Fern Bank Springs or Hueco Springs.

Comal Springs

The U.S. Geological Survey currently estimates flow at Comal Springs using a stage-discharge relationship to compute mean daily flows. The stage-discharge relationship is developed by measuring flow velocity profiles, using those profiles to calculate total flow, and then relating that flow to a stage level (water surface elevation). Flow measurements are made routinely at a selected cross section of the channel about 25 feet (10 meters) upstream of the control structure.

The accuracy of the stage-discharge relationship thus far in the 2008 water year is -1.92 percent. The independent manually measured flow accuracy range for the same period is -5.9 percent to -0.1 percent. At present there have been 675 discharge measurements made at this location. The accuracy of measurements has substantially defined the present rating in use.

The accuracy of measurements could be increased by additional measurements in the upper portions of the rating curve. Periodic discharge measurements could be made at a

cross section located about 150 feet (50 meters) downstream of the control structure and compared to the discharge measured at the upstream cross section to assess the accuracy of the measurements.

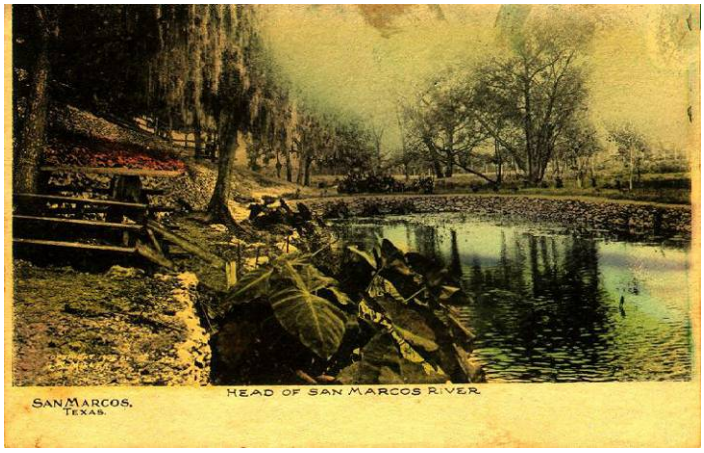
San Marcos Springs

Flows from San Marcos Springs are estimated in the same manner as for Comal Springs except for the location of the gage and where manual measurements of flow are made. There is also an acoustic velocity meter connected to the gage to continuously measure the velocity of the stream.

The accuracy of the stage-discharge relationship thus far in the 2008 water year is 11.6 percent. The independent manually measured flow accuracy range for the same period is -16.8 percent to +24.5 percent. The variability of accuracy is related to aquatic plant growth in the channel and the altering of flow caused by the addition or removal of water retention barriers of the upstream gated area.

Increased manual discharge measurements would provide a better relationship by reducing the computational efforts of rating shift applications and better define specific areas of the rating in use. More dramatic improvements could be achieved if a low-water control was added along with vegetation control.

One of the issues with past spring flow estimates has been the redefinition of the stage-discharge relationship. A stage-discharge relationship is affected by stream morphology, and stream morphology changes with time. Therefore, as time goes by, the stream-discharge relationship may become less accurate. This occurred in the fall of 2006 when a redefinition of the stream-discharge relationship caused the U.S. Geological Survey to revise spring flow rates for San Marcos Springs. These revisions elevated flows that had been under the Stage 2 critical period management trigger to above the trigger. Therefore, the Edwards Aquifer Area Science Subcommittee recommends that the U.S. Geological Survey measure flows to test to accuracy of the stage-discharge relationship whenever it appears spring flows may approach drought triggers. The subcommittee further recommends that the U.S. Geological Survey coordinate with the U.S. Fish & Wildlife Service and other resource agencies to select an appropriate location for a low-flow control section in the San Marcos River that minimizes the disturbance of endangered species and maximizes accuracy of continuous measurements.



Task 3: Should the trigger levels for San Marcos Springs for the San Antonio Pool be adjusted?

Recommendation: At this time, the Edwards Aquifer Area Expert Science Subcommittee believes that trigger levels for San Marcos Springs should not be adjusted.

Our interpretation of the task

This task is focused on whether or not the critical period management triggers for San Marcos Springs for the San Antonio Pool should be adjusted. We interpreted this task, given its timing in the recovery implementation process, to refer to the current critical period management plan as expressed in Senate Bill 3 of the 80th Legislature, Regular Session.

Task 3.1: Should the trigger levels for the San Antonio pool based on San Marcos Springs flow be adjusted?

To address this task, we requested that the Edwards Aquifer Authority provide San Marcos Springs flow data for when water levels in Index Well J-17 and flows in Comal Springs hit their different critical period management triggers for declining and increasing water levels and springflows, respectively. We requested this for the period 1980 to 2007, a period when flow at San Marcos Springs was being measured most accurately. We asked for this information to evaluate the importance of the San Marcos Springs triggers in the context of the other triggers.

Current trigger levels for San Marcos Springs are 96 cubic feet per second (2.7 cubic meters per second) for Critical Period Stage I and 80 cubic feet per second (2.3 cubic meters per second) for Critical Period Stage II. For Index Well J-17, critical period triggers are water level elevations of 660 feet (201 meters) at Critical Period Stage I, 650

feet (198 meters) at Critical Period Stage II, 640 feet (195 meters) at Critical Period Stage III, and 630 feet (192 meters) at Critical Period Stage IV. For Comal Springs, critical period triggers are flows of 225 cubic feet per second (6.4 cubic meters per second) at Critical Period Stage I, 200 cubic feet per second (5.7 cubic meters per second) at Critical Period Stage II, 150 cubic feet per second (4.2 cubic meters per second) at Critical Period Stage III, and 100 cubic feet per second (2.8 cubic meters per second) at Critical Period Stage IV. San Marcos Springs does not have trigger levels for stages III and IV.

When water levels are decreasing and hit the Critical Period Stage I trigger for Index Well J-17 (660 feet [201 meters]), most of the flows (94 percent) measured at San Marcos Springs are above the spring flow trigger (96 cubic feet per second [2.7 cubic meters per second]) (**Figure 16**). A similar pattern—most of the flows at San Marcos Springs are greater than the San Marcos Springs trigger—is observed for the Index Well J-17 Stage I trigger when water levels are rising (**Figure 17**). For the Stage II trigger for Index Well J-17 (650 feet [198 meters]), flows at San Marcos Springs have all been higher than the Stage II trigger for San Marcos Springs (80 cubic feet per second [2.3 cubic meters per second]; **Figures 16 and 17**). A similar pattern is observed for the Comal Springs triggers with respect to flow and San Marcos Springs—most if not all flows at San Marcos Springs are greater than its triggers when the triggers are hit for Comal Springs (**Figures 18 and 19**).

Based on modeling (Edwards Aquifer Authority 2007a, Mace and others 2007; Mace and Wade 2008), these current critical period triggers do not prevent the cessation of flow at Comal Springs during a repeat of the drought of record; however, these triggers do preserve flow at San Marcos Springs (Edwards Aquifer Authority 2007a). Given the broader purpose of the recovery implementation program, changes to these triggers may be recommended when the recovery implementation program has been developed.

Senate Bill 3 places the current trigger for flow at San Marcos Springs in a position where it occasionally leads Index Well J-17 and Comal Springs in hitting its trigger going into critical period drought and occasionally lags Index Well J-17 and Comal Springs when coming out of critical period drought. It is unclear from statute what the management goal is in the placement of this trigger; therefore, it is difficult for us to scientifically assess the appropriateness of the current trigger. Given this, the potential revisiting of the trigger as part of the recovery implementation program, and lack of understanding of flow with respect to San Marcos Springs as discussed in **Task 1**, we are not able to recommend an adjustment to the drought triggers for San Marcos Springs at this time.

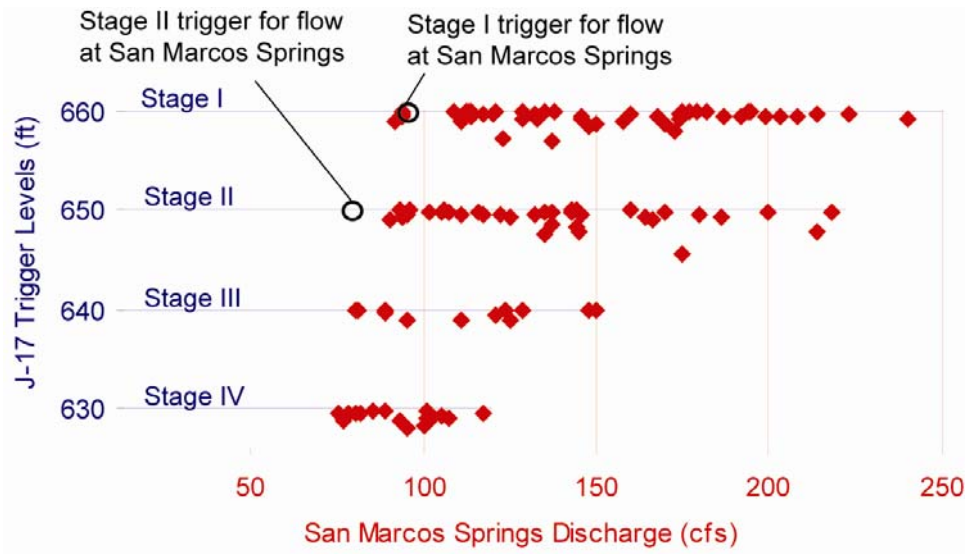


Figure 16: Flow at San Marcos Springs for whenever the water level in Index Well J-17 was decreasing and crossing a critical period management trigger. This figure shows that the flow at San Marcos Springs would almost always be above its critical period management trigger when water levels in Index Well J-17 were at its triggers. Note that San Marcos Springs does not have Stage III or Stage IV triggers (ft = feet; cfs = cubic feet per second; data shown for the period 1980 through 2007).

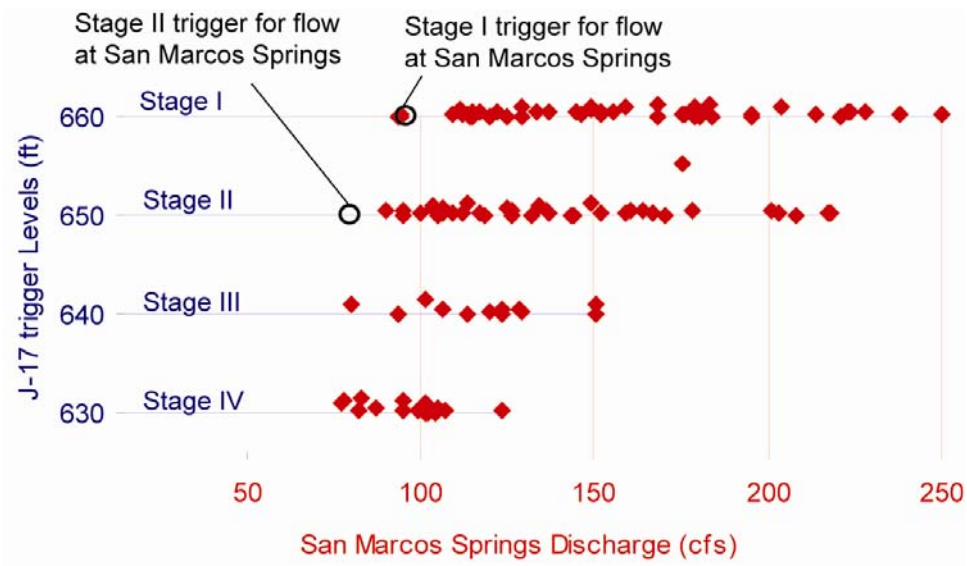


Figure 17: Flow at San Marcos Springs for whenever the water level in Index Well J-17 was increasing and crossing a critical period management trigger. This figure shows that the flow at San Marcos Springs would almost always be above its critical period management trigger when water levels in Index Well J-17 were at its triggers. Note that San Marcos Springs does not have Stage III or Stage IV triggers (ft = feet; cfs = cubic feet per second; data shown for the period 1980 through 2007).

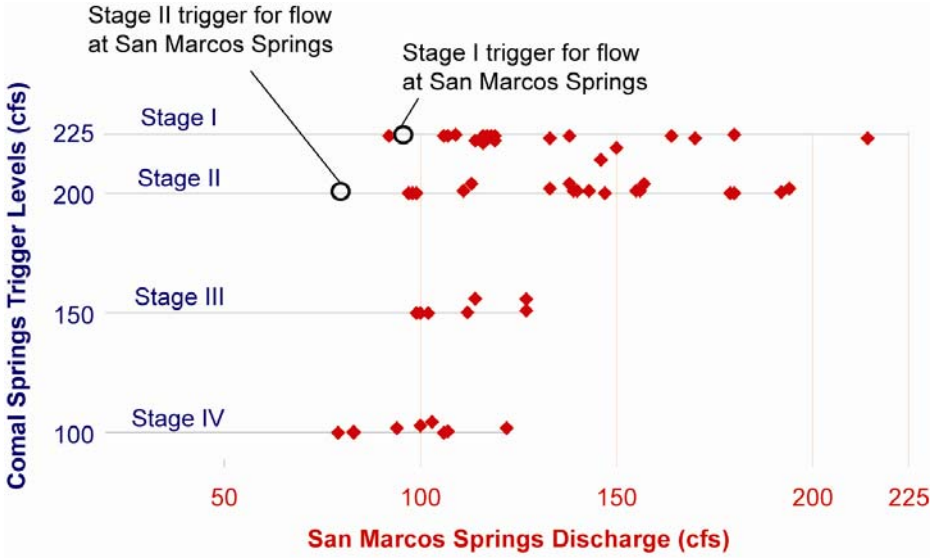


Figure 18: Flow at San Marcos Springs whenever flow at Comal Springs was declining and crossing its critical period management trigger. This figure shows that the flow at San Marcos Springs would almost always be above its critical period management trigger when flow at Comal Springs was at its triggers. Note that San Marcos Springs does not have Stage III or Stage IV triggers (cfs = cubic feet per second; data shown for the period 1980 through 2007).

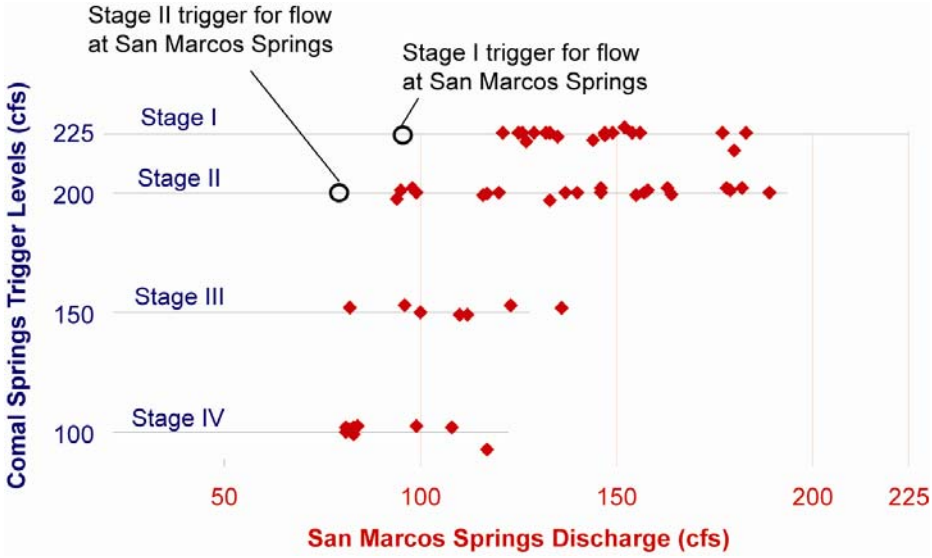


Figure 19: Flow at San Marcos Springs whenever flow at Comal Springs was increasing and crossing its critical period management trigger. This figure shows that the flow at San Marcos Springs would always be above its critical period management trigger when flow at Comal Springs was at its triggers. Note that San Marcos Springs does not have Stage III or Stage IV triggers (cfs = cubic feet per second; data shown for the period 1980 through 2007).

Task 3.2: ***Investigate spring flow volume measurement methodologies currently in use and evaluate their accuracy. If any are deemed to be inadequate, suggest alternative measuring methods.***

This task is the same as **Task 2.4**. Please see our response to **Task 2.4**.

Comal Springs in 2005 (photo by Mary Musick)

Acknowledgments

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The old power plant near Comal Springs (photo by Carol Patterson)

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Appendix A: The formation and operation of the Edwards Aquifer Area Expert Science Subcommittee

The Texas Legislature required the Steering Committee for the Edwards Aquifer Recovery Implementation Program to establish an Edwards Aquifer Area Expert Science Subcommittee of individuals "with technical expertise regarding the Edwards Aquifer system, the threatened and endangered species that inhabit that system, springflows, or the development of withdrawal limitations." The legislature required the subcommittee to prepare "initial recommendations by December 31, 2008", regarding:

- The option of designating a separate San Marcos pool, of how such a designation would affect existing pools, and of the need for an additional well to measure the San Marcos pool if designated
- The necessity to maintain minimum springflows, including a specific review of the necessity to maintain a flow to protect federally threatened and endangered species; and
- Whether adjustments in the trigger levels for the San Marcos Springs flow for the San Antonio pool should be made.

The Steering Committee refers to these recommendations as the "k" charges. In making their recommendations, the Science Subcommittee was tasked to "consider all reasonably available science" and "base its recommendations solely on the best science available." In addition, the legislature tasked the subcommittee to "operate on a consensus basis to the maximum extent possible."

The Steering Committee appointed 15 scientists to serve on the Expert Science Subcommittee and one non-voting member. A list of the members and their affiliations is included at the beginning of this report (page iii).

Members were seated using a formal nomination and selection process:

- The Steering Committee established an Expert Science Subcommittee nominations workgroup to handle the application process.
- The workgroup accepted nominations from members of the Edwards Aquifer Recovery Implementation Program (an individual could also nominate themselves).
- Nominated individuals were asked to complete and submit an application summarizing their applicable areas of expertise and any possible conflicts of interest.
- The workgroup reviewed and compiled all applications by area of expertise.
- The compiled applications information was made available to all members of the Edwards Aquifer Recovery Implementation Program.
- Members of the Edwards Aquifer Recovery Implementation Program were invited to endorse nominees without limitation on the number of endorsements.
- The workgroup presented the endorsement results to the Steering Committee.
- At the January 2008 general Edwards Aquifer Recovery Implementation Program meeting, the Steering Committee held open discussions regarding the selection of

the Expert Science Subcommittee members. Consensus was reached to seat seven members, and these seven members were tasked to make recommendations to the Steering Committee regarding filling the remaining eight vacancies from the original pool of nominees/applicants.

- The newly-formed Expert Science Subcommittee met in late January 2008 and reached consensus regarding recommendations to fill the remaining eight vacancies.
- At the February 2008 general Edwards Aquifer Recovery Implementation Program meeting, the Steering Committee reached consensus on the eight nominees recommended by the Expert Science Subcommittee. At this same meeting, the Steering Committee reached consensus on the addition of one non-voting member to the subcommittee.
- Subsequent filling of available Expert Science Subcommittee slots (due to resignations) was accomplished by the Expert Science Subcommittee reaching consensus on a nominee/applicant from the original pool and making a recommendation to the Steering Committee. In each case, the subcommittee's recommendation was accepted by the Steering Committee.

Additional information about the establishment and the work of the Science Subcommittee can be found at http://earip.tamu.edu/SciComm.cfm.

Appendix B: Excerpts from the Edwards Aquifer Authority Act, as amended by Senate Bill 3, Regular Session, 80th Legislature, that concern the Edwards Aquifer Area Expert Science Subcommittee

Section 1.14 WITHDRAWALS

(a) Authorizations to withdraw water from the aquifer and all authorizations and rights to make a withdrawal under this Act shall be limited in accordance with this section to:

(1) protect the water quality of the aquifer;

(2) protect the water quality of the surface streams to which the aquifer provides springflow;

(3) achieve water conservation;

(4) maximize the beneficial use of water available for withdrawal from the aquifer;

(5) recognize the extent of the hydro-geologic connection and interaction between surface water and groundwater;

(6) protect aquatic and wildlife habitat;

(7) protect species that are designated as threatened or endangered under applicable federal or state law; and

(8) provide for instream uses, bays, and estuaries.

(b) *Repealed by Act of May 28, 2007, 80th Leg., R.S., ch. 1351, § 2.09, 2007 Tex. Gen. Laws 4612, 4634; Act of May 28, 2007, 80th Leg., R.S., ch. 1430, § 12.09, 2007 Tex. Gen. Laws 5848, 5908.*

(c) Except as provided by Subsections (f) and (h) of this section and Section 1.26 of this article, for the period beginning January 1, 2008, the amount of permitted withdrawals from the aquifer may not exceed or be less than 572,000 acre-feet of water for each calendar year, which is the sum of all regular permits issued or for which an application was filed and issuance was pending action by the authority as of January 1, 2005.

(d) *Repealed by Act of May 28, 2007, 80th Leg., R.S., ch. 1351, § 2.09, 2007 Tex. Gen. Laws 4612, 4634; Act of May 28, 2007, 80th Leg., R.S., ch. 1430, § 12.09, 2007 Tex. Gen. Laws 5848, 5908.*

(e) The authority may not allow withdrawals from the aquifer through wells drilled after June 1, 1993, except for replacement, test, or exempt wells or to the extent that the authority approves an amendment to an initial regular permit to authorize a change in the point of withdrawal under that permit.

(f) If the level of the aquifer is equal to or greater than 660 feet above mean sea level as measured at Well J-17, the authority may authorize withdrawal from the San Antonio pool, on an uninterruptible basis, of permitted amounts. If the level of the aquifer is equal to or greater than 845 feet at Well J-27, the authority may authorize withdrawal from the Uvalde pool, on an uninterruptible basis, of permitted amounts.

(h) To accomplish the purposes of this article, the authority, through a program, shall implement and enforce water management practices, procedures, and methods to ensure that, not later than December 31, 2012, the continuous minimum springflows of the Comal Springs and the San Marcos Springs are maintained to protect endangered and threatened species to the extent required by federal law and to achieve other purposes provided by Subsection (a) of this section and Section 1.26 of this article. The authority from time to time as appropriate may revise the practices, procedures, and methods. To meet this requirement, the authority shall require:

(1) phased adjustments to the amount of water that may be used or withdrawn by existing users or categories of other users, including adjustments in accordance with the authority's critical period management plan established under Section 1.26 of this article; or

(2) implementation of alternative management practices, procedures, and methods.

Act of May 30, 1993, 73rd Leg., R.S., ch. 626, § 1.14, 1993 Tex. Gen. Laws 2350, 2360; as amended by Act of May 28, 2007, 80th Leg., R.S., ch. 1351, § 2.02, 2007 Tex. Gen. Laws 4612, 4627; Act of May 28, 2007, 80th Leg., R.S., ch. 1430, § 12.02, 2007 Tex. Gen. Laws 5848, 5901.

Section 1.26A DEVELOPMENT OF WITHDRAWAL REDUCTION LEVELS AND STAGES FOR CRITICAL PERIOD MANAGEMENT THROUGH RECOVERY IMPLEMENTATION PROGRAM.

(h) Where reasonably practicable or as required by law, any meeting of the steering committee, the Edwards Aquifer area expert science subcommittee, or another subcommittee established by the steering committee must be open to the public.

(i) The steering committee appointed under this section shall appoint an Edwards Aquifer area expert science subcommittee not later than December 31, 2007. The expert science subcommittee must be composed of an odd number of not fewer than seven or more than 15 members who have technical expertise regarding the Edwards Aquifer system, the threatened and endangered species that inhabit that system, springflows, or the development of withdrawal limitations. The Bureau of Economic Geology of The University of Texas at Austin and the River Systems Institute at Texas State University shall assist the expert science subcommittee. Chapter 2110, Government Code, does not apply to the size, composition, or duration of the expert science subcommittee.

(j) The Edwards Aquifer area expert science subcommittee shall, among other things, analyze species requirements in relation to spring discharge rates and aquifer levels as a function of recharge and withdrawal levels. Based on that analysis and the elements required to be considered by the authority under Section 1.14 of this article, the expert science subcommittee shall, through a collaborative process designed to achieve consensus, develop recommendations for withdrawal reduction levels and stages for critical period management including, if appropriate, establishing separate and possibly different withdrawal reduction levels and stages for critical period management for different pools of the aquifer needed to maintain target spring discharge and aquifer levels. The expert science subcommittee shall submit its recommendations to the steering committee and all other stakeholders involved in the recovery implementation program under this section.

(k) The initial recommendations of the Edwards Aquifer area expert science subcommittee must be completed and submitted to the steering committee and other stakeholders not later than December 31, 2008, and should include an evaluation:

(1) of the option of designating a separate San Marcos pool, of how such a designation would affect existing pools, and of the need for an additional well to measure the San Marcos pool, if designated;

(2) of the necessity to maintain minimum springflows, including a specific review of the necessity to maintain a flow to protect the federally threatened and endangered species; and

(3) as to whether adjustments in the trigger levels for the San Marcos Springs flow for the San Antonio pool should be made.

(l) In developing its recommendations, the Edwards Aquifer area expert science subcommittee shall:

(1) consider all reasonably available science, including any Edwards Aquifer-specific studies, and base its recommendations solely on the best science available; and

(2) operate on a consensus basis to the maximum extent possible.

(m) After development of the cooperative agreement, the steering committee, with the assistance of the Edwards Aquifer area expert science subcommittee and with input from the other recovery implementation program stakeholders, shall prepare and submit recommendations to the authority. The recommendations must:

(1) include a review of the critical period management plan, to occur at least once every five years;

(2) include specific monitoring, studies, and activities that take into account changed conditions and information that more accurately reflects the importance of critical period management; and

(3) establish a schedule for continuing the validation or refinement of the critical period management plan adopted by the authority and the strategies to achieve the program and cooperative agreement described by this section.

Act of May 28, 2007, 80th Leg., R.S., ch. 1351, § 2.06, 2007 Tex. Gen. Laws 4612, 4630; Act of May 28, 2007, 80th Leg., R.S., ch. 1430, § 12.06, 2007 Tex. Gen. Laws 5848, 5904.

Appendix C: Initial charges from the Steering Committee to the Edwards Aquifer Area Expert Science Subcommittee

INITIAL CHARGE OF THE STEERING COMMITTEE
TO THE SCIENCE SUBCOMMITTEE
February 21, 2008

The Steering Committee of the Edwards Aquifer Recovery Implementation Program ("EARIP") requests the expert science subcommittee ("Science Subcommittee"), through an open and collaborative process designed to achieve consensus, to, among other things, analyze species requirements in relation to spring discharge rates and aquifer levels, as a function of recharge and withdrawal levels. The Steering Committee further requests the Science Subcommittee to review existing legislative critical period management triggers and levels for their scientific merit and develop recommendations for withdrawal reduction levels and stages for critical period management including, if appropriate, establishing separate and possibly different withdrawal reduction levels and stages for critical period management for different pools of the aquifer needed to maintain target spring discharge and aquifer levels. Any significant direct work on these recommendations should await the development of the specific decision evaluation framework regarding endangered species from the U.S. Fish and Wildlife Service and the development of specific charges by the EARIP.

To begin fulfilling the request described above, the initial task of the Science Subcommittee will be to complete an evaluation of the following three items:

(1) The option of designating a separate San Marcos pool, how such a designation would affect existing pools, and of the need for an additional well(s) to measure the San Marcos pool, if designated;

(2) The necessity to maintain minimum springflows, including a specific review of the necessity to maintain a flow to protect the federally threatened and endangered species; and

(3) Whether adjustments in the trigger levels for the San Marcos Springs flow for the San Antonio pool should be made.

In conducting this evaluation, the EARIP expects the Science Subcommittee members to evaluate all reasonably available science and make its recommendations based solely on the best science available as determined by the Science Subcommittee. Because many of the members of the subcommittee have a history of involvement in the study and analysis of aquifer issues, we expect and require that they evaluate the reasonably available science with an unbiased perspective and considering the full range of options and issues.

The Steering Committee encourages the Science Subcommittee to identify any issues that are policy issues and to seek input from the Steering Committee on those policy issues as well as any questions the Science Subcommittee may have regarding this charge.

With respect to the three items listed above, we specifically ask the Science Subcommittee to develop the following information and provide answers to the following specific questions to assist the EARIP in evaluating their recommendations.

Item 1: The option of designating a separate San Marcos pool, of how such a designation would affect existing pools, and of the need for an additional well(s) to measure the San Marcos pool (if designated).

1.1 Identify the data and modeling that exist regarding whether a separate San Marcos pool should be designated? Are the data sufficient to support the designation of a separate San Marcos pool?
1.2 Provide your evaluation of the hydrogeological evidence and identify the data gaps.
1.3 If there are data to support the designation of such a pool, what should be the extent and boundaries of such pool?
1.4 To what extent is this pool hydrologically independent?
1.5 Is there a need for an additional well or additional wells to measure the San Marcos pool, if one were designated. If so, what is the most effective location for such well(s)?
1.6 Your evaluation of this issue should include consideration of information provided by RIP members.

Item 2: The necessity to maintain minimum springflows, including a specific review of the necessity to maintain a flow to protect the federally threatened and endangered species

2.1. Is a minimum springflow required for the survival and recovery of each species listed under the Endangered Species Act identified in Section 3.2 of the EA RIP Memorandum of Agreement?
2.2. If alternatives exist to minimum flows that may not reduce appreciably the likelihood of the survival and recovery in the wild by reducing the reproduction, numbers, or distribution of each species listed under the Endangered Species Act identified in Section 3.2 of the EA RIP Memorandum of Agreement, identify and provide a preliminary evaluation of those alternatives to protect those federally-listed species.
    2.2.1 Your consideration of alternatives, should include an evaluation of information provided by RIP members on this issue.
    2.2.2 Your consideration of alternatives also should be mindful of impacts on protected species other than those species listed under the Endangered Species Act identified in Section 3.2 of the EA RIP Memorandum of Agreement.
2.3. Identify existing studies regarding the ability of each alternative other than maintaining minimum springflows to protect federally threatened or endangered species. Identify additional studies or data needed to fully evaluate each of these alternatives, including an estimate of the time and cost to conduct such studies, and any different alternatives that might be explored in the future.
2.4. Investigate springflow volume measurement methodologies currently in use and evaluate their accuracy. If any are deemed to be inadequate, suggest alternative measuring methods.

Item 3: Whether adjustments in the trigger levels for the San Marcos Springs flow for the San Antonio pool should be made

3.1. Should the trigger levels for the San Antonio pool based on San Marcos springflow be adjusted? Identify the existing data available to develop recommendations regarding such adjustments and what additional information will be necessary to make such recommendations.
3.2. Investigate springflow volume measurement methodologies currently in use and evaluate their accuracy. If any are deemed to be inadequate, suggest alternative measuring methods.

S.B. 3 requires the Science Subcommittee to employ "a collaborative process designed to achieve consensus" and to "operate on a consensus basis to the maximum extent possible." Further, the meetings of the Science Subcommittee must be open to the public. In carrying out this charge, the Science Subcommittee is encouraged to invite outside scientists to participate in discussions, give presentations, or participate in any subgroups established by the Science Subcommittee.

The Science Subcommittee shall submit, in the form of a written initial report, its answers to these questions and a discussion of the basis for its answers and other relevant information to the steering committee and all other stakeholders involved in the EARIP no later than December 31, 2008. The Science Subcommittee shall present a brief report of its progress and its plans for future activities at each joint RIP and Steering Committee monthly meeting.

These charges may be modified by the Steering Committee during the course of the Science Subcommittee's discussions.

Appendix D: Memorandum of Agreement for the Edwards Aquifer Recovery Implementation Program

MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM

This Memorandum of Agreement ("MOA") is intended to serve as the Memorandum of Agreement for the Edwards Aquifer Recovery Implementation Program (the "Program") under the Endangered Species Act and as the Memorandum of Agreement required by Senate Bill 3. It is made and agreed to by the Parties signing below and is effective on the Effective Date. The Parties will work together in good faith and cooperation to achieve the purposes and goals provided in the following provisions of this MOA.

Article 1. Purposes

Section 1.1. The purpose of this MOA is to formally initiate the development and implementation of the Edwards Aquifer Recovery Implementation Program. The Program is a collaborative initiative among stakeholders to participate in efforts to contribute to the recovery of the Edwards Species, develop aquifer management measures, and develop conservation measures for the Edwards Aquifer.

Section 1.2. During the 80th Regular Session, the Texas Legislature enacted Senate Bill 3, establishing, among other things, minimum requirements applicable to the Program. It is the intent of the Parties to comply with those minimum requirements and to build upon them to ensure that the Program is as effective and as inclusive as is reasonably possible, while also maintaining compliance with applicable provisions of the Endangered Species Act.

Section 1.3. The Parties acknowledge that Program efforts will be mindful of minimizing impacts on other protected species when advancing Program initiatives. The Parties also acknowledge the necessity of finding ways to balance the Program's contribution to recovery of Edwards Species with human water needs, while maintaining compliance with applicable provisions of the Endangered Species Act.

Article 2. Goals

Section 2.1. The goals of the Program, which are intended to be broadly interpreted, include, but are not limited to, the following:

(a) review, develop, and implement sound scientific research, analysis and other measures which contribute to understanding and meeting the needs of the Edwards Species;
(b) review, develop, and implement strategies which balance the needs of the Edwards Species with overall water use and supply in the Edwards Aquifer region;
(c) develop and complete an implementing agreement by December 31, 2009;
(d) develop and complete a program document by September 1, 2012, that shall take effect December 31, 2012, and may be in the form of a habitat conservation plan for the Edwards Species;
(e) implement the program document; and

(f) secure federal, state, and other available funding to assist with the development and implementation of the Program.

Section 2.2. The Parties to this MOA will participate in good faith in a cooperative, consensus-based process consistent with the purposes of the Program, and the requirements and deadlines imposed by Senate Bill 3. The Parties acknowledge that reasonable flexibility to adapt Program activities, particularly in response to new information and changed circumstances, is necessary to effectively meet the purposes of the Program.

Article 3. Definitions and Construction.

Section 3.1. Definitions. In this MOA, the following terms shall have the meanings assigned in this section unless the context clearly specifies a different meaning:

"Edwards Aquifer" means the same as the definition for "Aquifer" used in The Edwards Aquifer Authority Act.

"Edwards Species" means aquatic species that (1) are listed as threatened or endangered pursuant to the Endangered Species Act, and (2) are found in the Edwards Aquifer or found in or around the springs associated with the Edwards Aquifer. The Edwards Species, as of the Effective Date, are as follows: fountain darter, San Marcos gambusia, San Marcos salamander, Texas blind salamander, Comal Springs riffle beetle, Comal Springs dryopid beetle, Peck's cave amphipod, and Texas wild rice. This definition may be expanded by decision of the Steering Committee, without amending the MOA, to include additional species that are proposed for listing as threatened or endangered and that otherwise meet the definition of Edwards Species.

"Effective Date" means the date this MOA is effective, which shall be that date on which the MOA has been executed by duly authorized representatives of (1) the Edwards Aquifer Authority, United States Fish and Wildlife Service, Texas Commission on Environmental Quality, Texas Parks and Wildlife Department, Texas Department of Agriculture, Texas Water Development Board and (2) of other interests designated in Senate Bill 3 as initial members of the Steering Committee such that, collectively, at least 75% of the initial members of the Steering Committee have signed the document.

"Endangered Species Act" means the federal Endangered Species Act of 1973, as amended, 16 U.S.C. §§ 1531, et seq.

"Habitat Conservation Plan" means a conservation plan as referred to in Section 10 (a)(2), 16 U.S.C. § 1539 (a)(2), of the Endangered Species Act.

"Recovery" means the process by which the decline of an endangered or threatened species is arrested or reversed, and threats removed or reduced so that the species' long term survival in the wild can be ensured.

"Senate Bill 3" means Article 12 of Senate Bill 3, 80th Regular Session, 2007, of the Texas Legislature and Article 2 of House Bill 3, 80th Regular Session, 2007, of the Texas Legislature.

The Articles amend the Edwards Aquifer Authority Act ("Act"), Chapter 626, Acts of the 73rd Legislature, Regular Session, 1993, Section 1.26(A) of the Act provides for the development of a recovery implementation program. Identical provisions are included in Article 2 of House Bill 3, 80th Regular Session of the Texas Legislature.

Section 3.2. Construction. The Parties intend this MOA to be construed to comply with Senate Bill 3 establishing, among other things, minimum requirements applicable to the Program and with applicable requirements of the Endangered Species Act.

Article 4. Participation

Section 4.1. The Parties pledge to participate in good faith in an open, voluntary, and cooperative process that will strive to reach consensus on issues that further the purposes and goals of the Program. To achieve these purposes and goals, the Program will be overseen by a Steering Committee designed to ensure opportunities for participation and adequate representation of stakeholders. The Steering Committee will adopt procedures consistent with the MOA to ensure the Program includes, but is not limited to, the following procedural elements: an open process, advance public notice of meetings and proposed actions, opportunity for stakeholder participation, open communication, and consensus-based decision-making.

Section 4.2. Senate Bill 3 established the composition of an initial Steering Committee. Senate Bill 3 also allows, upon execution of this MOA, the initial Steering Committee to vote to add Members and to change the composition of the Steering Committee. In order to ensure adequate stakeholder representation on the Steering Committee, the signatories of this MOA recommend that the Steering Committee, at its earliest opportunity, add to the Steering Committee five other persons in the following categories:

(a) A representative of a holder of an Edwards Aquifer Authority initial regular permit issued to a small municipality (population under 50,000) located east of San Antonio,
(b) A representative of Edwards Aquifer region municipal ratepayers/general public,
(c) A representative of Guadalupe River Basin municipal ratepayers/general public,
(d) A representative of a conservation organization, and
(e) A representative of the Nueces River Authority.

Section 4.3. The Steering Committee will adopt procedures for the designation of primary, alternate, and replacement members of the Steering Committee. When changing or adding members, including members in addition to those listed in Section 4.2, the Steering Committee shall seek to maintain the balance of interests represented in the initial Steering Committee as set out in Senate Bill 3.

Section 4.4. In accordance with Senate Bill 3, the Steering Committee shall appoint an Edwards Aquifer area expert science subcommittee no later than December 31, 2007. As soon as reasonably possible, the Steering Committee shall establish a recharge facility feasibility subcommittee; other subcommittees shall be established as the Steering Committee determines appropriate. The Steering Committee shall ensure procedural elements are adopted to ensure an open process, advance public notice of meetings and proposed actions, opportunity for

stakeholder participation, open communication, and consensus-based decision-making are followed in subcommittees.

Article 5. Governance

Section 5.1. In addition to the responsibilities expressed in Senate Bill 3, the Steering Committee will adopt procedures to: address employment of a Program Manager and determine the Program Manager's role in the Program; establish appropriate Program subcommittee processes, to include membership, responsibilities, and decision-making recommendations; obtain funding for the Program ; adopt or amend Program Operational Rules; and other matters for which the Steering Committee determines procedures are necessary.

Section 5.2. The goal of the Steering Committee is to achieve consensus-based decision-making. Consensus is reached when no Member of the Steering Committee is opposed to a proposal. It is understood and accepted that in order to achieve a consensus on the Steering Committee, each Member will be open to pursuing "win-win" alternatives and to considering variations on the proposal that he or she might initially prefer. In its deliberations, the Steering Committee shall seek to exhaust every reasonable and practicable effort to reach consensus.

Section 5.3. In furtherance of consensus-based decision-making, when a proposal to the Steering Committee involving a Tier 1 decision (as set out in Section 5.5) does not achieve consensus, the Steering Committee will adopt a process which requires further deliberation and development of the proposal by an Issue Team. The Issue Team will be a smaller team of stakeholders as appointed by the Steering Committee and will include, to the extent practicable, participants representing all different viewpoints on the proposal, which may include participants who are not members of the Steering Committee. The Issue Team process will provide an opportunity for input from other stakeholders. The goal of the Issue Team is to achieve consensus on the proposal, or to develop a restatement of the proposal that may better achieve consensus of the Steering Committee. If after resubmission to the Steering Committee, or restatement of the proposal and resubmission to the Steering Committee, consensus has not been achieved, the Steering Committee will then vote on the proposal. A resubmitted or restated proposal will be deemed to have been approved by the Steering Committee when at least 75 percent of the entire Steering Committee has voted in favor of the proposal in accordance with voting procedures to be adopted by the Steering Committee.

Section 5.4. The Steering Committee will adopt procedures for appointment of Issue Teams, time requirements for resubmission and restatement of proposals, flexibility to continue to pursue consensus, an allowance for a minority report to be included with Tier 1 decisions, and voting procedures. These procedures to be adopted by the Steering Committee will apply to all Tier 1 decisions.

Section 5.5. The following types of decisions are considered to be Tier 1 decisions:

(a) Hiring or terminating of Program Manager;
(b) Approval of annual budget;
(c) Formal Recommendations to the EAA;

(d) Recommendations or Reports to the Legislature;
(e) Membership, responsibilities, and procedures of subcommittees;
(f) Changes to the membership of the Steering Committee beyond initial changes set out in Section 4.2 above;
(g) Adoption and amendment of the decision process of the Steering Committee;
(h) Decisions related to adoption or amendment of any Program agreements including, but not limited to the Memorandum of Agreement, the Implementing Agreement, the Cooperative Agreement, and the Program Document;
(i) Adoption or amendment of Program Operational Rules; and
(j) Any significant action determined by the Steering Committee to require Tier 1 decision-making in accordance with procedures to be developed.

Section 5.6. The Steering Committee will adopt simplified procedures for all other decisions of the Steering Committee. For those decisions other than Tier 1 decisions, a decision will be deemed to have been approved by the Steering Committee when a majority of the entire Steering Committee has voted in favor of the proposal in accordance with voting procedures adopted by the Steering Committee. Non-Tier 1 decisions are not subject to the Issue Team process described in Section 5.3.

Article 6. General Provisions

Section 6.1. This MOA shall remain in effect until the earlier of September 1, 2012 or the execution of a program document in compliance with the requirements of Senate Bill 3 and the Endangered Species Act. However, any signatory retains the ability to withdraw from the Program at any time by providing written notice of withdrawal to the Steering Committee. This MOA, including the term of the MOA, may be amended by action of the Parties in accordance with Senate Bill 3 and the decision processes established by the Steering Committee.

Section 6.2. Nothing herein shall constitute, nor be deemed to constitute, an obligation of future appropriations by the signatories to this MOA where creating such an obligation would be inconsistent with applicable federal, state, or local laws. Funding commitments made under this MOA by the signatories are understood to be contingent on obtaining approval and appropriations by the applicable local, state, or federal regulatory or legislative bodies. This MOA does not create an exclusive arrangement between the United States Fish and Wildlife Service (Service) or the Department of the Interior and the Parties to this agreement or commit the Service or the Department of the Interior to enter into any contract or other binding obligation. By entering into this MOA, no Party is obligated to enter into any contract or other binding obligation. This MOA is subject to and is intended to be consistent with all applicable federal, state, and local laws.

Section 6.3. All signatories to this MOA recognize that various parties have statutory responsibilities that cannot be delegated. Nothing in this MOA shall be construed to abrogate any of the statutory responsibilities of any signatory of the MOA**,** including:

(1) responsibilities that relate to implementing specific strategies included in the Program Document;

(2) authority to decide whether to approve any document, or amendment thereto, specifically required to be entered into by the parties under Senate Bill 3; or

(3) the Service's statutory authority under the Endangered Species Act.

Section 6.4. This MOA is effective on the date fully signed as described in the Definition of Effective Date. The MOA may be signed by additional stakeholders, including other appropriate federal agencies, following the Effective Date of the MOA.

Appendix E. Presentations made to the Edwards Aquifer Area Expert Science Subcommittee

Dr. Geary Schindel (Chief Technical Officer, Edwards Aquifer Authority)

TOPIC: EAA San Marcos Report (Evaluation of the option to designate a separate San Marcos pool for critical period management)

Dr. Todd Votteler (Executive Director - Guadalupe-Blanco River Trust/Executive Manager of Intergovernmental Relations and Policy)

TOPIC: Analysis of how Index Well J-17 predicts springflow

Doyle Mosier (Inland Fisheries, River Studies Program, Division Manager, Texas Parks and Wildlife Department)

TOPIC: Habitat and minimum springflows

Doyle Mosier (Inland Fisheries, River Studies Program, Division Manager, Texas Parks and Wildlife Department) and **Michael Gonzales** (Manager, San Antonio River Authority, Environmental Services Department)

TOPIC: Instream flows

Jackie Poole (Botanist, Texas Parks and Wildlife Department) & **Dr. Mara Alexander** (Botanist, U.S. Fish & Wildlife Service, San Marcos National Fish Hatchery and Technology Center)

TOPIC: Texas wild-rice and refugia operations

Dr. Tom Brandt (Director, San Marcos National Fish Hatchery and Technology Center, U.S. Fish & Wildlife Service)

TOPIC: Refugia

Larry Land (Engineer, HDR Engineering, Inc.)

TOPIC: Hydrologic connection of the Edwards Aquifer between San Marcos Springs and Barton Springs

TOPIC: Impact of pumping the LCRA well on flow from Comal Springs during the 1950s drought

TOPIC: Calculations and comparisons of Edwards Aquifer recharge in the eastern recharge basins.

Dr. Charles Kreitler (Vice President, LBG-Guyton Associates)

TOPIC: Augmentation report as related to the San Marcos Pool question

TOPIC: Cibolo Creek transfers

George Ozuna (Assistant Director, U.S. Geological Survey, Texas Water Science Center)

TOPIC: U.S. Geological Survey science activities in the Edwards Aquifer

TOPIC: U.S. Geological Survey Comal Springs flowpath study

Rick Lindgren: (Hydrologist, U.S. Geological Survey, Texas Water Science Center)

TOPIC: U.S. Geological Survey numerical groundwater flow models

Darwin Ockerman (Hydrologist, U.S. Geological Survey, Texas Water Science Center)

TOPIC: Streamflow and recharge simulations in the Cibolo Creek watershed using the hydrological simulation program—FORTRAN (HSPF) model

Eddie Collins (Research Associate, Bureau of Economic Geology, The University of Texas at Austin)

TOPIC: Structure of the aquifer and lithologic barriers

Dr. Chris Nice (Associate Professor, Department of Biology, Texas State University)

TOPIC: Edwards Aquifer species genetics and conservation

Appendix F. Position papers submitted by the Recovery Implementation Recovery stakeholders

The Edwards Aquifer Area Expert Science Subcommittee solicited position papers from any interested stakeholder involved with the Edwards Aquifer Recovery Implementation Program. Instructions were to identify, per task/charge, three references that the stakeholder felt the subcommittee needed to consider and a position paper limited to one page. The positions are given according to Senate Bill 3's k(1), k(2), and k(3) charges to the subcommittee (see **Appendix B**) which correspond to tasks 1, 2, and 3, respectively, in this document. Except for formatting, we have not edited these submissions. This appendix includes these submissions, listed in alphabetical (citation style) order.

Guadalupe-Blanco River Authority
k(1) Position

Submitted by: Todd Votteler, Ph.D., Guadalupe-Blanco River Authority
Date: June 9, 2008

Supporting references/documentation:

1. Votteler, Todd H., *Water from a Stone: The Limits of the Sustainable Development of the Texas Edwards Aquifer*. Doctoral Dissertation, Southwest Texas State University, Chair Prof. Joe G. Moore, Jr., March 15, 2000, pp 468.
2. Mace, Robert, Andrew Donnelly, Shirley Wade, *GAM Run 06-33a*, Texas Water Development Board, February 12, 2007.
3. Milly, Betancourt, Hirsch, et al., "Stationarity Is Dead: Whither Water management?" *Science*, 319(2008): 573-574.

Position:

Based on current available information, there is no compelling reason for designating a separate San Marcos pool within the San Antonio segment of the Edwards Aquifer. Hydrologically, it appears correct that springflows from one or more of the spring openings at San Marcos Springs are driven by something other than, or in addition to, levels of the Aquifer as measured by groundwater index well J-17, but this does not mean that the flow system for San Marcos Springs is "separate" or "independent" from J-17 levels or the flow system for Comal Springs. To the contrary, it is clear that withdrawals of water from anywhere in the San Antonio segment of the Edwards Aquifer cause reductions in springflows at both San Marcos and Comal Springs, and that San Marcos springflows can be generally predicted, to some level of accuracy, based on J-17 levels. It may be that some additional source of water is driving, at least in part, flows from one or more of the spring openings at San Marcos Springs, and it may also be that this source extends beyond the boundaries of the San Antonio segment of the Edwards Aquifer. A serious effort should be made to determine whether there is such an additional source of water and, if so, to attempt to better predict San Marcos springflows based on both J-17 levels and the levels of water in the additional source.

In any case, it is also clear that current critical period withdrawal reduction measures are grossly insufficient to prevent Comal Springs from ceasing to flow, or to prevent San Marcos Springs from ceasing to flow or dropping to a trickle, during a repeat of the drought or record. This gross deficiency should be corrected first, before considering designation of any additional pools or other fine tuning. The drought of record has always been the MINIMUM standard to apply to determine the adequacy of water planning in Texas and other Western States, and it continues to be the minimum standard, especially in light of recent global warming concerns.

Guadalupe-Blanco River Authority
k(2) Position

Submitted by: Todd Votteler, Ph.D., Guadalupe-Blanco River Authority
Date: June 9, 2008

Supporting references/documentation:

1. Brandt, Thomas, *Refugia*, presentation to Edwards Aquifer Recovery Implementation Program Science Subcommittee, Texas River Systems Institute, May 19, 2008.
2. U.S. Fish and Wildlife Service, San Marcos/Comal Recovery Team, *San Marcos and Comal Springs and Associated Aquatic Ecosystems (Revised) Recovery Plan*. 121. Austin, Texas: U.S. Fish and Wildlife Service, 1996.
3. Shockey, Charles R. *Notice of Filing of Springflow Determinations Regarding 'Take' of Endangered and Threatened Species, in* Sierra Club et al. v. Babbitt et al*.* Washington, D.C.: U.S. Department of Justice 1993; and Shockey, Charles R. *Notice of Filing of Springflow Determinations Regarding Survival and Recovery and Critical Habitat of Endangered and Threatened Species, in* Sierra Club et al. v. Babbitt et al*.* Washington, D.C.: U.S. Department of Justice, 1993.

Position:

The implication of this charge is that a zero natural springflow system could be considered. Given that natural springflows ARE the natural habitat of the species at and downstream of the springs, zero natural springflows would preclude recovery, so it is not clear how such a concept could be included in a recovery implementation plan. Zero natural springflows for any period of time unquestionably would "appreciably reduce the likelihood of the survival and recovery of the species in the wild," which of course is prohibited by the Endangered Species Act. See, e.g., Section 10(a)(2)(B)(iv) of the Act; USFWS publication entitled "Endangered Species Recovery Program" (April, 2008); etc. If this issue is being raised in an effort to promote some form of springflow augmentation, then the response is simple: keeping species alive by artificial flows is ***not*** "recovery of the species in the wild" – at best, such an artificial system would be nothing more than an outdoor aquarium, subject to all the known and unknown risks of upsets, malfunctions and unintended consequences as any other aquarium. In addition, if the Aquifer is allowed to be drawn down to and below the point where natural springflows cease, there is the potential for contamination of the fresh water in the Aquifer because of intrusion of adjacent bad-quality water, and the discharge of contaminated water through the spring openings after the Aquifer rises again, thereby threatening the continued existence of species that live underground in the Aquifer as well as any residual populations of other species that might have somehow survived the zero natural springflow event. Failure to maintain minimum natural, high-quality springflows also would impact downstream river environmental flows, bay and estuary inflows, and downstream water rights, with direct adverse effects and indirect effects such as shifting

the burden to downstream parties to maintain adequate amounts and quality of flows or to suffer environmental and economic consequences.

Guadalupe-Blanco River Authority
k(3) Position

Submitted by: Todd Votteler, Ph.D., Guadalupe-Blanco River Authority
Date: June 9, 2008

Top Three Supporting References/Documentation:

1. Milly, Betancourt, Hirsch, et al., "Stationarity Is Dead: Whither Water management?" *Science*, 319(2008): 573-574.

Position:

Trigger levels for the San Antonio pool, as well as for the Uvalde pool, definitely should be changed based on springflows from both Comal Springs and San Marcos Springs. As noted in position statement k(1), current critical period withdrawal reduction measures are grossly insufficient to prevent Comal Springs from ceasing to flow, or to prevent San Marcos Springs from ceasing to flow or dropping to a trickle, during a repeat of the drought of record. This gross deficiency must be corrected. The drought of record has always been the MINIMUM standard to apply to determine the adequacy of water planning in Texas and other Western States, and it continues to be the minimum standard, especially in light of recent global warming concerns.

The only alterations that should be considered at this time are substantially higher trigger levels, and substantially greater decreases in aquifer pumping across the Edwards Aquifer region at every trigger level, in the absence of alternative water supplies to the nearly sole reliance on the Edwards Aquifer by Uvalde, Medina and Bexar Counties.

Kirk Patterson

k(1) Position

Submitted by: Kirk Patterson
Date: May 9, 2008

Supporting references/documentation:

1. MODFLOW model prepared by USGS for the EAA;
2. MODFLOW model prepared by USGS using "diffuse" high transmissivity areas
3. Kreitler's studies for the EAA, including the recent "Cibolo Transfer" study

Position:

Using the MODFLOW model, modeling needs to be done to show what geographic area (represented by cells in the MODFLOW model) would send a significant portion, such as over 70%, of the water saved by "not pumping" under critical period reduction rules to San Marcos Springs (instead of to aquifer storage or other springs). This geographic area could be the proposed "San Marcos pool" area in which special critical period reduction rules apply. Since this modeling has not yet been done, it is recommended that this modeling be done before the option of "designating a separate San Marcos pool" in k(1) is evaluated.

Another essential piece of information needed is to identify, map and quantify the present pumping permits, *as well as the historic actual pumping*, from the Edwards Aquifer in Hays and Comal County. Once this permit and pumping information is supplied, then the effect of creating special "critical period reduction rules" in a proposed "San Marcos pool area" on the springflows at San Marcos Springs can be evaluated. Since this information has not yet been provided, it is recommended that such information be provided by the EAA and other agencies.

Since the existing critical period rules found in S.B. 3 for the Edwards Aquifer provides a "baseline" for comparison, it is also recommended that a "baseline" run be prepared on the MODFLOW model to show what the effect of the *present* statutory critical period rules are on flows at San Marcos Springs during critical period times. Then, the springflows resulting from the "baseline" run based on existing critical period rules could be *compared* to the springflows resulting from various scenarios of critical period rules that might be proposed that would include a new "San Marcos Pool" with its own critical period pumping reduction rules.

Locating a possible new "index well" to measure the San Marcos pool needs to be done. The historic correlation between well levels in some proposed monitoring wells and the critical period flows at San Marcos Springs needs to be described. We also need to understand the issues presented when "spring flow" as presently measured at the gauging stations below San Marcos Springs are used as a "trigger" for critical period reductions.

If this information will not or cannot be developed by December 31, 2008, then some suggestion about how such information might be developed might be provided by the Science Committee, along with other recommendations as to what other items of

information the Science Committee believes that policy makers might need to know before a separate San Marcos Pool is designated.

Kirk Patterson
k(2) Position

Submitted by: Kirk Patterson
Date: May 9, 2008

Supporting references/documentation:

1. *Springflow Augmentation of Comal Springs and San Marcos Springs, Texas: Phase I – Feasibility Study*. Technical Report CRWR 247, Center for Research in Water Sources, College of Engineering, the University of Texas at Austin
2. *Evaluation of Augmentation Methodologies in Support of In-Situ Refugia at Comal and San Marcos Springs, Texas*. June 2004 – done for EAA by LBG-Guyton Associates in association with BIO-WEST, Inc., Espey Consultants and URS Corp.
3. Trans-Texas Water Program,West Central Study Area, Phase II, *Summary Report of Water Supply Alternatives.* (Including Option L-21). March 1998.

Position:

Part 2.2.1 of the charge provided by the Steering Committee calls for the Science Committee to provide a preliminary evaluation of "alternatives" provided by RIP members. Part 2.3 of the charge directs the Science Committee to "Identify existing studies regarding the ability of each alternative other than maintaining minimum springflows to protect federally threatened or endangered spedies. Identify additional studies or data needed to fully evaluate each of these alternatives, including an estimate of the time and cost to conduct such studies, and any different alternatives that might be explored in the future." With these charges in mind, the existing studies listed above with their multiple suggested "alternatives" are identified for your evaluation, and the following "additional studies and data and different alternatives that might be explored in the future," are proposed:

(1) Refugia at existing fish hatcheries, zoos and aquariums dedicated to maintaining the endangered species covered by the MOA, as well as improving the refugia that exist and creating new locations for refugia in the future.
(2) In-situ refugia as proposed by LBG-Guyton Associates/BIO-WEST and other refugia as proposed by Daene C. McKinney and John M. Sharp, Jr. in Technical Report CRWR 247, and other refugia created by bringing in Edwards waters and possible other waters to the spring/downstream locations from distant sources in the Edwards Aquifer and nearby surface water sources; and
(3) Recharge, both locally and regionally, that could provide water to San Marcos Springs and Comal Springs in time of severe drought and water supply, such as is being studied under the Scope of Work for Recharge & Recirculation Analyses for the EAA; and
(4) Springflow Augmentation *and* the multiple Recharge options identified in Trans-Texas Water Program, which can be analyzed both separately and in combinations.

If this information will not or cannot be developed by December 31, 2008, then some suggestion about how such information might be developed might be provided by the Science Committee, including an estimate of the time and cost to conduct such studies and any different alternatives that might be explored in the future.

Kirk Patterson

k(3) Position

Submitted by: Kirk Patterson
Date: May 9, 2008

Supporting references/documentation:

1. MODFLOW model prepared by USGS for the EAA;
2. MODFLOW model prepared by USGS using "diffuse" high transmissivity areas
3. Kreitler's studies for the EAA, including the recent "Cibolo Transfer" study

Position:

Since the existing critical period rules found in S.B. 3 for the Edwards Aquifer provides a "baseline" for comparison, it is also recommended that a "baseline" run be prepared on the MODFLOW model to show what the effect of the *present* statutory critical period rules are on flows at San Marcos Springs during critical period times. Then, the springflows resulting from the "baseline" run based on existing critical period rules could be *compared* to the springflows resulting from various scenarios of critical period rules that might be proposed that would include a modified "San Marcos Trigger" for the San Antonio Pool.

Information needed to inform the decisions called for under k(3) include determining the effect on the springs of designating a separate San Marcos Pool with its own critical period rules while adjusting the triggers based on San Marcos Springs flow for the remaining San Antonio Pool. By describing the effect of a separate San Marcos Pool on critical period flows at San Marcos and Comal Springs, both with and without changes in the "triggers" in the San Antonio Pool critical period rules, the effect of designating a separate San Marcos Pool, along with proposed adjustments in the critical period "triggers" in the remaining San Antonio Pool could be understood by policy makers.

As "adjustments in the "trigger levels" based on San Marcos Springs flow for the San Antonio pool are proposed, we need to understand what changes in "trigger levels" for the San Antonio Pool based on San Marcos Springs flow would do to critical time flows at both San Marcos Springs and Comal Springs.

Since the problem occurred in critical period stages I and II – a problem created by rising J-17 levels while San Marcos Springs flow was decreasing - analyzing adjustments to critical period stages I and II separately and apart from analyzing adjustments in critical period stages III and IV needs to be done. Remember that if the remaining San Antonio Pool is taken off the San Marcos Trigger for stages I and II, the Comal Springs and J-17 triggers will remain in effect.

If this information will not or cannot be developed by December 31, 2008, then some suggestion about how such information might be developed might be provided by the Science Committee, along with other recommendations as to what other items of information the Science Committee believes that policy makers might need to know before a separate San Marcos Pool is designated or adjustments are made in the triggers based on San Marcos Springs flow for the San Antonio Pool.

San Antonio River Authority

k(1) Position

Submitted by: Steve Raabe, San Antonio River Authority (SARA)
Date: June 9, 2008

k(1) of the option of designating a separate San Marcos pool, of how such a designation would affect existing pools, and the need for an additional well to measure the San Marcos pool if designates

Supporting references/documentation:

1. Johnson, Steven B. & Geary M. Schindel. 2008. Evaluation of the Option to Designate a Separate San Marcos Pool for Critical Period Management. Edwards Aquifer Authority. Report No. 08-01
2. Ockerman, Darwin J., 2007. Simulation of Streamflow and Estimation of Groundwater Recharge in the Upper Cibolo Creek Watershed, South-Central Texas, 1992-2004. United States Geological Survey. Scientific Investigations Report 2007-5202
3. Otero, Cassi, L. 2007. Geologic, Hydrologic, Geochemical Identification for Flow Paths in the Edwards Aquifer, Northeastern Bexar and Southern Comal Counties, Texas. United States Geological Survey. Scientific Investigations Report 2007-5285

Position:

An investigation by the USGS (Ockerman 2007) utilizing data from 1992 - 2004 indicates that 56% of the flow in the Upper Cibolo Creek is lost to groundwater recharge. The average groundwater recharge for the watershed was estimated to be 79,800 af/yr. 77% of the recharge occurred in the Trinity aquifer outcrop, 13% in the transition area and 6.4% in the Edwards outcrop.

An examination of flow paths by the USGS (Otero 2007) states that an increase in discharge at Hueco Springs in 2005 had no corresponding increase at Comal Springs, indicating that the pulse of water causing the increased discharge at Hueco Springs either was not sourced in the Central Comal Flow Path or did not reach Comal Springs. Otero also surmises that the lack of linear correlation between Hueco Springs and other Edwards aquifer sites could be the influence of inflow by the Trinity aquifer. Otero also indicates that during periods of low discharge, Hueco Springs might receive a larger contribution from the Trinity aquifer than periods of high discharge. An undetermined amount of water from the North Comal Flow Path might flow into the confined sections of the Central Comal Flow Path across Hueco Springs fault in areas where the fault does not completely offset the Edwards aquifer. The water remaining north of the Hueco Springs fault flows towards San Marcos Springs. Water that is not discharged at either Hueco or Comal Springs continues north-eastward toward the San Marcos Springs (Otero 2007).

The EAA (Johnson and Schindel 2008) investigated the hydrogeology and hydrodynamics of water discharging from San Marcos Springs to collect data that might provide justification for the development of distinct aquifer management rules and justification for the creation of a separate San Marcos pool. EAA findings indicate that most of the water discharging at Comal Springs originates from the Artesian fault block. During high water levels the Artesian fault block recharges the Comal fault block which provides water to both Comal and San Marcos Springs. When flows from Comal Springs are less than 100 cfs, a significant volume of water bypasses Comal Springs to discharge at San Marcos Springs. The findings also indicate that during low-flow conditions at San Marcos Springs, more than 90% of the water comes from the western (Trinity) portion of the aquifer. During normal and high flow conditions, water flows through the Artesian then Comal fault blocks, bypasses Comal Springs and discharges at San Marcos Springs. At higher discharge rates, supporting recharge occurs along Cibolo Creek, the Guadalupe River, Dry Comal Creek, Sink Creek and other streams. Because most of the flow at San Marcos Springs is derived from the western portion of the aquifer, during low-flow conditions, there is little technical justification at this time to create a separate San Marcos "Pool".

Based on the connection between water that recharges the Trinity Aquifer along the Upper Cibolo Creek, the Comal Flow Paths that move water in a northeasterly direction past the Hueco Springs and towards San Marcos Springs, SARA concludes that the San Marcos Springs is integrally connected to a complex dual aquifer system. Depending on the flow rate it seems that the San Marcos Springs are supported by both the Trinity and Edwards aquifers and is not a single aquifer system. The Edwards Aquifer Authority has recently initiated a second study to collect important information about whether or not the San Marcos Springs are supported by a separate underground reservoir. Until the second EAA study is complete and a separate pool is supported by additional technical information, SARA does not support the designation of a separate "San Marcos" Pool.

San Antonio River Authority

k(2) Position

Submitted by: Steve Raabe, San Antonio River Authority (SARA)
Date: June 9, 2008

k(2) of the necessity to maintain minimum spring flows, including a specific review of the necessity to maintain a flow to protect the federally threatened and endangered species

Supporting references/documentation:

1. LBG-Guyton and Associates. 2004. Evaluation of Augmentation Methodologies in Support of In-situ Refugia at Comal and San Marcos Springs. Prepared for the Edwards Aquifer Authority.
2. U.S. Fish and Wildlife Service. 1996. San Marcos and Comal Springs and Associated Aquatic Ecosystems (Revised) Recovery Plan. United States Fish and Wildlife Service, Austin, Texas.
3. U.S. Fish and Wildlife Service. 1984. San Marcos River Recovery Plan. U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

k(2) Position:

Securing the survival and recovery of the endangered species supported by the Comal and San Marcos Springs can only be achieved through the protection of their natural ecosystem with assured minimum spring flows. The ecosystems and sensitive biota are endangered by a number of threats to the required supply of thermally constant, clear, clean spring water. Threats include over drafting of groundwater from the Edwards aquifer, habitat modifications, and anthropogenic actions around the springs, rivers and watersheds. Additionally exotic and invasive species combined with habitat modifications may have synergistic effects that may extirpate endangered species. Some endangered species may be down listed to threatened when it is assured that spring flows with in natural cycles of variation can be assured. Off site Refugia can only provide limited short term protection for only 1 or 2 growing seasons. Even if an endangered species is able to survive in refugia, the natural habitat may have been reduced to the point that it will not be able to support all the life stages of the re-introduced endangered species. The cost of augmentation methodologies (LBG-Guyton 2004) to support in-situ refugia is excessive and is rising with inflation. Augmentation strategies do not seem to be able to increase the likelihood of endangered species survival into the future. It is unlikely that aquifer water users and rate payers will be willing to fund augmentation strategies.

Recovery goals (USFW 1996) to secure the survival of the endangered species in their native ecosystems; developing ecosystem approaches to address local, site specific and broad regional issues; and to conserve the integrity and function of the aquifer and spring

fed ecosystems, can realistically only be achieved by the maintenance of minimum spring flows.

SARA is supportive of the necessity to maintain minimum spring flows without jeopardizing human health and safety, and recommends a specific review of the necessity, and resulting impacts, of maintaining a flow to protect the federally threatened and endangered species.

San Antonio River Authority

k(3) Position

Submitted by: Steve Raabe, San Antonio River Authority (SARA)
Date: June 9, 2008

k(3) as to whether adjustments in the trigger levels for the San Marcos Springs flow for the San Antonio Pool should be made

Supporting references/documentation:

1. Johnson, Steven B. & Geary M. Schindel. 2008. Evaluation of the Option to Designate a Separate San Marcos Pool for Critical Period Management. Edwards Aquifer Authority. Report No. 08-01
2. Otero, Cassi, L. 2007. Geologic, Hydrologic, Geochemical Identification for Flow Paths in the Edwards Aquifer, Northeastern Bexar and Southern Comal Counties, Texas. United States Geological Survey. Scientific Investigations Report 2007-5285
3. Edwards Aquifer Authority. 2004. Draft Edwards Aquifer Habitat Conservation Plan and Draft Environmental Impact Statement. Edwards Aquifer Authority, San Antonio, Texas.

k(3) Position:

In 2006 the discharge at San Marcos Springs declined to less than 100 cfs, which required users of the Edwards Aquifer, in Medina, Bexar, Comal, Hays, Atascosa, Guadalupe, and Caldwell counties to reduce water use pursuant to Edwards Aquifer Authority rules. Although water levels at the Bexar County Index Well (J-17) and the discharge at Comal Springs in Comal County also declined in 2006, San Marcos Springs was more severely impacted by the dry conditions. When rainfall returned to normal or above normal conditions in early 2007, Comal Springs discharge increased, but San Marcos Springs remained below average and did not recover to average conditions until later in 2007 (Johnson and Schindel 2008).

Based on their findings, Johnson and Schindel recommend that:
"Hays and Comal Counties should continue to be included within the San Antonio Pool for critical period management. Critical Period rules for the San Antonio Pool should continue to be based on water levels in the Bexar County Index Well and flows at Comal and San Marcos Springs".

The 2006 implementation of a trigger level associated with San Marcos Spring flow successfully assisted with management of Edwards aquifer withdrawals and water uses. Even though the San Marcos Springs recovery did not correlate with the Bexar County Index Well and responded to rainfall slower than Comal Springs, the San Marcos Springs "trigger" provided a buffer in the water management strategies implemented at the time. The Edwards Aquifer Authority has recently initiated a second study to collect important information about whether or not the San Marcos Springs are supported by a separate

underground reservoir. Until the second EAA study is complete and a separate pool is supported by technical information, SARA does not support adjusting current management strategies.

San Antonio Water System
k(1) Position

Submitted by: Calvin Finch, San Antonio Water System
Date: June 9, 2008

Supporting references/documentation:

1. LBG-Guyton Associates, 2004, Evaluation of Augmentation Methodologies in Support of In-situ Refugia at Comal and San Marcos Springs, Texas: Report prepared for the Edwards Aquifer Authority.
2. Edwards Aquifer Authority, 2008, Evaluation of the Option to Designate a Separate San Marcos Pool for Critical period Management.
3. LBG-Guyton Associates, 1994, Edwards Aquifer Ground-Water Divides Assessment, San Antonio Region, TX. Report Prepared for Edwards Underground Water District, EUWD Report 95-01.

Position:

The scientific reports which have considered this issue clearly indicate that the San Marcos Pool (or some sort of separate local management designation) should be considered a separate system for Edwards Aquifer management purposes. The LBG-Guyton Report (2004) and the data in the EAA report (2008) provide evidence that there is poor correlation and limited hydrogeologic connectivity between the San Antonio pool and San Marcos Springs. The aforementioned reports also document a poor correlation between Comal Springs and San Marcos Springs. According to both reports, most significant sources of San Marcos springflows in normal or high flow conditions are from the Hueco Springs fault block, the unconfined Edwards block in the San Marcos area. This shows that the most profound affects on springflows at the San Marcos Springs are due to increased localized pumping and water usage in the springs area and are unaffected by pumping from the San Antonio pool. As recently shown in dry conditions in 2006, the San Marcos Springs continued to trigger Stage 1 reductions under EAA's critical period management scheme, when both the Comal Springs and J-17 indicators showed that the Aquifer had rebounded to normal levels due to increased rainfall. The rapid population growth in the I-35 corridor in Hays County has resulted in greater water usage in the area. Previous reports (LBG-Guyton Report of 1994) of water level data prior to this growth have also indicated a seasonal cone of depression in the Edwards Aquifer north of San Marcos each summer. This cone of depression may capture more groundwater that would otherwise have been destined for San Marcos springflow.

This body of evidence could be the basis for a separate pool (or local management area) for portions of Comal County north and east of Comal Springs, the City of San Marcos, and the remainder of Hays County north to the groundwater divide near Onion Creek. The existing documentation of the importance of local sources of San Marcos springflow above the range of 60cfs reinforces the necessity of local management strategies and regulations that realize the truly limited effects of regional pumping curtailments in terms of positive effects on San Marcos springflow.

The EAA report (2008) states that a Hays County index well should be established in the Comal Springs fault block near the City of San Marcos. A second Hays County index well should also be established in the Hueco Springs fault block near the San Marcos Springs area. These would gather data concerning flow contribution from the confined and unconfined Edwards in the San Marcos area which would be critical to monitoring springflow and triggering local management responses before management measures are initiated for the entire San Antonio Pool.

San Antonio Water System
k(2) Position

Submitted by: Calvin Finch, San Antonio Water System
Date: June 9, 2008

Supporting references/documentation:

1. BIO-WEST, 2007, Variable Flow Study: Seven Years of Monitoring and Applied Research. Report prepared for the Edwards Aquifer Authority.
2. LBG-Guyton Associates, 2004, Evaluation of Augmentation Methodologies in Support of In-situ Refugia at Comal and San Marcos Springs, Texas: Report prepared for the Edwards Aquifer Authority.
3. Horizon Environmental Services, Inc., for Crowell & Moring, LLP, 2004, An Analysis of the Take and Jeopardy Flows for the Fountain Darter Including Potential Flows required by the Endangered Invertebrates of Comal Springs.

Position:

As reports have shown, there is a paucity of data on the springflow needs of the Edwards Aquifer species. It is our position that continuous minimum springflows are not essential to the survival of the species, as the species have survived periods of extreme drought, and current aquifer management strategies have ensured more than adequate springflow for the species based on what have been recognized as extremely conservative "take" and "jeopardy" numbers for the Edwards Aquifer species. A science-based review of the data on springflow will likely result in a determination of no minimum springflow requirements for the species.

Work by BIO-WEST (2007) also demonstrates that the more frequent flood flow events have shown to be as detrimental, or more so, as low spring flows to the aquatic ecosystem. Development of management strategies should be considered to address response to flood events as well as low flows. Additionally, other factors affecting survival and health of the threatened and endangered species and their habitat, including recreational damage and non-native species, also must be evaluated. In addition to these threats, any need there may be to find alternative habitat for some species during periods of extremely low flow or cessation of flow, should consider the requirement for sound management of a captive refugia population. The implementation of such measures will benefit the species and lessen the perception that permitted Edwards Aquifer groundwater withdrawals and springflow are the only factors to consider when evaluating effects on the species.

Since aquifer management and regulation has hinged on water levels in specific Index wells and springflow, it is vital to accurately measure these "triggers" if they are going to continue to be used. Springflow is not currently well-measured, yet the water uses of the Edwards Aquifer region depend on the development of accurate springflow measurement methodologies.

The San Antonio Water System believes that the statutory task of the Science Subcommittee to determine the necessity to maintain minimum springflows cannot be pursued in a vacuum. The task includes a scientific responsibility to understand the implications of the "necessity," if any, of a minimum springflow requirement in the context of a program document to be used in issuance of an incidental take permit, while considering, among other things, maximizing the beneficial use of water available for withdrawal from the aquifer to meet the human needs of between one and two million people for whom the Edwards Aquifer will always be the cornerstone source of water.

San Antonio Water System
k(3) Position

Submitted by: Calvin Finch, San Antonio Water System
Date: June 9, 2008

Supporting references/documentation:

1. LBG-Guyton Associates, 2004, Evaluation of Augmentation Methodologies in Support of In-situ Refugia at Comal and San Marcos Springs, Texas: Report prepared for the Edwards Aquifer Authority.
2. Edwards Aquifer Authority, 2008, Evaluation of the Option to Designate a Separate San Marcos Pool for Critical period Management.
3. USGS Scientific Investigations Report 2007- 5285, by Cassi L. Otero, in cooperation with the San Antonio Water System.

Position:

The current trigger levels for San Marcos Springs require adjustment to ensure that those trigger levels accurately reflect the nonexistent or limited correlation with the San Antonio Pool. Currently, these trigger levels would require reduction in withdrawals from the San Antonio pool even when average levels at Comal Springs and J-17 Index Well would not require such a reduction. Therefore, in addition to adjustments to the current Critical Period Withdrawal Reduction Stages for the San Antonio Pool outlined in Senate Bill 3, it is recommended that water management strategies for the I-35 corridor north of New Braunfels should also be considered to address the separate and direct impact that activities in those areas have on the San Marcos Springs.

As indicated in the EAA report (2008), Hays and Comal counties should continue to be included within the San Antonio Pool for critical period management. The critical period rules for the San Antonio Pool should be based on water levels in the Bexar County Index Well and flows at Comal and San Marcos springs. However, the San Marcos Springs triggers for Stage 1 and Stage 2 should accurately reflect the limited correlation, if any, to Comal Springs and the J-17 Index Well. Data needs to be evaluated in higher flow regimes to adequately determine what the contribution is from the local unconfined portion of the aquifer during normal and low flow conditions. Local management plans must be developed and implemented to address the effects of local pumping on declining springflows in order to arrest the decline before that pumping has an unwarranted and disconnected effect on the withdrawals of municipal, domestic, agricultural, livestock, and industrial users of the Edwards Aquifer.

San Marcos River Foundation
k(1), (2), (3) Positions

Submitted by: Dianne Wassenich, San Marcos River Foundation
Date: June 9, 2008

Supporting references/documentation:

1. USGS website: River Gauge for San Marcos River at University Drive, on May 20, 2008, as boards are inserted into the dam, and EAA aquifer level readings in Ezell's Cave, five to six hours later.
2. Additional readings on instruments that EAA is placing in Spring Lake, Ezell's Cave, and wells between the lake and the cave as the Spring Lake dam boards are removed on Wednesday, June 11, 2008. Also again, the USGS website for the river gauge at University Drive, on June 11, if dam board removal happens as planned.
3. EAA dye tracing studies going on in May and June in wells and recharge features, and perhaps some done previously, on the Blanco side of San Marcos Springs, as well as the opposite side of the springs, toward San Antonio.

k(1) Position:

We believe that the San Marcos springs are fed by a "conduit" of aquifer water that comes from the direction of San Antonio and New Braunfels, as the recent study by EAA of well levels indicates (the study already presented to the Science Subcommittee). When Spring Lake dam boards were built up on May 20, 2008, in order to dry an area near the spillway for a construction project, the river flow was slowed, according to the USGS river gauge online, even after the lake filled and the water started flowing from a second spillway into the river channel. About 5 or 6 hours later, a small rise in aquifer levels was noticed by EAA in Ezell's Cave, on instruments in the cave in San Marcos. The cave is located in the direction of San Antonio, from the Springs. We hope that the additional information that will be gained by EAA's additional instrumentation being placed in wells, the cave, and the river during the removal of the boards from the dam on June 11, 2008, will be useful to this Science Committee in determining the connection between the San Antonio pool and the San Marcos Springs. We also think that the dye tracing studies going on by EAA staff this summer, and the past few months, should also be useful to the Science Subcommittee in determining what direction water flows in the aquifer during dry periods, like the current drought. If it rains this summer, it may also be useful to see if the flow direction changes in the aquifer during wetter periods. But it is the direction during dry periods that must be especially noted, since those are the conditions in which water conservation rules are triggered. EAA, with all their dye tracing studies, should be able to determine which wells should be monitored, if additional wells are needed to keep watch on flow direction in the future.

k(2) Position:

The information that Jackie Poole and Tom Brandt presented to the Science Committee regarding wild rice should be sufficient to conclude that springflows must be maintained,

since healthy, genetically diverse, and reproducing wild rice needs its natural habitat of the river to succeed in surviving and reproducing.

k(3) Position:

The San Marcos River Foundation has commented to EAA during rules changes that we believe the trigger levels should include an "anticipation factor" based on the rate of decrease of the J-17 well level. Without any "anticipation factor" there is little hope of reducing pumping in time to affect spring flow, when well levels are plummeting over a foot a day. It takes some time for the water from the San Antonio area to reach San Marcos, underground in the aquifer's faults and holey karst, and in our opinion, the trigger levels for Stage 1 should start much earlier to make sure that springflows are protected during droughts. It takes the public a while to get into the conservation mode, and to get the word out to all those using wells or city or rural coop water from aquifer wells. In fact, this winter, many months before the J-17 got near 660, the salinity levels reached excessively high levels in San Antonio Bay, negatively affecting food and water sources for the endangered whooping crane. (I don't have data on this, but heard this from Tom Stehn who does have such salinity data. He is the USFWS Whooping Crane Coordinator at Aransas National Wildlife Refuge, and he could send or present salinity data if the Science Committee wants to see it. I'd be glad to help provide that, and compare it to spring flow levels for those dates as well.) There was not any effort in the aquifer region to step up water conservation this past winter, while the springflow levels steadily dropped. There should also be real-time gauges on wells, which can be accessed electronically, to truly monitor pumping. With the current system to regulate aquifer pumping, long periods pass before EAA is able to learn whether a pumper is violating their permit. During critical periods, this would be unacceptable if the objective is to keep the springs flowing.

Texas Parks and Wildlife Department

k(2) Position

Submitted by: Chad Norris, Jackie Poole, Doyle Mosier, Gary Garrett, and Norman Boyd; Texas Parks and Wildlife Department
Date: June 9, 2008

Supporting references/documentation:

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Position:

TPWD staff believes it is imperative to maintain at least minimum springflows during periods of drought, and preferably a flow regime that mimics natural hydrologic conditions at all times, in order to maintain the federally listed species in their native habitat. It should go without saying that aquatic organisms need water. However, not all aquatic organisms have the same needs in terms of the quantity, quality, duration, and seasonality of flow. Discharge, or flow, has been termed the "master variable" in the structure and function of aquatic ecosystems. Springs, in general, are recognized for their consistency in terms of the quantity and quality of water they produce and many of the organisms that inhabit springs are adapted to their relative stability.

While little is known about specific life history requirements for many of the listed species, it is clear they are adapted to the thermal and hydrologic stability that characterizes the major springs issuing from the Edwards Aquifer (e.g. Comal, San Marcos, and Hueco springs). Their dependence on the characteristics of these springs is reflected not only in their restricted distribution, but also by the close association many species display with spring orifices (e.g. dryopid and riffle beetles, Peck's Cave amphipod, and epigean salamanders). The possible effects of not maintaining minimum springflows are many, including changes in the quality of water in the Aquifer and at the springs, a decrease in current velocity and corresponding reductions in habitat, increase in siltation, proliferation of exotic species, and an increase in temperature and temperature fluctuations in the aquatic habitat. All of these potential impacts would result in some form of degradation to the aquatic habitat and could potentially "jeopardize" the continued existence of these rare species with apparent narrow life history requirements.

Although little is known about specific life history requirements for many of the listed species, some information can be gleaned from reported observations, scientific research, and the life history of similar, closely related species. For example, flowing water is considered important to the respiration processes of riffle beetles and the Comal Springs riffle beetle (larvae and adults) is known to aggregate around spring upwellings. This information suggests the Comal Springs riffle beetle requires flowing water and has an affinity for spring orifices likely related to life history. The fountain darter requires undisturbed stream floor habitats, a mix of submerged vegetation, clear, clean water, a food supply of living organisms, constant temperatures within normal gradients and adequate spring flows. Texas wild-rice requires clear, thermally constant (72-75 degrees) water and must be submerged in water at least 6 inches deep, although it prefers depths of 1-6 feet. It cannot survive in dry or moist soil; it must be submerged. These and other life history requirements of the listed species are detailed in the Comal and San Marcos Springs Recovery Plan.

It is also important to note that the same species may have different requirements during different life stages (e.g. larvae vs. adult) and at different times of the year. Thus it is important to consider the different requirements that must be met to successfully maintain populations and recognize that these requirements do not have a single, minimum number associated with them, but are instead time dependent (season, duration, etc.). Mimicking the historical hydrology, in terms of the frequency and duration of flows, is perhaps the only way to ensure these requirements are met without understanding the interrelated intricacies of these parameters.

The observations and research of numerous individuals at Comal and San Marcos springs were used to develop specific criteria in the Recovery Plan. This document should be viewed as valuable information based on the experience of many scientists. Most research done over the last decade has been in surface water habitats and has focused on correlating occurrence to specific parameters, such as velocity, discharge, and substrate type. While this data is useful, little to no information has been gathered at the microhabitat level or in subterranean habitats which are likely critical for all of the listed species, especially the macroinvertebrates. Without understanding what changes may occur at the microhabitat level in relation to overall reduced springflows, it is difficult to truly assess potential impacts on these listed species. Furthermore, so little is known about the use of subterranean habitats by the listed species, especially the macroinvertebrates and salamanders, that any attempt to define a “minimum” would be purely conjecture.

The fountain darter was extirpated from Comal Springs when it ceased to flow during the drought of the 1950’s. Despite the survival of the listed species through the 1950’s drought and the successful reintroduction of the fountain darter that followed, other factors might preclude a similar outcome if the springs should cease to flow again. Foremost, groundwater pumping has increased since the 1950’s so the springs are more likely have reduced flows or to be dry for a much longer period of time given the recent response of the aquifer to much shorter droughts (e.g. summer 2000 and 2006). As such, it is likely that a reoccurrence of the drought of record would have a more severe impact on the Comal and San Marcos springs ecosystems and their resident biota.

The argument that the rare species survived the drought of record and therefore must have mechanisms by which to survive drought is not scientifically sound. The biological community (especially the invertebrate community) was not thoroughly studied prior to the drought of record, thus there are no available means to ascertain what impacts, if any, the drought of record had on these species. It is also important to note that many of the exotic species found in these systems, such as the giant rams-horn snail, suckermouth catfish, and tilapia were not present during the drought of the 1950's. The presence of these species may have large and potentially cascading effects on the ecosystem as exotic species often thrive in new environments where they are not subject to many of their natural controls.

Attempting to maintain species in refugia is not a viable option for several reasons. First, the ESA states that species will be conserved in their habitat, not apart from it. Second, keeping any species in refugia for an extended period of time will result in genetic drift and the potential loss of adaptations to the natural habitat. Third, so little is known about the life history of many of the species (e.g. Peck's Cave amphipod, Comal Springs dryopid and riffle beetles), it is currently unclear if successful refugia can be established.

Given the importance of springflows in maintaining baseflows that sustain streams, rivers, estuaries, and their resident biota during times of drought, TPWD staff believes it is important to also consider the impacts that reduced springflows will have on instream flows and freshwater inflows. The regional importance of Comal and San Marcos springs in maintaining baseflows to their respective river systems and the greater Guadalupe River Basin cannot be overstated as they collectively account for over 30% of the baseflow to the lower Guadalupe River and 70% or more during periods of drought. These flows not only sustain fish and wildlife resources along the river, but they provide freshwater inflow to San Antonio Bay. The loss of freshwater inflows into these estuaries represents a potential loss of biological resources in these systems in addition to economic losses associated with recreation, and the commercial and sport fishing industries.

Appendix G. Additional references not cited in the text related to the Edwards Aquifer Recovery Implementation Program species

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APPENDIX C:

SUSTAINABLE ECOSYSTEMS INSTITUTE, "PEER REVIEW OF THE EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM'S SCIENCE SUBCOMMITTEE'S "K" CHARGE RECOMMENDATIONS," MARCH 2009

Peer Review of the Edward aquifer Recovery Implementation Program's Science Subcommittee's "k" Charge Recommendations

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MARCH 2009

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INTRODUCTION

Sustainable Ecosystems Institute (SEI) is a public benefit, non-profit organization, founded in 1992. The goal of the Institute is to provide impartial scientific support for conservation decisions; the Institute is non-partisan, and seeks science-based, cooperative solutions to environmental issues. The organization has previously carried out extensive work on resource conservation and management, and has developed the use of peer review in such situations (Brosnan 2000).

The Edwards Aquifer Recovery Implementation Program (EARIP) contracted with SEI to conduct a peer review of the EARIP's Science Subcommittee recommendations of the "'k' charges" described in the Request for Proposal and Statement of Work provided to SEI by the EARIP (appended as appendices 1,2) (SSC report hereafter).

The specific charges to SEI included:

- To scope the review and, based on SEI's experience with other reviews and the materials to be considered, to determine the size, composition and academic specialties of reviewers.

- To select the reviewers best suited to the review, and to contract with them to carry out the review. SEI was also charged with maintaining the scientific integrity of the process, by allowing EARIP to observe the process, but not to influence the selection of reviewers.

- To set up a wiki site, and to make all relevant materials (provided by EARIP) available to reviewers, and to ensure that reviewers carry out a timely and well prepared review.

- To provide a written report that summarizes the opinions of individual reviewers, and of the review group as a whole, including any rebuttal or changes to reviews following comments received from EARIP.

The overall goal of this review then is to provide a comprehensive, and critical evaluation of relevant information regarding the k charges and important science issues discussed by EARIP. Ultimately, this evaluation may be used by EARIP, USGS and partner agencies in making science and management decisions. These are appropriately the responsibility of the various agencies. SEI's process is designed to provide an impartial scientific evaluation. It is not our role to provide advice on management decisions, and reviewers were instructed to avoid such comments. Our approach is restricted to summarizing, critiquing, analyzing, and synthesizing scientific materials.

The process we adopted was to set up a panel of experts drawn from a range of different academic backgrounds relevant to the review. These experts read the materials that were available or that were developed. Overall project lead was Dr. Steven Courtney, Vice-President of SEI, who has expertise in endangered species research and management, and in the application of peer review processes to natural resource management issues.

Panel members and their particular expertise in the review were:

• Dr. Mark Bain	Cornell	Ecology
• Dr. Alan Fryar	U Kentucky	Karst hydrology
• Dr. Tom Dunne	Tulane	Karst hydrology
• Dr. Carol Wicks	Louisiana SU	Karst hydrology

Dr. Bain was selected for several reasons. He is an icthyologist and ecologist of national standing, and has previously visited the Edwards Aquifer region, so that he is familiar with organisms discussed in the review. He has also previously worked with SEI on other reviews where the hydrology/ecology interface was relevant, and he has a strong quantitative background.

Dr. Fryar is a nationally recognized hydrologist, who carries out field-based studies and mathematical modeling of ground-water flow, mass transport, and reactions in the subsurface. He has extensive experience with recharge issues, and has very strong quantitative and modeling experience.

Dr. Toran is chair in Environmental Geology at Tulane University, and is an expert in karst hydrology in the eastern US. She also has published extensively on ground-water/ surface interactions in general.

Dr. Wicks is a nationally recognized expert on karst hydrology, with an interest in interaction with organisms, as well as the factors affecting recharge in large systems. She also has expertise in modeling of such systems.

SEI was asked to select 4 to 5 reviews, the exact number to be determined by SEI, on the basis of covering all the necessary academic disciplines, and with adequate relevant experience. In the event, SEI elected to employ just 4 reviewers. Our rationale was that 1. We were asked to provide at least one reviewer with karst experience – in fact all three hydrologists are karst experts, and the ecologist also has relevant experience; 2. We were asked to provide a review with quantitative strengths – in fact all four reviewers have such strengths, and several carry out modeling of aquifer systems. Hence we decided that it was unnecessary to expend additional resources to augment the panel, since the four reviewers were so well

qualified to carry out the review (this will result in cost-savings to the EARIP program).

The four reviewers were selected using standard SEI approaches. We consulted our database of experts who have already committed to carrying out reviews for management-relevant science. This resulted in a large list of potential reviewers, including hydrologists, but no karst or recharge modelers. Ultimately Dr. Bain was the only reviewer we selected on the basis of our first search. We then sought the opinion of experts who have previously worked with SEI on hydrology issues (e.g. Everglades flow, fluvial modeling). These suggestions provided a larger group of hydrologists, but ultimately did not provide us with appropriate experts who were of sufficiently high academic standing. We also carried out research of our own into identifying which scientists had well-established reputations in karst hydrology. Ultimately it was this approach that allowed us to identify and select the three hydrological reviewers.

In addition to the four reviewers selected, we also approached and interviewed several other potential reviewers. We asked one of these, Dr Jean Bahr of U Wisconsin, to serve as a reviewer, but she declined due to extensive prior commitments.

REVIEWS

Given the varying expertise of the reviewers we elected not to provide a single list of questions, but instructed each reviewer to consider the report of the EARIP science subcommittee (and relevant background materials) on the basis of her or his own area of expertise. In the event, most of the comments made were positive, with some suggestions for additions or better documentation.

The sections that follow first present an overview of the reviews received, followed by the individual reviews of the four panelists. The written responses and verbal comments of the science subcommittee were also discussed with the panelists, and we provide a summary of the final conclusions reached on the important points of discussion between reviewers and the SSC.

Overview of reviews

In general, all four reviewers felt that the SSC report was well conceived, well written, and did a good job of justifying its conclusions. No major problems were identified with the report or with the conclusions it reached, and the reviewers unanimously felt that the SSC report represented good science. This overall high standard indicates that the SSC report will be a useful scientific document on

which to base management decisions, and that decision-makers can have high confidence in the scientific quality of the document. Based on SEI's experience elsewhere, it is unusual to have such positive reviews, and the SSC appears to have done an exemplary job of synthesizing and analyzing materials.

Each reviewer did identify some areas that were poorly explained, in need of further clarification, or where the reviewer had slightly different opinions than the SSC. In part, these reviewer comments reflected genuine scientific differences of opinion. During the group discussion following the written reviews and SSC responses, the SSC acknowledged the need to make some corrections or clarifications to address these comments. However on some points, reviewers asked for material to be included in the report that is best reported elsewhere, or addressed issues that will be the subject of future SSC reports. In these cases, the reviewers and SEI agree that it is not necessary for the SSC to make corrections and additions.

In general then, the SEI reviewers were supportive of the analyses and conclusions described by the SSC report. Many of the reviews addressed technical details rather than overall conclusions. As noted by Toran in her review, and other reviewers in discussion, the reviewers did not feel that SSC needs to change any of its conclusions, and they offered minor critiques that are likely only to affect details of presentation etc.

Review by Mark Bain

General Assessment

My review of this report focused on task 2 which heavily considers the environmental requirements of the threatened and endangered species. My background is aquatic ecology, fish and invertebrate biology, and environmental analysis methods. I have visited the Edwards Aquifer area, both Comal and San
Marcos Springs, and been thoroughly oriented to the endangered species and water management issues of the aquifer. I found the conclusions of the Edwards Aquifer Area Expert Science Subcommittee well founded using the available local information. I do not disagree with the main conclusions reported.
While the basic findings are acceptable, I found shortcomings in the analyses and reporting. The information used to support the findings are almost entirely of local origin. Also, the analyses were direct and simple, and there was a lack of quantification on many topics normally presented in numeric terms (water volumes, habitat values, population size, etc). Inconsistencies were limited in scope. I found that more thorough review and analyses would be possible. Finally, the scope of the report was very constrained although this may be appropriate under the assignment to the Subcommittee. Overall, I found this report well reasoned, prepared with simple and direct analyses, and complete with local information.

Task 1 - A San Marcos Pool?

The review of relations between well elevations and spring discharges is done on a well by well basis. Figure 13 plots four well elevations and the discharge of San Marcos Springs. This plot suggests to me that a multivariate statistical model that combines data across wells may be much more effective in predicting spring flows. I am familiar with multivariate statistical methods and I am aware of that groundwater modelers have other tools for integrating well data. Consideration should be made of multi-source analyses such those used by Ritzi et al. (1993) and Stetzenbach et al. (1999).

The relationship between Comal and Sam Marcos Springs appears unrelated in Figure 14 however accounting for aquifer levels at multiple wells could provide relations that results in a time series of discharges shown. The discussion of flows and levels across the aquifer could be captured using water elevations in multiple wells together. The hydrologists on this review panel would be better for advice on this point.

Task 2 - Minimum Spring Flows

Flow Regime and Minimum Flows

The primary conclusion by the Science Subcommittee for task 2 is that minimum spring flows are required. My judgement is that this conclusion is proper and supported by the information presented. However, no information is provided on the magnitude of minimum flows. Also, the conclusion is embedded in a broader concept that a flow regime is needed for maintenance and recovery of the threatened and endangered species.

The conclusion that a minimum flow is necessary is not very informative without some scale of quantification. Clearly no flow or zero spring discharge would very likely

eliminate some threatened and endangered species. This was observed when Comal Springs experienced a lack of spring flow (no minimum flow, no flow) in 1956. Therefore, the need for a minimum flow has been demonstrated at the aquifer spring sites.

The primary conclusion and task 2 discussion includes the concept of a flow regime or mix of low, 'normal', and high flows. I was part of the group (Poff et al. 1997) that published the primary paper on the importance of flow regimes for conservation of river biota. The logic supporting our argument was that flowing water species are adapted to environments with different flows through an annual cycle, and that they depend on the habitats created by different flows. In the case of spring environments, the biota may be especially dependent on flow constancy and a very limited range of environmental conditions. The report makes this argument in many parts of Task 2 and in the description of the biology of some threatened and endangered species. In general, the constancy of spring and groundwater dominated streams has been recognized as supporting species poor, specialized, and unique communities (Ward and Stanford 1983), and this is a natural although rare situation. I conclude from the information reported and familiarity with constant flow environments outside Texas, that there is not a strong case for a regime of flow variability for the aquifer spring environments or their unique biota.

While I conclude the argument for a flow regime is not well supported, there is some information presented that suggests some variation in flows could be important to a few species. Texas wild-rice uses different modes of reproduction and expansion depending on current velocity and possibly water depths. This finding suggests variable flows may be important for population recovery of this species. Note that Texas wild-rice appears least obligate to the highly specialized conditions of the springs because its distribution can be well removed from the immediate spring outlets. The San Marcos salamander also appears to require rock substrates that may need periodic high flushing flows for maintaining clean coarse substrate. Again, this species is found outside the immediate influence of the springs. Overall then, I suggest that the discussion and conclusions about the need for flow regimes is currently speculative and will need further support to be accepted with confidence as a general finding for all spring dependent species.

Assemblage Scale Assessment

The report reviews the biology and dependency of the eight threatened and endangered species found in the Comal and San Marcos springs ecosystems. The primary environmental variables defining the habitat of the surface species are: water clarity, velocity, temperature, and carbon dioxide level. In some cases (e. g., fountain darter, San Marcos salamander) the species depend on secondary conditions (e. g., aquatic vegetation, rock substrate) linked to the primary environmental variables. On page 48, the report comments that most species associated with the springs are endemic but not ESA-listed since enough species are already listed to protect the spring dependent community. All this makes a case for considering the community in a more comprehensive manner with the species level assessments provided in the report now.

Bearing directly on the assigned tasks, a consolidation of environmental requirements

would help identify the need for spring flow and habitat conditions. I recommend a chart or series of charts showing the range of values required by each species on a gradient from immediate spring conditions to beyond all the species needs. For example, plot each species on a gradient spanning temperatures at the point of spring flow discharge (at or very near 69.8oF) to temperatures considerably above the most high temperature tolerant species. In this way, one could easily visualize the conditions that are required to maintain the community. The spatial scale associated with these gradients could be approximated to convey the scale of habitat area. This charting and synthesis form of reporting would summarize effectively the needs by species and the spring dependent community.

Good scale maps of the systems would be helpful. Locations are discussed that only those familiar with the spring sites would know. Also, the potential range of the species could be shown.

Finally, non-native species are a real threat to the threatened and endangered species. A similar analysis showing tolerances of non-native species could indicate the extent of threat and the need for conditions providing refuge from non-native species.

Fountain Darters

On page 39 there is a lengthy discussion of population fluctuations of fountain darters in response to high flow events and changes in aquatic vegetation. This information is valuable in considering spring flows and habitat conditions. However, no numbers are reported for darters, flows, or vegetated area. To make the case, some level of quantification should be reported. The current lack of numbers makes this discussion much less valuable than it could be. Also, sources for population data are not clear in this text.

Flushing Flows

High flows for shaping habitats, cleaning substrates, and possibly reducing non-native species is invoked at different points in the report. On page 46 the comment is made that no research exists for the magnitude of these flushing flows. I agree there is probably no empirical field studies at the spring sites on this topic. However, methods to estimate flows needed to shape channels and move fine sediment are well established. Some examples are: Dunne and Leopold (1978), Gordon et al. (1992), Carling (1996).

While the waterways associated with the springs are far from natural channels, it would be possible to estimate flows that would accomplish some habitat maintenance objectives.

Habitat Manipulations

The assigned tasks focus on spring flow needs for the species listed under the federal Endangered Species Act. The Science Subcommittee recommendation on page 52 states the belief that no alternatives exist to minimum flows. I agree if only water volumes are to be considered. The report does raise surface water habitat modification at a few points as well as spring flow alternatives like flow augmentation and recirculation. Further, the

discussion of in-situ refuge approximates habitat enhancement and states that this orientation should be evaluated and has potential merit. Much more could be done on this. The Science Subcommittee states in page 56 that restoration of the San Marcos ecosystem has not been attempted but should be considered. The current surface waters at both San Marcos and Comal Springs are highly artificial and engineered. I believe reengineering the surface waters to maximize use of spring flow to promote space meeting species requirements has much merit. The report introduces the topic in a subtle fashion while suggesting significant potential.

Artificial Rearing and Holding Capability

Off-site propagation conclusion well discussed and sound. Propagation is one conservation technique commonly used for endangered species but sometimes seen as a solution on its own. The report makes a good case for not adopting this perspective.

Miscellaneous

Both 'springflow' and 'spring flow' are used throughout the report. One form should be selected.

Task 3 - Trigger Levels for San Marcos Springs

This short discussion of changes to trigger levels may benefit from a more thorough analysis as I suggested under task 1 above. Several of the plots and triggers are shown for well J-17 which is described by the Science Subcommittee as not related to San Marcos Springs discharge (page 21). This inconsistency draws into question the analyses in this section.

Review by Alan Fryar

I have read this report to the EARIP Steering Committee, including attachments, and I generally agree with the methodology and conclusions. I am a hydrogeologist who studies karst systems and I have lived in central Texas, but I have not conducted research on the Edwards aquifer. The subcommittee members seem to have done a thorough job compiling the existing literature and addressing the specified tasks, including considering stakeholder input. In particular, the section on Task 1 ("Are the data sufficient to designate a San Marcos Pool?") is clearly written. My relatively minor critiques (including edits) are as follows:

p. vii, ¶ 4: "data was" should be "data were", and "this data" should be "these data"
p. 6, ¶ 1: "addition information" should be "additional information"
p. 8: For the bulleted list in Task 1.3, hydraulic correlation analyses should precede water chemistry analyses, since the sections fall in that order.
p. 8, ¶ 3: "in the case" should be "in this case"
p. 11, ¶ 1: "in large parts the Hueco Springs Fault Block" should be "in large parts of the Hueco Springs Fault Block"
p. 20, ¶ 2: Should Schindel and Johnson (2008) be Johnson and Schindel (2008)?
If rivers are largely spring-fed, I would expect river stage to depend on spring discharge, rather than vice versa. To what extent do "rivers act as recharge to groundwater feeding the springs"?
p. 21: Inclusion of a map showing locations of springs and key index wells would be helpful.
Fig. 11 shows that hydraulic heads in well 68-23-302 "have a strong correlation with Comal Springs discharge" above a threshold of 619 ft MSL (italics mine).
Fig. 13 shows correlations between hydraulic head and San Marcos Springs for four wells. Because the correlation for well 68-16-701 is the weakest of the four (r2 = 0.32), I think "strongly correlate" should just be "correlate" (or one of the other wells should be highlighted).
p. 24: In the caption for Fig. 12, I think well 67-09-110 should be Southwest Texas Farms Well, not "Landa Park or Panther Canyon well" (based on p. 21).
p. 27-28: The section on water chemistry is too brief. What are the differences in chemistry between the two groups of springs at San Marcos Springs? Are they consistent with differences in residence time and/or lithology? See Musgrove, M., Fahlquist, L.S., and Houston, N.A., 2008, An overview of the geochemistry of Edwards aquifer ground water in south-central Texas, in Kuniansky, E.L. (ed.), U.S. Geological Survey Karst Interest Group Proceedings, Bowling Green, Kentucky, May 27–29, 2008: USGS Scientific Investigations Report 2008-5023, p. 67.
p. 28, ¶ 4: What does "the most fundamental projections of future conditions" mean?
p. 29, ¶ 3: The sentence "Some interchange of ground water of the aquifer that includes a storage unit and a zone in which water is transmitted from this storage unit to major points of discharge" should be deleted.
p. 33: Where is Fern Bank Springs?

The MODFLOW conduit-flow model of Lindgren and others (2004) should be rerun with MODFLOW-2005 Conduit Flow Process. See Shoemaker, W.B., Kuniansky, E.L., Birk, S., Bauer, S., and Swain, E.D., 2008, Documentation of a Conduit Flow Process (CFP) for MODFLOW-2005: USGS Techniques and Methods, Book 6, Chapter A24, 50 p.

p. 38, ¶ 1: Although water quality is integral to maintenance of threatened and endangered species at Comal and San Marcos springs, water quality was not explicitly part of Task 2.

p. 39, ¶ 1: What are temperature ranges in the springs? What are examples of fountain darter predators?

p. 42, ¶ 3: "Experimentation…and observation has shown" should be "Experimentation…and observation have shown".

p. 43, ¶ 2: "moderate temperate water" should be "moderate temperature water"

p. 44, ¶ 2: The sentence "All these non-native species occur at least in part in habitats that could be occupied by Texas wild-rice" is redundant and can be deleted.

p. 46, ¶ 3: "affect" should be "effect"

p. 47, ¶ 3: Are riparian areas intact around Comal and San Marcos springs?

p. 56, ¶ 2: Is the study of planting Texas wild-rice seeds in degradable cloth bags still in progress? If completed, what were the results?

p. 61, ¶ 4: Rating curves are commonly limited by a lack of high-flow measurements. Are "additional measurements in the upper portions of the rating curve" practicable?

p. 63–67: Relative to Tasks 1 and 2, the section on Task 3 is overly brief. For readers like me who are not intimately familiar with the Edwards aquifer, provide background information on what actions are taken when the triggers are exceeded. What do stages I–IV represent?

p. 68: "U.S. Fish & Wildlife Department" should be "U.S. Fish & Wildlife Service"

p. 77: I didn't see Taylor (1904) cited in the text.

p. 79: "an individual could also nominate themselves" should be "individuals could also nominate themselves"

Review by Laura Toran

TOPIC 1: Evaluate designating a San Marcos Pool

The conclusion of the committee is that it is not appropriate at this time to designate a San Marcos Pool. This conclusion is supported by the data presented and by most of the comments in the position papers (Appendix F).

Nonetheless, some of the supporting information could be strengthened. In the executive summary (and repeated on p 32), lack of hydrologic information is cited as the reason the SM pool cannot be separated: "a more complete understanding is required of the various elements of the hydrogeologic framework". This phrasing is so general that it could be applied to any problem at any time and it is especially true in karst systems where many doubt we will ever have "complete" understanding. I think the phrasing could be more specific. There is a much more pointed statement on p 32: "aquifer levels, recharge, and pumpage in Comal and Bexar counties have sufficient effects on San Marcos Springs that management of a fully separate San Marcos Pool would be an administrative action rather than a scientifically-based decision." This statement makes clear that flow comes from multiple directions that overlap with the existing pool, and it should be the emphasis in the executive summary. Furthermore, evidence from geochemical data supports the conclusion.

Given the importance of flow paths to the interpretation, I would like to see clarification of the flow path discussion around pp 15-16. The sources of information are referenced, but the methods aren't discussed much. How much of the information on flow direction is from tracer tests, how much from water levels in wells and springs, how much from geologic consideration of permeabilities and likely barriers? One of the final recommendations is to do "more" tracer tests, but the reader doesn't have a sense of what has already been done. Tritium dating is mentioned later but seems likely to help the flow path interpretation since the dates suggest different sources for northern (local) and southern (regional) springs at San Marcos. This information could be discussed earlier to tie together different lines of evidence for the flow paths.

One specific example using water levels to interpret flow paths is the drought story from the 1950s (p 15). Although this is a good example of methods, I'm concerned about citing 1950's data for interpretation. Land use has undoubtedly changed since then. Couldn't that affect flow paths? It would help to have a description of current land use and any significant changes.

Sometimes the flow path descriptions were hard to follow. Fig 2 shows water from the upthrown to downthrown block while Fig 6 shows prominent arrows with water from downthrown to upthrown sides. Fig 4 doesn't show either of these flow arrows, although maybe it is at a different scale that doesn't include this detail. A reader scrutinizing the figures could use some help to decide how each one relates to the text and the interpretation.

A sentence or two describing Puente's "traditional recharge estimate" is needed, especially since this source isn't readily available. EPA has published a method that sounds similar (Ginsberg and Palmer 2002) and it might be helpful to compare the methods since the EPA method is thoroughly described in the referenced (readily available) report.

The summary comparison of the spring and river discharges (p 20) was very useful to the interpretation of source areas. The water balance estimates point out that multiple recharge areas contribute to the SM spring discharge. This summary is based on estimates used in Fig 8 -- does that mean Fig 7 could be omitted? There were some confusing statements in the recharge section preceding (used to set up the water balance discussion.) For example "Recent studies (HDR Engineering, Inc., 2002, LBG-Guyton Associates 2005) suggest that recharge occurring in the primary streambed is variable…" What is recharge occurring in the streambed? Is this a losing stream? Or was the text supposed to read discharge? The sentence goes on … "and may be less than half of the calculated total recharge for some basins." I don't see why a streambed would be compared to a basin unless it is discharge in the stream compared to recharge in the basin. The relevance of this discussion needs to be made clear. A lot of HDR reports with different dates are cited here and it was hard to follow which is the most recent or whether the dates of the report indicate which is most up to date. The reports are summarized thus: "While overall estimates of long-term average recharge were quite similar", but then the following sentence says recharge was greater. Maybe the sentence was supposed to say the recharge AREA was greater? These statements aren't clear. It was a bit odd to say on p 19 that the HSPF model was completed in 2002, then on p 20 say the HSPF model is being refined. I think the point is that it has been revisited but maybe different wording should be used on p 19.

I had mixed feelings about the correlation discussion that followed (bottom of p20 and after). The text states: "Correlations between river stage and spring discharge provide an indication of whether the rivers act as recharge to groundwater feeding the springs. Correlations between spring discharge hydrographs measure the hydraulic communication between the springs, either
in terms of sharing similar recharge zones or in terms of discharging from the same groundwater reservoir." This statement ignores some important concepts – it may be acceptable as a shortcut, but some cautions need to be included and a better description of the data analysis is needed for the reader to understand both the strengths and the limitations of this data.

First caution: The response of a well and a spring is not really expected to correlate. The spring has an obvious conduit pathway for at least part of the flow path. The well may intersect no conduits. For these reasons, we consider springs, wells, and streams to fall on an overlapping spectrum in terms of their response times and peaks. These differences have been quantified in various studies and are well recognized. In many cases wells are the only upgradient source of information, so they are a necessary part of the picture. However, lack of correlation doesn't mean the well isn't along the flow path

for the spring, as implied by the text. Instead, the well and spring lacking correlation may share some but not all of the flow paths. The text should include these cautions, while still comparing well and spring response. (Later I point out how the different responses of the well and spring may suggest conduit pathways in the well do exist.)

Second caution: The data analysis significantly affects the interpretation of the correlations. It is important that the sampling interval and time periods be the same when trying to compare the data. The correlation figures after don't give a time period for the data or a sampling interval. Questions arise such as: In Fig 13 the San Marcos discharge isn't the same for all of the lines – does this mean different times were used for the different plots? The time period can influence the results, so it needs to be stated. Was it a full year? More than one year? This is important to mention so the reader knows how seasonality might affect the data. Are the discharges peak flows or what interval? Is it the same interval for each data point? Answering these questions is also relevant to the discussion of drought triggers in section 3. Furthermore, it would help to have the wells all plotted on the same map with the springs. I couldn't find locations for some of the wells.

As long as these concepts can be clarified, the information presented in Figs 9-13 contributes to the discussion of source areas.

The modeling discussion raises some interesting questions. Perhaps they can't yet be answered, but it is worth posing them to better place the modeling in the context of determining the source areas. What is the implication of the predicted decline (dry up) in flow at San Marcos in the 1979 model? What does it imply about source area? About development? Did the model- predicted decline occur? What does that say about the source area? Does the moving groundwater divide between SM and Barton springs suggest the boundary is transient and thus any pool would be transient? Is this a reasonable conclusion? How does the possibility of transient recharge area complicate designation of a pool? The answers to these questions point to tasks that could be important follow on studies.

Section 1.3 ends with recommendation for follow on studies (p 33). These recommendations didn't seem to be linked closely with the previous text and several of them are too broad to be useful. Most of the tasks would further delineate overlapping pools; if that is the goal, it should be explicitly stated. One of the position papers stated this more bluntly (Guadalupe-Blanco River Authority): since there is NOT a separate pool, future studies should be geared to better prediction not to finding out if there is a separate pool. This may be stating things too strongly given the task assigned, but studying temporal changes in the pool and improving management strategies (suggested by San Antonio Water Authority) is within the stated task and would make a better focus for future work. I suggest rewriting the list of recommendations with this focus, and providing stronger justification and links to the previous discussion.

TOPIC 2: Evaluate the necessity of maintaining minimum spring flows.

The discussion of threats to the aquatic ecosystem and lack of alternatives to minimum flows was for the most part straightforward. There wasn't much ambiguity about the relationship between spring flow and ecosystem health: minimum spring flows are necessary for ecosystem health. Furthermore, the position papers in Appendix F were also in accord that there need to be minimum spring flows, although the definition could perhaps be better quantified.

The need for stable water chemistry and supply is stated clearly. The unique habitat of the springs (their stability) is also described. Species requirements are thoroughly discussed.
A few questions about the details are worth noting. Answering these questions might clarify the writing, but not change the outcome. I didn't understand the distinction between definitions of "required" and "necessary" in the opening paragraph on p 36. After this sentence, the rest of the paragraph made clear the importance of different definitions of minimum flows and how minimum springs flows could be used in different contexts.

I'm not sure how the discussion of non-native species competition fits in (p 40). I don't think spring flow can prevent invasion. A similar comment on p 44 implies spring flow control: "As discussed above, the natural timing, frequency, duration, and magnitude of springflows are important in controlling invasive and non-native species." It seems to be that because of variations in the needs of different species, whether native or not, there isn't one springflow rate or range of rates that is optimal. No flow is a problem, but I don't see information in this discussion that helps determine optimal flow.

The discussion of alternatives around pp 55-58 could include cost comparisons, for example the costs of reintroduction compared to costs of maintaining minimum flows. However, the cost of failure is perhaps incalculable, so perhaps no other costs matter?

The suggestions for future study seem reasonable. For instance, temperature and CO2 are important for evaluating flow diversion (p 59). Also, reassessing stage-discharge as low flow is approached (p 62) seems a reasonable suggestion. Wouldn't it be a good idea to reassess the relationship after flooding too, since that can alter stream morphology?

TOPIC 3: Evaluate whether adjustments to drought triggers for San Marcos Springs should be made

This section starts with a summary of the trigger levels on pp 63-64. This summary could be presented better with a table (see below). I didn't see an explanation for why San Marcos doesn't have trigger III, IV, but I assume it related to minimum flows. This should be clarified.
The SSC states that they can't recommend adjustment because of lack of scientific understanding of current trigger. The report summarizes current data. It could perhaps

go a bit further in interpreting the data. This interpretation would provide guidance on how one would go about adjusting the drought triggers if the conceptual model could be clarified. In other words, suggest a basis for adjustment; make more clear what the missing information is. I make a few suggestions below. Some of the data interpretation is provided under task 1, so it isn't clear whether these issues should be discussed in this section or the previous section.

Discuss the issue of timing for the triggers. Do plots (Fig 1, 14, 15 or other similar figures examined by the committee) show that triggers provide sufficient warning? Time period not clear on Fig 9-13, and number of periods not clear, which make it difficult to address this question.

Discuss how the response at SM compares to the other spring and wells. In Figure 1 SM is more muted except for June 05. Why is it more muted? Larger recharge area? Does this implied it has more sources (i.e. a larger pool). However, isn't an alternative explanation for muted response that SM has more matrix flow? Wells and springs overlap, which means that the spring doesn't have to be more responsive than the well! Answering these questions about likely flow paths would help to better interpret and set triggers. In other words, I recommend including a discussion of flow paths in the section on triggers.

Trigger	San Marcos Spring	Well J17	Comas spring
I	96 cfs	660 ft	225
II	80 cfs	650	200
III		640	150
IV		630	100

Overall Summary

For the most part, addressing my comments would change focus but not the conclusions of the report. One exception is the suggested future research direction on p 33, which I think could be improved by rethinking to address some of the questions raised in this review.

Reference on recharge calculation

Ginsberg and Palmer, 2002. Delineation of Source-water Protection Areas in Karst Aquifers of the Ridge and Valley and Appalachian Plateaus Physiographic Provinces: Rules of Thumb for Estimating the Capture Zones of Springs and Wells. (available at http://www.epa.gov/safewater/sourcewater/pubs/guide_karstaquifersrvapp_2002.pdf

Review by Carol Wicks

The clearly written report specifies three tasks that had to be addressed 1) to evaluate designating a San Marcos Pool, 2) to evaluate the necessity of maintaining minimum spring flows, and 3) to evaluate whether adjustments to drought triggers for San Macros Springs should be made. I have been asked to evaluate uncertainty, in general. Specifically, I will consider the following questions for each of the three tasks.

How would I evaluate the use of scientific information in the document? Is there a clear and consistent use of relevant data and facts? Are management or other decision clearly linked to objective evaluations of fact?

Task One – excellent, yes, yes
Task Two – excellent, yes, yes
Task three – excellent, yes, yes
Was all available and relevant information used? If not, what available data are missing? Could these omissions have affected the decisions made?
Task one – very good, the work of a few authors is missing, likely NOT.
Task two – excellent, none missing
Task three – excellent, none missing
Does the document make explicit discussion of uncertainty? If not, please indicate any areas where such uncertainties might influence management decisions.
Task one – very good
Task two – diffuse, but included and very good
Task three – clear, very good

Task One: to evaluate designating a San Marcos Pool

How would I evaluate the use of scientific information in the document? Is there a clear and consistent use of relevant data and facts? Are management or other decision clearly linked to objective evaluations of fact? My evaluation of the use of scientific information is very good. The authors have compiled and reviewed relevant data and facts and have used the data consistently. The decisions the authors made are clearly based on these data and facts.

Was all available and relevant information used? If not, what available data are missing? Could these omissions have affected the decisions made?
Nearly all relevant data were used.

Reports and papers by the research groups of Jack Sharp (UT-Austin), Bridgette Scanlon (Bureau of Economic Geology), and George Veni (NCKRI) are missing from the otherwise extensive list of works used

Sharp's work deals with recharge to the Edwards Aquifer. His findings are associated with the impact of urbanization on recharge. The lack of this work probably does not impact the findings. Scanlon's work is a large-scale numerical model of the Edwards. The EARIP report is based on a smaller scale, however Scanlon's work places uncertainty in a more regional context. Given the role of uncertainty in these management decisions, Scanlon's work should be included. George Veni's work is field-based basin and flowpath delineation. I am uncertain if Veni completed any studies in this segment of the Edwards; if Veni did, then these studies should be included.

Does the document make explicit discussion of uncertainty? If not, please indicate any areas where such uncertainties might influence management decisions.
The uncertainty of the structural (geologic) control on flowpaths and hydrogeologic conceptualization is made very clear. The two major studies (Guyton; Maclay and Land) that are extensively reviewed and relied upon are clearly presented; the differences in the findings are pointed. These differences lead to uncertainty and that is pointed out. Scanlon's work might provide an overall assessment of uncertainty of using numerical models in general

In general the flowpaths are to northeast. The uncertainty associated with direction is clearly stated by including the work of Otero (2007) who finds flowpaths through a portion of the aquifer to be toward the southwest. The uncertainty is clearly documented.

The recharge assessments are more consistent in quantity, although there are spatial differences. These differences in spatial patterns are clearly outlined. In addition, there are several methods that can be used to estimate recharge and those methods are presented.

The uncertainty associated with the water balance estimates is clearly stated.

I think the authors need to make clear that correlation is not necessarily cause and effect. There probably is cause and effect underlying these relations, however correlation analyses does not address cause and effect. Correlation analyses are a good first step and should more clearly be stated in that light.

Spatial and temporal changes in chemistry of water are difficult to understand when the flowpaths are well known. In this case, these changes are very difficult to understand given the uncertainty associated with the flowpaths. The authors were correct in limiting water chemistry to a short section that highlights these complexities.

Task Two: to evaluate the necessity of maintaining minimum spring flows
How would I evaluate the use of scientific information in the document? Is there a clear and consistent use of relevant data and facts? Are management or other decision clearly linked to objective evaluations of fact?

This section of the report is exceptional. The clearly presented data are used consistently and all relevant data have compiled. The decision is clearly based on objective assessment of the data and the uncertainty associated with that data.

Was all available and relevant information used? If not, what available data are missing? Could these omissions have affected the decisions made?
The authors have pulled together a massive literature base for each species of concern. They also relied on scientific literature related to ecohydrology in general. The report is based on the current understanding of ecohydrology and the role of disturbances and on current scientific research for each species. All relevant and available information was used.

Does the document make explicit discussion of uncertainty? If not, please indicate any areas where such uncertainties might influence management decisions.
The uncertainty is discussed for each species, which make the uncertainty discussion appear diffuse, which it is, but that discussion is explicit in each subsection.

Task Three: to evaluate whether adjustments to drought triggers for San Macros Springs should be made

How would I evaluate the use of scientific information in the document? Is there a clear and consistent use of relevant data and facts? Are management or other decision clearly linked to objective evaluations of fact?

The relevant data and facts were clearly presented and consistently used. Management decisions are linked to objective evaluations of the data.

Was all available and relevant information used? If not, what available data are missing? Could these omissions have affected the decisions made? This task is quite focused on one issue and the authors relied on the best data available – records of spring discharge and water levels in wells collected over a nearly thirty year period. These are the best data to use to assess this task.

Does the document make explicit discussion of uncertainty? If not, please indicate any areas where such uncertainties might influence management decisions. The uncertainties

associated with measuring spring discharge are clearly presented within the report as a whole. The records of water levels are known with a high degree of certainty. Finally, the analyses of trigger level against flow is appropriate for assessing this task.

FINAL CONCLUSIONS FOLLOWING DISCUSSIONS

The reviewers raised several issues in their comments. Some of these were important scientific concerns, but inappropriate for the task at hand (k charges) and will be addressed in future reports of SSC. SEI (as the final arbiter of the review process) agrees with SSC that it is not necessary to address such issues further in their current report. Some other issues raised were minor technical points, suggestions for improving clarity, adding scientific literature, etc. These were adequately discussed in the SSC responses to reviewers (often by simple statements that the points were accepted), and in the teleconference, and do not need further elaboration here.

This section concerns those areas where there was substantive scientific discussion between the reviewers and the SSC, and documents the conclusions reached by the group.

Comprehensiveness of review

As indicated above, there was extensive discussion by reviewers of whether all topics were adequately covered. It is important to note that reviewers were often seeking to understand the background and context for conclusions, rather than critiquing the report itself. Some of the issues which the panelists ultimately accepted as beyond the scope of the report included large analyses of water chemistry, or further literature review of the biology of the organisms affected. On other issues the SSC felt there was inadequate information to make strong statements, but the panelists persisted in asking for whatever information was available so that the context could be better understood (such as population ballpark estimates, or the results of dye studies).

As noted by Wicks on the conference call, the reviewers felt the SSC had done a very good job of developing a scientific report that addressed all the charges set forth by legislation.

Biological information

There was discussion, following the review by Bain, of the need for more information on the species assemblage. The SSC members articulated that there were limited data for many of the species, and that such a presentation would be of limited value. Bain and Wicks however persisted that such a summary table would be useful to help understand species' potential responses. Indeed, the lack of data on many topics is itself useful information, indicating the relative strengths of conclusions. However it may not be possible to provide any information at all for some species.

Bain also asked for information on population status and fluctuations, and pointed out that there was no way from the initial report to determine that there are hundreds of thousands of fountain darters. It was acknowledged by all that such data as exist are preliminary, and have high variance estimates. Fryar asked for similar data on temperature variation, which might have biological consequences.

Issues of flow

Although there was some discussion of quantification of minimal flow estimates, it was agreed that the current effort was sufficient for the task in hand, and that qualitative estimates of minimal flow were sufficient.

There was more extensive discussion on the issue of whether the case had been made that variation was an important component of the flow regime. The group agreed that there was some natural variability in flow (but not chemistry), and there was further discussion on whether this variability was important to maintain the ecosystem and its component species. Brant and other members of the SSC stated their belief that variability might not be important on an annual basis – indeed very low or very high flows might have negative effects. Over the long term however, such variability could affect and enhance the evolutionary potential of the species. Bain and other panelists stated that the case for this view is not yet well articulated and supported for karst systems, as opposed to river systems, where it is well established that variability is needed for some species to complete their life cycle.. However no panelist felt that this view was incorrect – merely that the document as yet does not make a strong case for it. Toran and others pointed out that different species have different minimal (and probably optimal) flow levels, which implies the need for variability in order to maintain all component species.

Barker has prepared revisions to the SSC report that address the flow issues, and modeling aspects. Panelists were supportive of these revisions. Toran noted that some of the language used in the conference call was particularly useful and easy to understand, and might be considered for insertion.

Issues of recharge

Reviews and discussions made clear that there was a complex relation between rivers and pools, with some rivers contributing to recharge, and others being dependent on pools. It was also noted that some of the water contributing to recharge is derived from distal sources (inflow with rivers) on the plateau. It was agreed by all that this complexity needs to be better explained in the SSC document, and that Barker is addressing this need well by his additions. The reviewers thought it important that all relevant approaches to recharge (e.g. EPA) be at least referenced.

Connectivity
Several reviewers were surprised to learn of dye tracing results implying limited connectivity, and encouraged the SSC to include reference to them. Toran pointed out (in conversation with SEI) that such connectivity might vary temporally, and that spatial relations among rivers, pools and wells might therefore vary over time in a complex manner (as inputs from rain etc varied).

Correlation and causation
A persistent issue in reviewer's comments, and in the resulting discussions is the need for caution when evaluating correlations. As was acknowledged by both reviewers and the SSC, correlation does not imply causation, and there may be many factors in operation. This was raised in particular regarding the correlation between springs and wells. Nevertheless, Fryar was comfortable with the implied relationships (index use), although several reviewers pointed out that there may be threshold effects (e.g. above 619 feet, there may be a decoupling as physical limits are reached), and other non-linear interactions. The reviewers felt that the SSC were aware of the problem, and would address it in their final revision.

Discussion of water chemistry
Reviewers initially disagreed on the issue of water chemistry; Fryar asking for more discussion, while Wicks described the document as 'appropriately brief'. This apparent difference was resolved with the agreement that some more documentation is appropriate, but that an exhaustive analysis would be disproportionate to the benefit – a couple of paragraphs were thought to be sufficient.

Recommendations for future work
The SSC report makes reference to several possibilities for future research. While such prioritization issues may fall outside the scope of the review (as representing policy decisions), it is worth noting that reviewers felt that some topics would be more likely to fill perceived data gaps than would other topics. Toran in particular felt that the currently described future research topics were poorly justified at present, and that additional work would help to set better priorities. Reviewers also suggested that the SSC distinguish work that is possible in the future from work that is actually underway.

Potential research topics raised by reviewers including additional modflow modeling with conduit simulations; improving the accuracy of rating curves at high flow measurements; flushing flows; habitat manipulation; and the use of multi-variate statistical modeling. Although this latter topic has so far received little attention from karst hydrologists, it is clear that variables appear to not all be

independent, suggesting that multi-variate approaches may indeed have some value.

Use of literature

There was some discussion about the use of the scientific literature by the SSC. The reviewers suggested the inclusion of references to some omitted work (EPA recharge, Barton Springs studies). While the SSC did not initially agree that such references were necessary, arguing that there was a limit to the inferences that can be drawn from distant studies, or from exploratory work, the panel persisted in maintaining that well-recognized and cited work should be referenced – if only to explain why they are not relevant here.

Appendices

1. RFP
2. Scope of work
3. E-mails and notes regarding final review

Also provided to EARIP

1. mp3 of conference call with reviewers
2. wiki materials

1

REQUEST FOR PROPOSAL

The Edwards Aquifer Recovery Implementation Program ("EARIP") is a collaborative, consensus-based stakeholder process tasked with the development of a plan to protect the federally-listed species potentially affected by the management of the Edwards Aquifer and to contribute to these species' recovery. The stakeholders in the process include State of Texas agencies, local water resource authorities, water purveyors, environmental groups, municipalities, public utilities, and other individuals and groups interested in the Aquifer and the species residing in the Edwards Aquifer or in the springs and river systems fed by the springs. *See* Attachment 1. The EARIP is seeking proposals for independent peer review of a study conducted by its Science Subcommittee.

BACKGROUND

Edwards Aquifer System

The Edwards Aquifer is a unique groundwater resource, extending 180 miles from Brackettville in Kinney County to Kyle in Hays County. It is the primary source of drinking water for over 2 million people in south central Texas and serves domestic, agricultural, industrial, and recreational needs of the area. The Edwards Aquifer is the source of the only two major springs remaining in Texas - the San Marcos and Comal springs. These springs feed the San Marcos and Comal rivers, which are tributaries to the Guadalupe River.

Eight species that depend directly on water in, or discharged from, the Edwards Aquifer system are federally-listed as threatened or endangered. These species include: fountain darter (*Etheostoma fonticola*), San Marcos salamander (*Eurycea nana*), San Marcos gambusia (*Gambusia georgi*), Texas blind salamander (*Eurycea rathbuni*), Peck's cave amphipod (*Stygobromus pecki*), Comal Springs dryopid beetle (*Stygoparnus comalensis*), Comal Springs riffle beetle (*Heterelemis comalensis*) and Texas wild rice (*Zizania texana*). The San Marcos gambusia has not been seen since 1983 and may be extinct.

The primary threat to the aquifer-dependent listed species is the intermittent loss of habitat from reduced springflows. Springflow loss is the combined result of naturally fluctuating rainfall patterns, regional intermittent pumping, and temporal drawdown of the aquifer. Other threats include invasive non-native species, recreational activities, predation, flood flows, and direct or

indirect habitat destruction or modification by humans and other factors that decrease water
quality (U.S. Fish and Wildlife Service 1996).
For more background information regarding the Edwards Aquifer see
http://www.edwardsaquifer.org/pages/eaaact.htm

The Edwards Aquifer Recovery Implementation Program

In 1991, the Sierra Club filed a lawsuit under the Federal Endangered Species Act that ultimately
resulted in the creation of the Edwards Aquifer Authority ("EAA"). The Texas Legislature
directed the EAA to regulate pumping from the aquifer, implement critical period management
restrictions, and pursue measures to ensure minimum continuous springflows of the Comal and
San Marcos springs are maintained to protect endangered and threatened species to the extent
required by Federal law. Today, competing water needs within the region continue to influence
2
management of the resource, and a workable comprehensive plan for the long-term protection for
the federally-listed species has yet to be adopted among the region's stakeholders.
As a result, in late 2006, the United States Fish and Wildlife Service ("FWS") brought together
stakeholders from throughout the region to participate in a unique collaborative process to
develop a plan to contribute to the recovery of federally-listed species dependent on the Edwards
Aquifer. This process is referred to as the Edwards Aquifer Recovery Implementation Program.
In May 2007, the Texas Legislature directed the EAA and certain other State and municipal
water agencies to participate in the EARIP and to prepare a FWS-approved plan by 2012 for
protecting the Edwards Aquifer-dependent listed species at Comal and San Marcos springs. The
Legislature directed that the plan must include recommendations regarding withdrawal
adjustments during critical periods (*i.e.*, droughts) that ensure that federally-listed species
associated with the Edwards Aquifer will be protected.
For more information regarding the EARIP see http://irnr.tamu.edu/earip

Science Subcommittee

The Texas Legislature required the EARIP to establish a Science Subcommittee of individuals
"with technical expertise regarding the Edwards Aquifer system, the threatened and endangered
species that inhabit that system, springflows, or the development of withdrawal

limitations." The
Legislature required the Science Subcommittee to prepare "initial recommendations by December 31, 2008, regarding:

• The option of designating a separate San Marcos pool, of how such a designation would affect existing pools, and of the need for an additional well to measure the San Marcos pool if designated
• The necessity to maintain minimum springflows, including a specific review of the necessity to maintain a flow to protect federally threatened and endangered species; and
• Whether adjustments in the trigger levels for the San Marcos Springs flow for the San Antonio pool should be made.

The EARIP refers to these recommendations as the "k" charges. In making these recommendations, the Science Subcommittee is to "consider all reasonably available science"
and "base its recommendations solely on the best science available." The Subcommittee is
supposed to "operate on a consensus basis to the maximum extent possible."
The Steering Committee appointed 15 scientists to serve on the Science Subcommittee and one
non-voting member. A list of the members and their affiliations is included in Attachment 2.
Ms. Susan Aragon-Long from the United States Geological Survey chairs the Subcommittee.
More detailed information about the work of the Science Subcommittee on the "k" charges can
be found at http://earip.tamu.edu/SciComm.cfm

REQUESTED PROPOSAL

3

The EARIP is seeking a proposal for independent peer review of the Science Subcommittee
recommendations regarding the "k" charges. The recommendations will be available on or
before December 31, 2008. The recommendations will be in the form of a report that will be
approximately 75 pages in length. The work of the Science Subcommittee was based largely on
review of available literature, invited speakers, and discussions among the members. The work
did not involve new field work or the development of new hydrologic or biological models.
Because of the limited scope of the Science Subcommittee's work, the EARIP does not seek to
use the peer review process to "redo" the work of the Subcommittee. The EARIP does expect
that the reviewers will focus on the entirety of the referenced research and historic observations
used to support the Subcommittee's conclusions and recommendations and the extent to

which
the recommendations adequately address the Legislature's "k" charges. However, you should
feel free in your proposal to suggest a different scope of review.
Your proposal should be in the form of a brief scope of work and include:
• The number of reviewers proposed
• A description of how the reviewers will be selected
• A description of the deliverable including whether the individual reviewer's comments will be included
• Whether the Science Subcommittee will be able to comment on a draft report and/or respond to any questions the reviewers may have
• The length of time required for the review assuming that the recommendations are provided to you on December 31, 2008.
• A description of your group's experience in managing peer review processes
It is anticipated that the contract will be a time and actual expense contract with a not to exceed
amount. Your proposal should provide the hourly rates of the personnel and a proposed cap for
the contract. If the hourly rates of the reviewers are unknown at this time, an estimate of those
rates should be provided.
The objective of the EARIP is to ensure an unbiased, independent review. Accordingly, the
EARIP will not suggest or recommend reviewers. The EARIP, however, does believe that the
reviewers should be from outside of the region and not have directly worked on projects
involving the Edwards Aquifer previously but may have expertise in ecohydrology, endangered
species, karst aquifer systems, and other appropriate disciplines.
Texas A&M University will serve as the contracting agent for the EARIP with respect to this
project. The project will be managed by Robert L. Gulley, the Program Manager for the EARIP.
All proposals and inquiries should be directed to:
Robert L. Gulley, Ph.D.
Program Manager
Edwards Aquifer Recovery Implementation Program
Texas A&M University
Institute of Renewable Natural Resources
4
3355 Cherry Ridge Dr., Suite 212
San Antonio, Texas 78230
210-467-6575, ext 232 (W)
210-930-1753(F)
RLGulley@ag.tamu.edu
Proposals should be received no later than October 10, 2008.

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ATTACHMENT 1
PARTICIPANTS IN THE EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM

The following thirty-eight Stakeholders have executed the 2007 Memorandum of Agreement
with the United States Fish and Wildlife Service regarding participation in the Edwards Aquifer
Recovery Implementation Program:

Aquifer Guardians in Urban Areas
Alamo Cement Company
Bexar County
Bexar Metropolitan Water District
Carol G. Patterson
City of Garden Ridge
City of New Braunfels
City of San Marcos
City of Victoria
Comal County
CPS Energy
East Medina Special Utility District
Edwards Aquifer Authority
Gilleland Farms
Greater Edwards Aquifer Alliance
Greater San Antonio Chamber of Commerce
Guadalupe Basin Coalition
Guadalupe-Blanco River Authority
Guadalupe County Farm Bureau
John M. Donahue, Ph.D.
Larry Hoffman
Mary Q. Kelly
Nueces River Authority
New Braunfels Utilities
Regional Clean Air and Water Association
San Antonio River Authority
San Antonio Water System
San Marcos River Foundation
South Central Texas Water Advisory Committee
South Texas Farm and Ranch Club
Texas Bass Federation
Texas Commission on Environmental Quality
Texas Department of Agriculture
Texas Living Waters Project

Texas Parks and Wildlife Department
Texas Water Development Board
Texas Wildlife Association
6
Union Carbide Corporation
7

ATTACHMENT 2
Edwards Aquifer Recovery Implementation Program
Science Subcommittee Members

Members with biological or ecological expertise
Norman Boyd (Texas Parks and Wildlife Department)
Doyle Mosier (Texas Parks and Wildlife Department)
Jackie Poole (Texas Parks and Wildlife Department)
Michael Gonzales (San Antonio River Authority)
Tom Brandt (U.S. Fish and Wildlife)
Ed Oborny (Bio-West)
Glenn Longley (Texas State University)
Members with geological or hydrological expertise
Mary Musick (TCEQ – retired)
Rene Barker (Texas State University)
Alan Dutton (University of Texas at San Antonio)
Ron Green (Southwest Research Institute)
Robert Mace (Texas Water Development Board)
Sam Vaugh (HDR Engineering Inc.)
John Waugh (San Antonio Water System)
Susan Aragon-Long (U.S. Geological Survey)
Charlie Kreitler (non-voting member LBG-Guyton)

EXHIBIT B

Scope of Work For Peer Review of the Edward aquifer Recovery Implementation Program's Science Subcommittee's "k" Charge Recommendations

Sustainable Ecosystems Institute ("SEI") will conduct a peer review of the EARIP's Science Subcommittee recommendations of the "'k' charges" described in the Request for Proposal provided to SEI by the EARIP conformance with this Statement of Work ("SOW"), and SEI's Proposal for Peer Review ("Proposal") (attached hereto as Attachment 1). To the extent that there is a conflict between the RFP or Proposal and this SOW, the SOW will govern the conduct of the work.

After initial scoping and review of materials and questions, SEI will set up a process that will provide a clear, transparent peer review of the highest caliber. SEI will use a peer review process that is well-documented and which can be shown to be impartial. The following describes the specific tasks that will be used to meet these needs and provide a clear record.

Task 1: Scoping of review: Conclusions regarding documents to review and reviewer expertise

SEI will review the Science Subcommittee's recommendations and assemble a panel of four-to-five scientists. Based on the RFP, SEI has initially determined that panel of experts should focus primarily on hydrological issues but also include ecological or species specific expertise. Accordingly SEI intends to put together a panel comprised of three hydrologists (with at least one scientists with expertise in karst systems), a population biologist, and a quantitative expert. SEI's initial determination regarding the expertise on the panel may be refined after SEI reviews the Science Subcommittee's recommendations.

Task 2: Selection of reviewers

SEI will follow its normal procedures in selecting highly-qualified reviewers who are able to review the materials. SEI will solicit the names of possible reviewers from SEI board members, from previous SEI panelists, from other eminent scientists, and from SEI's standing panels of exerts in various fields. SEI will develop a file for each scientist considered as a reviewer, and the reasons for selecting (or not selecting) that scientist will be included in that file.

After considering the available pool of reviewers, SEI staff will select those reviewers who best meet the criteria of scientific eminence and experience, and who also pass all other criteria of independence and impartiality set out in the RFP. SEI will interview the

reviewers, record their responses, and ask them to sign statements attesting that they have no conflicts of interest (as per National Academy and SEI guidelines [*we should attach these guidelines*], and as in RFP).

To ensure that the review is independent of the stakeholders and interested parties, the EARIP, its Science Subcommittee or Program Manager will not control or be involved in the selection of the reviewers.

Task 3: Preparation of reviewers

After SEI has selected reviewers, panelists will be provided with background and other materials as soon as they become available, through SEI's dedicated wiki-site (see below). SEI will also set up conference calls with reviewers, and facilitate discussions ahead of the actual review. SEI staff will work with individual panelists to ensure that they understand the materials, the review requirements, and their individual tasks.

Task 4: Wiki site

SEI will maintain a clear record of all materials disseminated to the reviewers, the communications between SEI and the reviewers and among the reviewers, and individual panelist's responses using SEI's wiki. The individual and group reports will also be crafted on-line, so that there will be a complete record of any changes made to any document. SEI will ensure that the site is secure so that EARIP participants may watch the review unfold, but will not be able to comment on the reviews unless expressly allowed by SEI in the limited circumstances described below.

Task 5: Preparation of review

To obtain the individual opinions of panelists, SEI will require that each panelist provide written responses to a series of review questions. SEI will also allow panelists to discuss their responses, the issues involved, and to modify their written responses in light of such discussions. SEI will reflect any differences of opinion among the panelists in the final report.

After a draft final report has been completed, SEI will allow the Science Subcommittee to interact with the review panel under SEI supervision, by asking questions, or by providing additional material as requested by the reviewers. This will be accomplished either by allowing the Science Subcommittee access to the wiki or through a recorded conference call. SEI will work with Susan Aragon-Long, the chair of the Science Subcommittee, to set up the arrangements for the interactive process. At the close of the interactive process the panel will finalize the review.

Task 6: Deliverables

Draft and Final reviews of documents, including individual reviewers opinions.

A full Administrative Record (to include all e-mails, drafts, ancillary materials)

Timetable of events

By December 31, 2008	Set-up project specific wiki Select reviewers Load background materials to wiki Develop instructions for reviewers Conferences with reviewers regarding the review and their responsibilities
December 31, 2008	Delivery of Science Subcommittee Recommendations by EARIP Program Manager for review
January 26, 2009	Draft report completed and provided to Science Subcommittee
February 16, 2009	Discuss results with Science Subcommittee
March 2, 2009	Final Review completed and submitted to EARIP Program Manager
March 16, 2009	Administrative Record completed and submitted to EARIP Program Manager

Appendix 3
E-mails on final reviews and discussions

1.Bain

Steven P Courtney, Vice President
Sustainable Ecosystems Institute
PO Box 80605
Portland, Oregon 97280

30 March 2009

Dear Steven:

Prior to the response to the review and phone discussion, I had stated in my review that the findings of the reports were acceptable, well reasoned, and supported by local information and direct analyses. My concerns were on the limited information used, reliance on simple analyses, and lack of quantification for some findings. These were discussed on the conference call

Task 2 (minimum spring flows) was discussed relative to the need to have a minimum flow and all were in agreement that it is an obvious and established requirement. The team explained that there was a need to make the point in their report. I had a minor disagreement on flow regime for springs justified using facts from rivers. The inconsistency was acknowledged on the call and all agreed the regime requirements needed to be analyzed and presented in more detail. Again, the conclusions of the report on this topic were fine.

My recommendation to develop an assemblage-level justification for water needs was for enhancing the impact and use of reported information. This was discussed as a good idea that was not needed for this study but would be beneficial in other communications. Discussion on the call made clear the case it is beyond the study scope as assigned.

My question on the magnitude of the fountain darter population was answered by reporting the approximate range of numbers of darters. It was far larger than I expected and this made the point that putting even rough ranges in the report would help readers.

Habitat manipulations and flushing flows suggestions I made were seen as good ideas for future studies. Such work relies a lot on non-local

information and was beyond the scope of this study.

Other minor points were also discussed and some changes were made in the report text to respond.

Overall, I felt my review and suggestions were recognized by the study team and worked to introduce some new ideas and approaches for their future work. Our discussion provided answers for me on why they chose their approach to complete their assignment. This resolved my questions and some limited concerns on how study was conducted and reported. It was a concsturctibe review discussion and I think both sides gained insight on this hard conservation case.

Feel free to follow up further if more information is needed.

Sincerely,
Mark Bain

2. Fryar

Hi Steven,

I jotted down some notes during the conference call. My sense is that the rewrite and the discussion during the call addressed most of my concerns (including those of Laura Toran, who wasn't on the call). The remaining issues for the final version of the report were:

(1) note explicitly that groundwater-stream interactions vary up- and down-stream of San Marcos Springs;
(2) note the limits of correlation between hydraulic heads in wells and spring discharge;
(3) expand the section on water chemistry enough to explain the differences in chemistry between the 2 groups of springs at San Marcos Springs, and whether they're consistent with differences in residence time and/or lithology;
(4) discuss previous dye traces in the San Marcos Springs segment of the Edwards aquifer;
(5) provide background information in Section 3 on actions taken when triggers are exceeded, and note what stages I - IV represent;
(6) revise suggested future research directions to address questions raised during the review.

If you're satisfied that these issues have been or are being addressed, I don't need to see the final version of the report.

Regards--Alan

Alan E. Fryar, Associate Professor Department of Earth and Environmental Sciences University of Kentucky 101 Slone Building Lexington, KY 40506-0053 USA phone 1 859 257 4392 fax 1 859 323 1938 e-mail alan.fryar@uky.edu

3. Toran
Steven

Thanks for the opportunity to comment on the responses to the SSC review. I have read the responses and listened to the conference call.

I don't have anything new to add to the discussion in the conference call, but I would reiterate or amplify some points brought up in the call.

-The addition of the figure and text describing stream recharge was helpful.

-When using the word "correlation" it is important to qualify that we don't expect wells and springs to necessarily correlate, and that correlation doesn't mean causation. It sounded like this was going to be clarified in the next revision of the report, and this clarification will help keep the readers from misinterpreting data.

-The report provides a good basis for minimal flow. However, optimal flow is still a question. It would be helpful to specifically state that different species have different flow needs, so there may not be an optimal flow rate. This statement would not alter the conclusions.

-I wasn't clear how much tracer test information was going to be included in the final report. A short paragraph would be helpful to amplify the references cited. In particular, point out how much of the conclusions on flow direction is from tracer tests. The other reviewers supported this addition.

-There was an interesting statement in the conference call that I would recommend including in the report: "Temporal distribution of recharge is variable." This statement helps explain why the pools are difficult to sort out. The pools may be connected at some times and not at others. This may have already been stated, but I thought the linkage to temporal variability of recharge was interesting. This could provide a focus for one future study. (How does recharge are vary through time?)

-There were some other examples of future studies mentioned in the conference call and in the reviews. These could easily fit into section 1.3. Some modification of this section would be helpful.

-I agree with Alan that the point of citing the EPA report was not to do extra work but just to provide a more readily accessible reference to a method for estimating recharge. Explaining Puente's method better would suffice as well.

Again, no substantial changes are being suggested in my comments here.
- Hide quoted text -

Dr. Laura Toran, P.G.
Temple University
Dept of Earth and Environmental Science
1901 N 13th St.
Philadelphia, PA 19122
215 204 2352
215 204 3496 (fax)
ltoran@temple.edu

4. Wicks

Hello,

I am satisfied that my concerns were addressed. The recommendations the authors made were supported by the science presented and the science presented was clear. If the science had not yet advanced to answering a question, the authors noted that lack.

The correlation needs to be better explained, but if you (Steven) are satisfied, then I do not to see it again.

As I had a slightly different understanding of my role as a reviewer than the other reviewers had of their roles, my comments were easily for the authors to address.

Carol M. Wicks

Department of Geology and Geophysics

Chair and Frank W. and Patricia Harrison Family Professor

E237 Howe-Russell Geoscience Complex

Louisiana State University

Baton Rouge LA 70803

cwicks@lsu.edu

225-578-2692

APPENDIX D:

REPORT OF THE EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM SCIENCE SUBCOMMITTEE, "ANALYSIS OF SPECIES REQUIREMENTS IN RELATION TO SPRING DISCHARGE RATES AND ASSOCIATED WITHDRAWAL REDUCTIONS AND STAGES FOR CRITICAL PERIOD MANAGEMENT OF THE EDWARDS AQUIFER," DECEMBER 28, 2009

Analysis of Species Requirements in Relation to Spring Discharge Rates and Associated Withdrawal Reductions and Stages for Critical Period Management of the Edwards Aquifer

Report to the Steering Committee
for the Edwards Aquifer Recovery Implementation Program

The Edwards Aquifer Area Expert Science Subcommittee
for the Edwards Aquifer Recovery Implementation Program

December 28, 2009

The photograph on the preceding page is of a flowing well in San Antonio from the 1890s (Hill and Vaughan 1896).

December 28, 2009

To: The Steering Committee for the Edwards Aquifer Recovery Implementation Program

From: The Edwards Aquifer Area Expert Science Subcommittee

Attached please find a final report titled *Analysis of Species Requirements in Relation to Spring Discharge Rates and Associated Withdrawal Reductions and Stages for Critical Period Management of the Edwards Aquifer*. This report meets the requirements of Article 12, Senate Bill 3, Regular Session, 80th Texas Legislature, Section 1.26A(j).

At our meeting held on December 16, 2009, Dr. Robert Mace called for a motion to approve the findings in the report. Mr. Sam Vaugh made the motion which was seconded by Dr. Glenn Longley. There were no objections; thus, the motion passed and consensus was reached. Fourteen of the 15 members were present at the meeting. Dr. Ron Green was not able to attend the meeting; however, Dr. Mace learned that Dr. Green had no objections to the findings in the report.

If you have any questions, please do not hesitate to contact our chair, Dr. Robert E. Mace with the Texas Water Development Board, at (512) 936-0861 or robert.mace@twdb.state.tx.us.

Analysis of Species Requirements in Relation to Spring Discharge Rates and Associated Withdrawal Reductions and Stages for Critical Period Management of the Edwards Aquifer

Report to the Steering Committee
for the Edwards Aquifer Recovery Implementation Program

The Edwards Aquifer Area Expert Science Subcommittee
for the Edwards Aquifer Recovery Implementation Program

December 28, 2009

The Edwards Aquifer Recovery Implementation Program
Edwards Aquifer Area Expert Science Subcommittee

Chair

Robert E. Mace, Ph.D., P.G., Texas Water Development Board

Facilitator

Susan Aragon-Long, U.S. Geological Survey (non-voting)

Members

Rene Barker, P.G., Texas State University
Norman Boyd, Texas Parks and Wildlife Department
Thomas Brandt, Ph.D., U.S. Fish & Wildlife Service
Michael Gonzales, San Antonio River Authority
Ron Green, Ph.D., P.G., Southwest Research Institute *(not in photo)*
Charles Kreitler, Ph.D., P.G., LBG-Guyton Associates
Glenn Longley, Ph.D., Texas State University
Robert E. Mace, Ph.D., P.G., Texas Water Development Board
Doyle Mosier, Texas Parks and Wildlife Department
Mary Musick, P.G., Musick Groundwater Consulting
Edmund L. Oborny, Jr., BIO-WEST, Inc.
Jackie Poole, Texas Parks and Wildlife Department
Sam Vaugh, P.E., HDR Engineering, Inc.
Shirley Wade, Ph.D., P.G., Texas Water Development Board
John Waugh, P.G., San Antonio Water System

Executive summary

In 2007, the 80th Texas Legislature passed Senate Bill 3 which, among other items, formalized the Edwards Aquifer Recovery Implementation Program. The legislation requires a group of stakeholders in a Steering Committee to develop a Program Document. The Program Document provides recommendations for withdrawal adjustments to protect threatened and endangered species at all times and includes provisions to pursue funding for programs to achieve that goal.

The Steering Committee is served by several subcommittees, one of which is the Edwards Aquifer Area Expert Science Subcommittee (subcommittee). Senate Bill 3 requires the formation of the subcommittee, with its members appointed by the Steering Committee. The subcommittee's initial charges were to (1) evaluate designating a San Marcos Pool, (2) evaluate the necessity of maintaining minimum springflows, and (3) evaluate whether adjustments to drought triggers for San Marcos Springs should be made. The subcommittee delivered a report in November 2008 titled *Evaluation of Designating a San Marcos Pool, Maintaining Minimum Spring Flows at Comal and San Marcos Springs, and Adjusting the Critical Period Management Triggers for San Marcos Springs* in response to these charges. The subcommittee concluded in this report that (1) there is not sufficient data to support the designation of a separate San Marcos Pool, (2) minimum springflows are required within the context of a system flow regime for the survival and recovery of each species, and (3) trigger levels for San Marcos Springs should not be adjusted at this time.

Senate Bill 3 also required the subcommittee to (1) analyze species requirements in relation to spring discharge rates and aquifer levels and (2) develop withdrawal reduction levels and stages for critical period management associated with the species requirements. This report is in response to these legislative charges.

It is important to note that the results presented in this report are driven by science only and do not consider or include policy implications or any actions that the Edwards

Aquifer Recovery Implementation Program Steering Committee may recommend as part of its Program Document. Actions recommended in the Program Document will likely affect these results; therefore, the results in this report can be considered as the beginning of a conversation among scientists, stakeholders, and various agencies on the ultimate management of the Edwards Aquifer to protect the endangered species that rely on springflow for survival.

When evaluating specific flow requirements for the listed species, the subcommittee (1) examined the overall condition of the system as it is today, (2) examined the available information to assess when impacts to a given species might first be evident, and (3) evaluated potential flow-related thresholds for the species. Throughout our assessment, we started with actual monitoring data when available, proceeded to modeling results when available, considered the historical hydrology, and finally confirmed or rejected hypotheses based on professional judgment.

The subcommittee chose to address our charges within the context of a flow regime for the protection of all listed species as well as the integrity of each ecosystem. Our interpretation of a protective flow regime is one that will ensure the "survival and recovery of the species in the wild". To accomplish this goal, the subcommittee determined that the recommended flow regime must sustain an overall trend of maintaining or increasing the populations of the threatened and endangered species. This by definition means that conditions cannot go beyond thresholds necessary for survival of any of the listed species.

The subcommittee selected the following components of the flow regime based on a comprehensive review of the best available science for the listed species in these systems:

- a long-term average flow,
- a minimum 6-month average flow, and
- a minimum 1-month average flow with an embedded minimum flow requirement (1 day).

Based on the analyses described in the body of this report, the subcommittee has determined the following spring discharge rates incorporated into a flow regime in association with the assumptions presented herein are necessary for the long-term survival of the aquatic communities of the Comal and San Marcos springs, in particular the federally listed species.

- Comal Springs Flow Regime:
    - Long-term average flow: 225 cubic feet per second
    - Minimum 6-month average flow: 75 cubic feet per second
    - Minimum 1-month average flow: 30 cubic feet per second with no flow below 5 cubic feet per second
- San Marcos Springs Flow Regime:
    - Long-term average flow: 140 cubic feet per second
    - Minimum 6-month average flow: 75 cubic feet per second

- Minimum 1-month average flow: 60 cubic feet per second with no flow below 52 cubic feet per second

The subcommittee made a conscious decision not to add a margin of safety to the proposed recommendations. It was our interpretation of our charges to evaluate the best available science objectively, clearly state the assumptions associated with the recommendations, and acknowledge the need for further study where appropriate. For instance, if it is later revealed that significant impacts are not captured in the model results or efforts to control parasites, exotic species, sedimentation, or recreation are not in place or successful in the future, then one needs to be cautious with strict implementation of the proposed flow recommendations. However, should information come forward that these species are able to tolerate short periods of lower flow conditions or more frequent occurrences without significant consequence, or mitigation activities are in place that could be effective in providing additional levels of protection, then the proposed flow regime recommendations would also need to be revisited. One thing is clear, long-term monitoring is essential and further study and research specifically during critical low-flow periods (or simulated critical low flows) are needed to accurately determine the potential impacts to the species.

This task is focused on developing withdrawal reductions and stages for critical period management based on the flow requirements for eight threatened and endangered species found in the Comal and San Marcos springs ecosystems (fountain darter [*Etheostoma fonticola*], San Marcos gambusia [*Gambusia georgei*], Texas blind salamander [*Eurycea rathbuni*], San Marcos salamander [*Eurycea nana*], Texas wild-rice [*Zizania texana*], Comal Springs dryopid beetle [*Stygoparnus comalensis*], Comal Springs riffle beetle [*Heterelmis comalensis*], and Peck's cave amphipod [*Stygobromus pecki*]). We assumed that our task was limited to adjusting withdrawal (pumping) reduction levels and stages for critical period management. We did not suggest changes to the overall permitting cap or how the act or the authority implements withdrawal reductions or permitting (although we did request model runs at different levels of constant pumping to better understand how the aquifer responds to different levels of pumping). Therefore, we restricted ourselves to considering adjustments of (1) the current number of stages; (2) the current trigger levels for J-17, J-27, Comal Springs, and San Marcos Springs; and (3) reductions in pumping at each of the stages. Based on our interpretation of the task, we developed withdrawal reductions and stages for critical period management that met or exceeded the flow requirements for the endangered species—we did not consider minimum pumping (or additional water supply infrastructure) needed to maintain health and human safety or any management actions that could be taken to lower springflow requirements. Our understanding is that these policy issues will be considered by the Steering Committee during the development of a habitat conservation plan.

We used an existing numerical groundwater flow model of the Edwards Aquifer and its associated management module to develop withdrawal reductions and stages for critical period management. We used the model to look at meeting or exceeding the three flow criteria for each of the two springs. After 38 model runs, the last run showed that pumping needed to be reduced 85 percent in a single stage to meet or exceed the springflow requirements. Therefore, the final critical period management scenario that meets or exceeds the final springflow recommendations is

San Antonio Pool

Comal (cfs)	San Marcos (cfs)	J-17 (feet)	Stage -	Reduction (%)
<225	<96	<665	I	85

Uvalde Pool

J-27 (feet)	Stage -	Reduction (%)
< 865	I	85

where cfs is cubic feet per second.

Several other model runs also met or exceeded the spring flow recommendations. One of these runs assumed constant pumping (that is, no critical period management) of 75,000 acre-feet per year, and another run had two critical period management stages, the first with a 30 percent reduction in pumping and the second with a 100 percent reduction in pumping.

We believe further study is needed to (1) improve springflow measurement, (2) conduct sensitivity analyses, (3) run optimization models, (4) estimate the probability of recurrence of the 1950s drought, (5) evaluate the potential effects of climate variability on recharge, (6) conduct additional runs to refine withdrawal reductions, (7) update the model, (8) refine the calibration of the model, (9) enhance the management module, and (10) refine model calibration between San Marcos and Barton springs.

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Introduction

The Edwards Aquifer is recognized as a vital water resource for a multitude of agricultural, environmental, industrial, municipal, and recreational uses. Several springs, specifically Comal Springs and San Marcos Springs, provide habitat for a number of species protected under the federal Endangered Species Act. After a lawsuit and the specter of federal control of the aquifer, the Texas Legislature created the Edwards Aquifer Authority to regulate pumping in the aquifer and to ensure that, by December 31, 2012, endangered and threatened species dependent on springflow are protected to the extent required by federal law.

In 2007, the Texas Legislature passed Senate Bill 3 which, among other items, formalized the Edwards Aquifer Recovery Implementation Program. The legislation requires a group of stakeholders in a Steering Committee to develop a Program Document. The Program Document provides recommendations for withdrawal adjustments to protect threatened and endangered species at all times and includes provisions to pursue funding for programs to achieve that goal. The Program Document may be in the form of a Habitat Conservation Plan used in the issuance of an Incidental Take Permit by the U.S. Fish and Wildlife Service. The Edwards Aquifer Authority, the Texas Commission on Environmental Quality, the Texas Water Development Board, and the U.S. Fish and Wildlife Service must approve and execute the Program Document no later than September 30, 2012, with the document going into effect by December 31, 2012.

The Steering Committee is served by several subcommittees, one of which is the Edwards Aquifer Area Expert Science Subcommittee (subcommittee). Senate Bill 3 requires the formation of the subcommittee, its members appointed by the Steering Committee (see Appendix A for information on the formation and operation of the

subcommittee). The subcommittee's initial charges were to (1) evaluate designating a San Marcos Pool, (2) evaluate the necessity of maintaining minimum springflows, (3) evaluate whether adjustments to flow triggers for San Marcos Springs should be made, and (4) submit the results to the Steering Committee and all other stakeholders involved in the Recovery Implementation Program by December 31, 2008 (see Appendix B for the exact words in statute). In response to these charges, the subcommittee delivered a report in November 2008 entitled *Evaluation of Designating a San Marcos Pool, Maintaining Minimum Spring Flows at Comal and San Marcos Springs, and Adjusting the Critical Period Management Triggers for San Marcos Springs* (EAAESS 2008). The subcommittee concluded in this report that (1) there is not sufficient data to support the designation of a separate San Marcos Pool, (2) minimum springflows are required within the context of a system flow regime for the survival and recovery of each species, and (3) trigger levels for San Marcos Springs should not be adjusted at this time.

Senate Bill 3 also charged the subcommittee to (1) analyze species requirements for springflow and aquifer levels as a function of recharge and withdrawal levels, (2) develop withdrawal reductions for critical period management associated with those requirements, and (3) submit results to the Steering Committee and all other stakeholders involved in the Recovery Implementation Program by December 31, 2009 (see Appendix B for the exact words in statute). In conducting its work, the statute required the subcommittee to consider all "reasonably available science" and to base its conclusions "solely on the best science available" (see Appendix B for the exact words in statute).

The purpose of this document is to report the r 1 of these latter charges. This report is organized according to the major charges in sta

Task 1: Analyze species requirements for springflow and aquifer levels as a function of recharge and withdrawal levels, and

Task 2: Develop withdrawal reductions for critical period management associated with the species requirements.

Under each task, we list our results, followed by our interpretation of the task, the information we considered, and the results of our analysis. Supporting documentation is included in the appendices where appropriate.

Because Task 1 was primarily a biological task and Task 2 was primarily a hydrological task, the subcommittee divided into two workgroups—one of biologists and one of hydrologists—to focus on their respective tasks. The full subcommittee continued to meet to discuss progress on both tasks and to coordinate activities where needed. All workgroup meetings were open to the general public. The nature of these two tasks was such that Task 2 depended upon the results of Task 1. The ambitious deadlines required by statute required us to make concessions on what information we considered (for example, work to update the habitat models for bathymetry and vegetation at the springs was not available in time for us to consider in this report) and what analyses we conducted (for example, we could have investigated other critical period management scenarios or refined the scenarios if given more time).

Task 1: Analyze species requirements in relation to spring discharge rates

Results: Based on the analyses described in the body of this report, the Edwards Aquifer Area Expert Science Subcommittee has determined the following spring discharge rates in association with the assumptions presented herein are necessary for the long-term survival of the aquatic communities of the Comal and San Marcos springs, in particular the federally listed species.

Comal Springs Flow Regime:

- **Long-term average: 225 cubic feet per second**
- **6-month average: 75 cubic feet per second**
- **1-month average: 30 cubic feet per second with no flow below 5 cubic feet per second**

San Marcos Springs Flow Regime:

- **Long-term average: 140 cubic feet per second**
- **6-month average: 75 cubic feet per second**
- **1-month average: 60 cubic feet per second with no flow below 52 cubic feet per second**

The Edwards Aquifer, including its two largest spring ecosystems, Comal and San Marcos springs, maintains a diversity of species, many of which are endemic. The species listed under the Endangered Species Act identified in Section 3.1 of the Edwards Aquifer Recovery Implementation Program Memorandum of Agreement (EARIP 2007) consist of eight threatened and endangered species found in the Comal and San Marcos springs ecosystems. These include two fish [fountain darter (*Etheostoma fonticola*) and San Marcos gambusia (*Gambusia georgei*)], two salamanders [Texas blind salamander (*Eurycea rathbuni*) and San Marcos salamander (*Eurycea nana*)], one plant [Texas wild-rice (*Zizania texana*)], and three invertebrates [Comal Springs dryopid beetle (*Stygoparnus comalensis*), Comal Springs riffle beetle (*Heterelmis comalensis*), and Peck's cave amphipod (*Stygobromus pecki*)]. Of these, only the San Marcos salamander is listed as threatened by the U.S. Fish and Wildlife Service (USFWS 1996); the rest are listed as endangered.

Each of these species has a restricted distribution limited to springs associated with the Edwards Aquifer, and several are found in either Comal Springs or San Marcos Springs but not both. Originally, only the fountain darter was believed to occupy both spring ecosystems, but recent collections of the Comal Springs riffle beetle in Spring Lake at the headwaters of the San Marcos River (Gibson and others 2008) reveal that this species is also found in both ecosystems. Among the other species, San Marcos salamander and Texas wild-rice occur only in the San Marcos River, while the Texas blind salamander is found in the aquifer below San Marcos and nearby springs. Two of the three invertebrates, Comal Springs dryopid beetle and Peck's cave amphipod, are found only in

Comal and nearby springs (that is, Hueco and Fern Bank springs). The San Marcos gambusia is considered extinct as no individuals have been collected since 1982, despite subsequent intensive surveys (USFWS 1996).

Our interpretation of the task

We interpreted the legislative charge to have the following focus:

(1) an emphasis on surface dwelling species that are directly influenced by "spring discharge rates",
(2) springflow will be used as the driving variable in the assessment, with the underlying acknowledgment that there are additional driving variables in these systems, and
(3) spring discharge rate does not simply mean a minimum flow, but as described in EAAESS (2008) represents a flow regime that will be protective of the species.

While the aquifer and its spring systems are closely associated with respect to water quality, water quantity, and thermal conditions, the Edwards Aquifer supports a highly adapted biological assemblage that differs considerably from those species found in the spring ecosystems. It is assumed that the individual species within the subterranean biological assemblage have adapted to seasonal and weather-related variations in groundwater levels. These levels have been known to change rapidly (for example, after a heavy rainfall event), but the water temperatures and water quality within the aquifer remains consistent (McKinney and Sharp 1995). Therefore, it is our interpretation of this task that the focus of this assessment should be on species inhabiting Comal and San Marcos springs that directly rely on spring discharge. For the surface-dwelling species, such as the fountain darter, San Marcos salamander, Texas wild-rice, and Comal Springs riffle beetle, some amount of springflow is necessary for survival and for recovery, and thus a detailed examination of individual species requirements for springflow is presented below. For the aquifer-dwelling listed species such as the Texas blind salamander, Peck's cave amphipod, and Comal Springs dryopid beetle, maintaining the same amount of discharge needed for the protection of surface dwelling species would likely protect these species also; however, potential impacts on these species are considered.

A host of environmental attributes shapes the partitioning of habitat and controls distributions of the various species in the Comal and San Marcos springs ecosystems. These attributes include depth, current velocity, temperature, substrate size and distribution, oxygen and carbon dioxide content, turbidity, and other physical and chemical conditions that combine with biotic influences to control population dynamics of individual species (USFWS 1996). Although each of these parameters is important individually, they are influenced by springflow as a group. As such, springflow will be treated as the driving variable for the discussion, although in instances where an individual environmental attribute (for example, water temperature) influenced by springflow appears to be the driving function, it will be highlighted. Additionally, it is acknowledged that these spring ecosystems are highly dynamic environments which react to many drivers, only one of which is springflow. Other factors influencing the springs and their environment are pumping, meteorology, physiographic modifications, local

watershed and recharge zone activities, recreational pressures, and many others. Any one or more of these factors can be of primary importance in influencing spring ecosystem conditions at any point in time. Our interpretation of the charge is that springflow is to be treated as the major driver and we have included assumptions pertaining to these other factors in the report.

We have previously described the importance of springflow to the aquatic ecosystems associated with Comal and San Marcos springs (EAAESS 2008). As described in EAAESS (2008), minimum flows are a necessary part of a flow regime of a given aquatic ecosystem for the protection of its component species, but the maintenance of minimum flows alone is not considered sufficient to maintain a sound ecological environment. The recommendation in EAAESS (2008) was that "minimum springflows are required within the context of a system flow regime for the survival and recovery of each species listed under the Endangered Species Act identified in Section 3.1 of the Edwards Aquifer Recovery Implementation Program Memorandum of Agreement. A system flow regime includes low flows which support the survival of individuals for limited periods of time, normal flows which support reproduction within the population, and higher flows that periodically rejuvenate the system." We continued to build upon that recommendation in the assessment of the legislative charge.

Approach

Our charge was to use the best biological information within the timeframe and resources currently available to assess the species requirements relative to springflow (used interchangeably with "flow", "spring discharge rate", and "total discharge"). This assessment will assist in predicting biological impacts (positive and negative) associated with changes in flow resulting in a flow regime that promotes survival and recovery of the threatened and endangered species of the Comal and San Marcos springs ecosystems.

Species requirements relative to spring discharge rate are very complex and any tool used to assess these relationships has pros and cons. Scientists have used instream flow modeling with species specific life-history information or more ecosystem based approaches, natural flow theory, and professional judgment to try and tease out these answers over the past several decades. We used components of all of these assessment tools to assist the decision with the following understanding of their limitations and applicability. A brief overview of each technique is provided in the following sections. Following the textual overview is a summary of the major data sources and key components that have been used to analyze the species requirements in relation to spring discharge rates at Comal and San Marcos springs. This summary is not meant to be all inclusive as we evaluated many individual research efforts and additional references; however, the summary is representative of the major sources that were directly applied while addressing the legislative charge.

In addition to this substantial body of work that exists on both the Comal and San Marcos rivers, the Edwards Aquifer Recovery Implementation Program contracted with Dr. Thomas Hardy to compile existing data for both systems and to provide analyses of the relationships between flow and habitat for protected species for which sufficient data were available (Hardy 2009). Additionally, Dr. Hardy convened a workgroup consisting

of biologists with knowledge of various aspects of the life history of the protected species being evaluated. Dr. Hardy convened facilitated work sessions to identify factors that are important to the survival of the federally listed species and their associated aquatic communities. This information was graphically represented as influence diagrams for each target species and was useful in identifying key parameters and issues that may directly, or indirectly, impact the long-term survival of the species. While an emphasis was placed on flow-dependent variables, the diagrams also provided a good overview of intrinsic and extrinsic factors that are recognized as potential or actual threats that have not been adequately addressed. We have identified many of these issues as recommended studies.

Instream flow modeling

Basically, all commonly used models and methods for setting instream flow requirements have been criticized for their overly simplistic and reductionist treatment of complex ecosystem processes and interactions (Mathur and others 1985, Orth 1987, Gore and Nestler 1988, Arthington and Pusey 1993, Stanford 1994, Castleberry and others 1996, Williams 1996). Although these methods may be useful for assessing protective flow regimes for some individual species, they provide little insight into complex ecosystem dynamics involving multivariate habitat influences, biotic interactions, and complex and varied life histories of riverine species (Richter and others 1996). Management decisions based on information or objectives keyed to a limited number of species and a limited number of their habitat requirements may actually result in undesirable effects on the ecosystem as a whole (Sparks 1992).

Despite the noted shortcomings, researching life history requirements of individual species and modeling projected conditions with respect to protective flow regimes provides vital information. This methodology has been used by both state and federal resource agencies on both the Comal and San Marcos springs systems to address the flow requirements of individual species and the ecosystem overall. The study design and justification of these efforts were well founded and, although somewhat limited by the number of habitat parameters considered, the studies have provided valuable information with respect to specific requirements of individual organisms. An overview of the major instream flow modeling studies used for our legislative charge assessment including key components and references is provided below.

- **Texas Parks and Wildlife Department instream flow study—San Marcos Springs**

  KEY COMPONENTS: Ecosystem approach
  Habitat modeling—native vegetation including Texas wild-rice
  Temperature modeling

  REFERENCE:
  Saunders, K.S., Mayes, K.B., Jurgensen, T.A., Trungale, J.F., Kleinsasser, L.J., Aziz, K., Fields, J.R., and Moss, R.E., 2000, An evaluation of springflows to

support the Upper San Marcos Spring ecosystem, Hays County, Texas: Texas Parks and Wildlife Department.

- **U.S. Fish and Wildlife Service instream flow study—Comal Springs**

KEY COMPONENTS: Species specific approach
Habitat modeling—Fountain darter
Temperature modeling

REFERENCE:

Hardy, T.B., Bartsch, N.R., Stevens, D.K., and Connor, P.J., 2000, Development and application of an instream flow assessment framework for the fountain darter (*Etheostoma fonticola*) in Landa Lake and the Comal River system, U.S. Fish and Wildlife Service.

- **U.S. Fish and Wildlife Service instream flow study—San Marcos Springs**

KEY COMPONENTS: Species specific approach
Habitat modeling—Fountain darter and Texas wild-rice
Temperature modeling

REFERENCE:

Bartsch, N.R., Hardy, T.B., and Connor, P.J., 2000, Development and application of an instream flow assessment framework for the fountain darter (*Etheostoma fonticola*) and Texas wild-rice (*Zizania texana*) in Spring Lake and the San Marcos River System: U.S. Fish and Wildlife Service.

- **Dr. Thomas Hardy "j Charge" technical report—Comal and San Marcos springs**

KEY COMPONENTS: Overview and revision of aspects of U.S. Fish and Wildlife Service's instream flow studies
Species specific approach
Habitat modeling—Fountain darter and Texas wild-rice
Habitat modeling for Comal Springs riffle beetle—spring run surface habitat only

REFERENCE:

Hardy, T.B., 2009, Technical assessments in support of the Edwards Aquifer Science Committee "j" Charge"—Flow regime evaluation for the Comal and San Marcos river systems: Prepared for the River Systems Institute, Texas State University.

<u>Biological monitoring/life history studies</u>

Biological monitoring programs and specific life history studies also provide vital information relative to an evaluation of species requirements for spring discharge rates.

The positive with this type of information is that it is typically based on data from the wild, not models, and thus the level of confidence in the results is greater. The negative is that in order to have sufficient data for analysis, the monitoring must be quite robust and continue for an extended period of time covering a wide range of discharge conditions. Fortunately, two such programs exist relative to Comal and San Marcos springs: the long-term Texas wild-rice annual monitoring conducted by Texas Parks and Wildlife Department and the Edwards Aquifer Authority variable flow monitoring program. Additionally, numerous individual studies have been conducted over the years to evaluate life-history components of the threatened and endangered species both through research activities conducted at the San Marcos National Fish Hatchery and Technology Center and Texas State University among others, and specific laboratory studies supported by the Edwards Aquifer Authority variable flow program, San Marcos National Fish Hatchery and Technology Center, U.S. Fish and Wildlife Service, Texas State University, and others. Although caution must be applied when interpreting laboratory results in the context of the wild, this information can be very informative and was used in our assessment. An overview of the major biological monitoring and life history studies used for the legislative charge assessment including key components and references is provided below.

- **Texas Parks and Wildlife Department Texas wild-rice annual monitoring**

  KEY COMPONENTS: Species specific approach
  Texas wild-rice spatial distribution and reproduction

  REFERENCES:

  Poole, J.M., 2002, Historical distribution of Texas wild-rice (*Zizania texana*) from 1989 to 2001: Section 6 Final Report: U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

  Texas Parks and Wildlife Department unpublished data 2002–2009.

- **Edwards Aquifer Authority variable flow study—Comprehensive and critical period monitoring program**

  KEY COMPONENTS: Ecosystem and species specific approach
  Aquatic vegetation, water quality
  Fountain darter, Comal Springs riffle beetle, Comal Springs dryopid beetle, Peck's Cave amphipod, San Marcos salamander, and Texas wild-rice

  REFERENCES:

  BIO-WEST, 2002a–2010a, Comprehensive and critical period monitoring program to evaluate the effects of variable flow on biological resources in the Comal Springs/River aquatic ecosystem: Final reports to the Edwards Aquifer Authority, San Antonio, Texas.

  BIO-WEST, 2002b–2010b, Comprehensive and critical period monitoring program to evaluate the effects of variable flow on biological resources in the San Marcos Springs/River aquatic ecosystem: Final reports to the Edwards Aquifer Authority, San Antonio, Texas.

- **Edwards Aquifer Authority variable flow study—Special studies and laboratory evaluations**

KEY COMPONENTS:
Species specific approach
Comal Springs riffle beetle—range evaluation
Comal Springs riffle beetle—flow response
Fountain darter—water temperature, parasite, and reproduction
Native aquatic vegetation, including Texas wild-rice—response to water quality and carbon dioxide concentrations

REFERENCES:

BIO-WEST, 2002c, Comal Springs riffle beetle habitat and population evaluation: Final report to the Edwards Aquifer Authority, San Antonio, Texas, 24 p.

BIO-WEST, 2002d, Comal Springs riffle beetle laboratory evaluation study: evaluation under variable flow conditions: Final report to the Edwards Aquifer Authority, San Antonio, Texas, 27 p.

BIO-WEST, 2004c, Aquatic vegetation laboratory study: Phase 1: Observations of water quality changes and plant growth under various flows, Phase 2: Effects of carbon dioxide level on aquatic plants found in the Comal and San Marcos springs/River Ecosystems: Final report to the Edwards Aquifer Authority, 25 p.

McDonald, D.L., Bonner, T.H., Oborny, E.L., and Brandt, T.M., 2007, Effects of fluctuating temperatures and gill parasites on reproduction of the Fountain Darter, *Etheostoma fonticola*: Journal of Freshwater Ecology, v. 22, no. 2, p. 311–318.

- **Edwards Aquifer Authority variable flow sponsored studies**

KEY COMPONENTS:
Species specific approach
Gill parasite response to flow conditions
Fountain darter—water temperature, parasite, and reproduction
Gill parasite response to fountain darter
Invertebrates response to flow variability

REFERENCES:

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- **National Fish Hatchery and Technology Center sponsored studies**

KEY COMPONENTS: Species specific approach
Fountain darter—water temperature and reproduction

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KEY COMPONENTS: Species specific approach
Texas wild-rice—spatial distribution, habitat characterization, genetics, life history and reproductive strategies, transplantation

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Natural flow theory

Another approach commonly employed to evaluate protective flow regimes is the Natural Flow Paradigm. At the extreme interpretation, this theory implies that the perpetuation of the native aquatic biodiversity and ecosystem integrity depends upon maintaining or restoring some semblance of natural flow variability (Minckley and Meffe 1987, Sparks 1992, Kinsolving and Bain 1993, Walker and Thoms 1993, Richter and others 1996). The probability of survival of native species and communities is reduced if the environment is altered outside of the range of its natural variability (Resh and others 1988, Swanson and others 1993).

In instances where natural flow variability can be maintained or restored (that is, by modifying a single parameter and restoring the ecosystem to pre-human contact), benefits to the native communities can be substantial. However, this is an unrealistic scenario in most cases, and it is implausible in the Comal and San Marcos springs ecosystems. These two spring ecosystems have been altered by humankind for at least 150 years. Alterations have included aquifer pumping, dam placement, extensive channelization, high recreational demands, extensive development in the riparian zone as well as the watershed, stormwater runoff, point and nonpoint source pollution, exotic species introduction (including parasites on native species), and others. These impacts have played a major role in the makeup and interactions of the residing aquatic communities over the past 150 years.

As such, the evaluation of the recorded hydrograph at both springs was used to some extent in our assessment. The premise to the flow analysis presented herein is that maintaining a flow regime similar to the recorded hydrograph, taking into consideration species-specific biological needs, might provide a valid approach for maintaining or enhancing endangered and threatened species in the Comal and San Marcos springs ecosystems. With the exception of the San Marcos gambusia, each of these species is currently present in its respective spring ecosystem. This indicates persistence through the drought of record for all species (though likely extinct now, the San Marcos gambusia was sampled subsequent to the drought of record) with the major exception of the fountain darter at Comal Springs. The fountain darter at Comal Springs was extirpated during the drought of the 1950s and reintroduced from San Marcos populations in the mid-1970s (Schenck and Whiteside 1976). One assumption that has been debated is that these species will continue to survive if flows do not go lower than historically recorded. Because of the changed conditions in these systems since the 1950s, we determined that a conservative strategy should be the goal at historically low flows. For example, while it is

impossible to state unequivocally that the stoppage of springflow at Comal Springs was the sole cause for the disappearance of the fountain darter in that system in the 1950s or that Texas wild-rice survived in the San Marcos River without human intervention, there is consensus that any period of zero flow or flows below what was historically observed would greatly increase the risk for reduced survival of the surface dwelling species. Therefore, our assessment evaluates the past hydrological records within the context of being protective when faced with the uncertainties surrounding risk at the lowest historical flows. The hydrology used for this assessment was taken directly from the U.S. Geological Survey gage data for both the Comal and San Marcos rivers.

Professional judgment

Our membership consists of dedicated scientists that, in some cases, have spent much of their careers working with the threatened and endangered species in these springs' ecosystems. As such, all analysis conducted has been reviewed and interpreted within the context of this institutional knowledge base. Based on that review, professional judgment is inherently embedded in our decisions. We have used the best available science for the determination of recommendations which in some cases is a direct result of professional judgment at this time.

Analysis, assumptions, and recommendations

Impacts to the flora and fauna within the Comal and San Marcos springs ecosystems are directly related to the amount and quality of occupied and potential habitat that is available to each species. The dynamic nature of stream ecosystems dictates that the amount of habitat available to each species will fluctuate in response to a number of variables, one of the most significant being streamflow. Instream flow must be sufficient to meet the necessary requirements of the species dependant on the stream system. Periods of drought pose risks to several species of concern in both the San Marcos and Comal springs systems because of the resulting periods of low-flow and probable loss of occupied and potential habitat. Although water quantity is a major factor determining such habitat for these species, other requirements include adequate water quality; preferred vegetation composition; low incidence of competitive, non-native species; and other species-specific conditions.

Flow regime

We chose to address the legislative charge within the context of a flow regime for the protection of all threatened and endangered species as well as the integrity of the ecosystem. In order to ensure the "survival and recovery of the species in the wild", we determined that the suggested flow regime must sustain an overall trend of maintaining or increasing the populations of the threatened and endangered species. This by definition means that conditions cannot go beyond thresholds that would not allow for the survival and recovery of any of these species in their natural environment.

Based on a comprehensive review of the best available science for the threatened and endangered species and professional judgment coupled with the underpinnings of

instream flow science and, to a limited extent, natural flow theory, we selected the following components of the flow regime for evaluation:

- long-term average flow,
- minimum 6-month average flow, and
- minimum 1-month average flow with an embedded minimum flow requirement.

The long-term average provides high quality habitat conditions throughout most of the spatial distribution of the species evaluated. Maintaining this condition on average over a long time period will provide habitat conditions necessary for survival and recruitment under limited to no stress. The most important component of the long-term average is that, by having this requirement, the system would not be able to have repeated 6-month or 1-month events also prescribed in the flow regime. As such, the lower flow criteria were developed with the understanding that they would rarely be experienced in the future.

The minimum 6-month average flow was incorporated into the flow regime to provide a safeguard from extremely low flow events. The 6-month flow is sufficient to maintain populations, albeit declining, through the short term. Under these flow conditions, it is assumed that there would be reduced habitat availability and populations of target species would be declining but would not be reduced to critically low numbers. The reproductive capability of the target species will be maintained, although perhaps at a reduced level. This discharge condition is one whose goal is to be protective of occupied aquatic habitat within the higher quality habitat areas of the system. The 6-month average is interpreted to be a rare hydrologic event.

The minimum 1-month average flow was incorporated into the flow regime to provide a threshold condition below which, for ecological reasons, the system should not fall. Should the system fall below this threshold, the probability of severe ecological impact considerably increases. The minimum 1-month average flow incorporates a minimum flow condition within the requirement. This threshold condition was included because it is widely acknowledged in the scientific literature that ecological systems are naturally defined by extreme events on both the high- and low-flow end of the spectrum. Having occasional extremes supports populations of native species that have evolved life history strategies in response to the natural flow regime (Poff and Allan 1995, Poff and others 1997, Bunn and Arthington 2002). Experiencing these natural extremes puts stress on non-native species and promotes the survival of the native flora and faunal community (Poff and Allan 1995, Poff and others 1997, Bunn and Arthington 2002). However, the frequency and duration of these extreme events are of critical importance and, if extended beyond the natural tendency of the system, can be detrimental to the resident ecological community. As such, the minimum 1-month average is only supported within the context of our recommended flow regime. It is important to understand that during this short time period, limited habitat would be supported within the system. However, sufficient habitat and water quality conditions would be maintained to ensure continued existence of the species in the wild. This may mean that the temperature is too warm for successful reproduction of fountain darters throughout most of the system during this month. However, the temperature within the entire system has been modeled to show that it

would likely not be lethal to any of the endangered species. The minimum 1-month average flow incorporates a minimum daily flow condition within the requirement.

We reviewed and considered two additional flow regime aspects (high flow pulses and seasonality). We acknowledge that high flow pulses are very important in both the Comal and San Marcos springs ecosystems to flush the system, remove vegetation mats, move sediment, and occasionally scour out vegetation. Impacts to habitat or the species themselves (in the case of Texas wild-rice) often occur during these events but, following the events, habitat rejuvenation usually occurs, providing refreshed habitat conditions for the species. Texas wild-rice sometimes rebounds from these events. However, the 1998 flood scoured the lower section of the San Marcos River below the Interstate 35 bridge, removing 20 percent of the total areal coverage. Over 10 years later, Texas wild-rice has still not recovered in this area. We evaluated high flow pulses within the context of each of the threatened and endangered species and made the determination that as these events are driven by precipitation, they would occur naturally.

Instream flow studies often embed a seasonality component within a proposed flow regime to attempt to mimic the normal patterns of climatology in the region. We reviewed this aspect in the consideration of the flow regime and determined that, because of the erratic climate of Central Texas, more or less stable nature of the spring systems and the reproductive potential of the species being considered, this component would be taken care of via natural recharge conditions and the variable flow conditions embedded in the flow regime recommendation which should address pumping withdrawals.

Species response to flow

We reviewed information from the aforementioned studies and direct observation to examine the influence of flow on species response. As previously stated, the best available science for the threatened and endangered species and their ecosystem was reviewed to assist in the determination of species requirements that could be incorporated within each of the proposed flow components. We also reviewed information from a more holistic approach using the aforementioned studies and observations to indirectly try and establish flow requirements deemed protective of the species via the habitat conditions that those flows are predicted to achieve.

The following section provides an overview of the distribution and habitat requirements of the species within each spring system. Additionally, this section provides an overview of our assessment which was conducted within the context of the flow regime components discussed above. When evaluating specific flow requirements for the threatened and endangered species we first started by (1) examining the overall condition of the system as we know it today, (2) followed by examining the available information to assess when impacts to a given species might first be evident, and (3) concluding with an evaluation of potential flow-related thresholds for the species. Throughout our assessment, we started with actual monitoring data when available, proceeded to modeling results when available, considered the historical hydrology, and finally confirmed or rejected based on professional judgment. Separate analysis, assumptions, and recommendations are provided for the Comal and San Marcos springs ecosystems.

Comal Springs analysis and assumptions

- Fountain darter (*Etheostoma fonticola*)

Fountain darters were collected for the first time in the Comal River in 1891. The last collection of fountain darters in the Comal River before its apparent extirpation was 1954. Whiteside and Schenck released 457 adult fountain darters, collected from the San Marcos River (mostly from below Rio Vista Dam), into the Comal Springs system from February 1975 through March 1976. A reproducing population has been reestablished and is now found throughout the entire Comal aquatic ecosystem from Landa Lake to the vicinity of the Comal/Guadalupe River confluence.

Habitat requirements for the fountain darter are dominated by water quantity, quality, water temperature, and vegetation composition attributes (Schenck and Whiteside 1976, Bonner and others 1998, Linam and others 1993). Biological monitoring conducted over the past nine years (BIO-WEST 2002a-2010a) has focused on four reaches of the Comal Springs system: Upper Spring Run (upstream most portion of the system to Spring Island), Landa Lake (Spring Island to the outflow to Old and New channels), Old Channel, and New Channel (Figure 1). Data collected via the Edwards Aquifer Authority variable flow study suggest that the highest quality fountain darter habitat at all flows in the Comal Springs system is in Landa Lake. Landa Lake maintains a diverse aquatic vegetation community, supports year round reproduction of fountain darters, and exhibits exceptional water quality conditions. These factors contribute to the continuance of large populations of fountain darters within Landa Lake. Prior to 2004, the old channel of the Comal River also supported similar conditions. However, the reconstruction of a new culvert system on the Old Channel coupled with an extended period of high flow conditions (facilitated by the new culvert system) led to a scouring of the native filamentous algae from this reach, which was subsequently repopulated with mostly non-native vegetation. As a result, habitat quality and resulting population numbers have both decreased within the Old Channel. Fountain darter reproduction in recent times in the Old Channel has shifted to primarily seasonal (spring time) peaks, evidence of lesser quality habitat conditions.

The Upper Spring Run and New Channel in the Comal River (Figure 1) have variable habitat conditions for fountain darters relative to spring discharge (BIO-WEST 2002a–2010a). The Upper Spring Run maintains high quality fountain darter habitat during moderate to higher flow (greater than 200 cubic feet per second total Comal Springs system discharge) conditions because of the expansion of bryophytes during these periods and subsequent use by fountain darters. Periodic pulses scour out the bryophytes and make this reach less suitable for darters. Additionally, lower flows (less than 200 cubic feet per second total Comal Springs system discharge) limit the amount of spring upwelling in this reach, which limits the amount of carbon dioxide (CO_2) in the water column. This limitation also causes a decline the in the CO_2 obligate bryophytes leading to lesser quality habitat for fountain darters. The New Channel reach acts somewhat in an opposite fashion to the Upper Spring Run reach. The New Channel supports higher quality habitat at below average flow (~250 cubic feet per second total Comal Springs system discharge) conditions because at these flows the establishment of aquatic

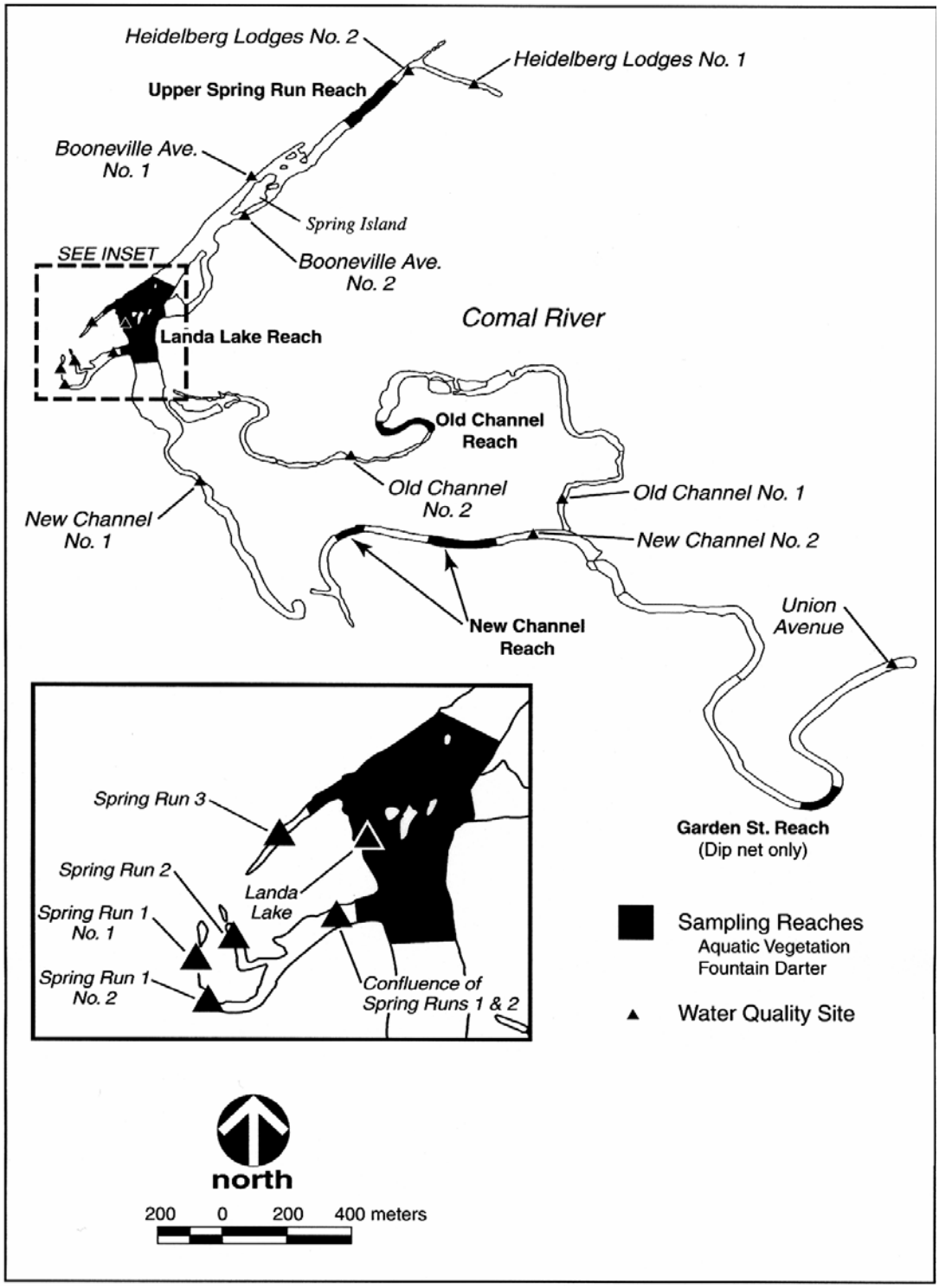


Figure 1: Comal River water quality and biological sampling areas for the Edwards Aquifer Authority variable flow study (BIO-WEST 2009a).

vegetation is possible throughout much of the reach. More aquatic vegetation leads to higher quality fountain darter habitat in the New Channel. Total Comal Springs system discharge greater than 350 cubic feet per second or high flow pulses cause a combination of factors that lead to lesser quality habitat in this reach. First, high flow pulses or sustained high flows scour out the aquatic vegetation in this highly altered reach. Secondly, higher flow conditions (greater depths) coupled with recreational use (which causes more turbidity) collectively cause less light penetration to sustain aquatic vegetation growth. Ultimately, these conditions lead to reductions in aquatic vegetation and quality of fountain darter habitat.

Over the past nine years of monitoring (BIO-WEST 2002a–2010a), total Comal Springs system discharge greater than 225 cubic feet per second has been shown to provide high quality fountain darter habitat throughout most of its range, not considering high flow events. Considerable habitat alteration has occurred several times over the years as a result of high flow pulses (heavy localized rain events) scouring out extensive areas of aquatic vegetation. These time periods are generally short-lived (hours to days) and the aquatic vegetation typically recovered and/or expanded in one to six months. BIO-WEST (2007c) has concluded that in most cases these represent flow events that have direct impacts on fountain darter habitat but only on a temporary time scale. One exception to date was the non-native vegetation that replaced native vegetation after high flow conditions in the Old Channel resulting in lower quality habitat. During the nine years of monitoring at Comal Springs, springflow has been documented to cease horizontal flow over the concrete wall at Spring Run 5 (Upper Spring Run reach, near Heidelburg Lodge 2; Figure 1) at approximately 150 cubic feet per second total discharge in the Comal Springs system. At this total discharge level, the flow through the Upper Spring Run reach becomes limited. This, coupled with warm weather conditions present in the summer, leads to the development of extensive mats of green algae (this is not the filamentous algae previously described as high quality habitat). Under those conditions, fountain darter habitat quality related to discharge was reduced, thus indicating a good starting point for discussion as when impact to fountain darter habitat starts to occur in the Comal Springs system. At 150 cubic feet per second total system discharge, conditions observed (albeit for only a short period of time) in Landa Lake and subsequent downstream habitat in the Comal Springs system indicated no signs of aquatic habitat reductions.

Another example of a direct flow-related impact to fountain darter habitat on the Comal Springs system happened following the reconstruction of the culvert system on the Old Channel. This reconstruction, coupled with extended periods of wet weather, led to higher than average flow (greater than 80 cubic feet per second Old Channel discharge) conditions in the Old Channel that resulted in considerable alteration in fountain darter habitat. Exotic vegetation has subsequently colonized areas of the Old Channel that previously maintained filamentous algae and other native vegetation, which has caused this section of river to not return to the pre-impacted condition. A detailed description of this impact is presented in BIO-WEST (2007c). Prior to the recent conditions described for the Old Channel, it supported higher populations of fountain darters (Linam 1993, Hardy and others 2000, BIO-WEST 2002a, BIO-WEST 2003a).

The U.S. Fish and Wildlife Service, in conjunction with Utah State University, conducted a study in the early 1990s to determine the amount of habitat available to the fountain darter under various streamflow conditions in the Comal Springs ecosystem. The designation of suitable habitat included the presence of water (wetted perimeter), preferred vegetation composition, and water temperature (Hardy and others 2000). This is the same study reviewed and presented in the Hardy (2009) report.

The results presented in the Hardy and others (2000) study indicate that a 50 percent decrease in discharge (from 300 cubic feet per second to 150 cubic feet per second) has very little impact on predicted fountain darter habitat (99.2 percent of the suitable habitat is maintained) (Table 1). Available habitat remains relatively high (>90 percent overall) as flow is reduced to 100 cubic feet per second. The spring runs are the only areas where substantial reductions (more than 40 percent, Table 1 (b)) begin to occur at 100 cubic feet per second total discharge.

In all probability, however, the impact of habitat loss in the spring runs is minimal for the fountain darter; fountain darters are rarely collected or observed within the spring runs, and modeling predicts that even at a flow of 300 cubic feet per second, suitable spring run habitat comprises only 1.3 percent of the total calculated area (Table 1(c)).

Based on the modeling efforts of Utah State University and the U.S. Fish and Wildlife Service, when total springflow drops to 60 cubic feet per second and 30 cubic feet per second in the Comal Springs system, about 75 percent and 60 percent, respectively, of total darter habitat remains (Table 1(b)). The majority of this habitat loss is due to thermal conditions that cause a reduction in the survival of larval fountain darters (Figure 2). Temperature remains a variable of primary importance because individuals farthest downstream periodically experience temperatures that reach or exceed 77º F (25º C). This is the value at which research indicates spawning success and juvenile growth rates of fountain darters are reduced (Brandt and others 1993, Bonner and others 1998, McDonald and others 2007). Although spawning success and larval growth begin to decline at this temperature, it is a conservative upper temperature limit; the critical thermal maximum for the fountain darter is 94.6º F (34.8º C) (Brandt and others 1993). Figure 2 shows that at 60 cubic feet per second only the middle portion of the Upper Spring Run reach and lower portion of the Old Channel provide unsuitable temperatures for fountain darters. At 30 cubic feet per second, the unsuitable area increases, but no affects are predicted in the upper portion of the Old Channel or within Landa Lake. Modeled temperature conditions throughout the entire Comal Springs system remain suitable for some fountain darter survival at both these flow conditions.

The Hardy and others (2000) findings also suggest that 40 cubic feet per second should be diverted into the Old Channel reach whenever total Comal Springs springflow allows. The weighted usable area calculated in that report doubles at flows between 30 cubic feet per second and 40 cubic feet per second in the Old Channel.

A major factor in the Comal Springs system is the continued presence of an Asian trematode, *Centrocestus formosanus*. This parasite was first discovered on fountain darters in the Comal River during October 1996. The parasite attaches to the fish's gill filaments causing extensive gill tissue proliferation and damage (Mitchell and others

Table 1: (a) Predicted area of suitable fountain darter habitat ($x10^3$) at various levels of total springflow from Comal Springs, (b) suitable habitat that remains as a percent of the segment, and (c) suitable habitat remaining as a percent of the total area in the system.

(a) Predicted Fountain Darter Habitat [a]

Total Springflow Rate (cfs)	Landa Lake (ft^2)	New Channel (ft^2)	Main Spring Runs 1-3 (ft^2)	Old Channel (ft^2)	Total Area (ft^2)
300	811.9	210.8	18.0	344.2	1384.9
150	798.0	218.9	13.1	344.1	1374.1
100	680.6	220.4	10.7	341.3	1253.0
60	544.9	223.4	6.5	267.3	1042.0
30	524.3	178.9	2.9	125.4	831.5

(b) Percent of Segment [a]

Total Springflow Rate (cfs)	Landa Lake	New Channel	Main Spring Runs 1-3	Old Channel	Total Area
300	100.0	100.0	100.0	100.0	100.0
150	98.2	103.8	72.8	100.0	99.2
100	83.8	104.6	59.4	99.2	90.5
60	67.1	106.0	36.1	77.7	75.2
30	64.6	84.9	16.1	36.4	60.0

(c) Percent of Total Area [a]

Total Springflow Rate (cfs)	Landa Lake	New Channel	Main Spring Runs 1-3	Old Channel	Total Area
300	58.6	15.2	1.3	21.9	100.0
150	57.6	15.8	0.9	24.8	99.2
100	49.1	15.9	0.8	24.6	90.5
60	39.3	16.1	0.5	19.3	75.2
30	37.9	12.9	0.2	9.1	60.0

Source: USFWS draft report (2000).

[a] For these calculations, a total springflow level of 60 cubic feet per second directs 50 cubic feet per second into the New Channel and 10 cubic feet per second into the Old Channel, while a total springflow level of 30 cubic feet per second directs 25 cubic feet per second into the New Channel and 5 cubic feet per second into the Old Channel. Cfs = cubic feet per second; ft^2 = square feet.

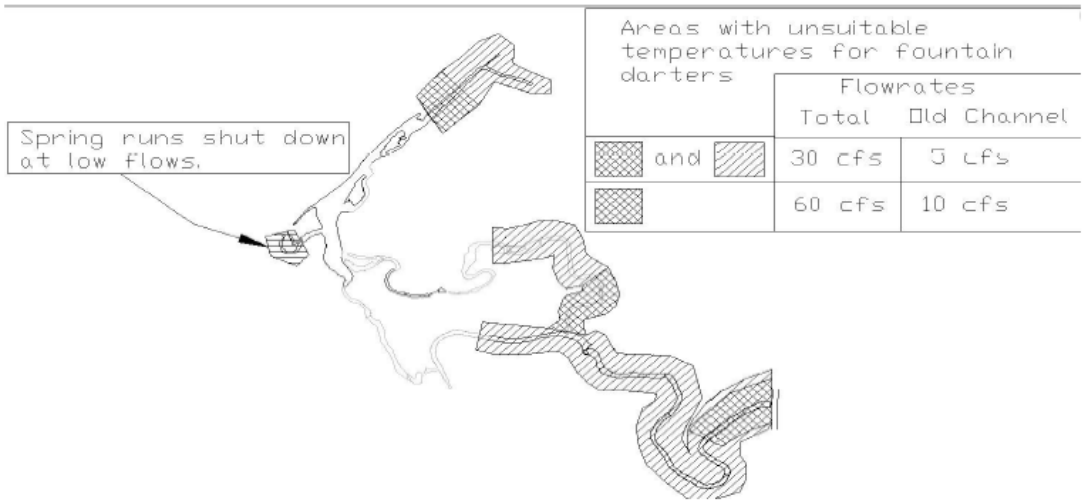


Figure 2: Predicted areas of unsuitable temperatures ("unsuitable" refers to a reduction in the spawning success of fountain darters and declines in larval growth) for fountain darters at a total discharge of 60 cfs and 30 cfs in the Comal Springs system (Hardy 2009) (cfs = cubic feet per second).

2000) with mortality in the wild being reported following the discovery in 1996 (Thomas Brandt, personal communication). A non-native snail, *Melanoides tuberculatus*, that has been in Central Texas since 1964 (Mitchell and others 2005) has been confirmed as its Central Texas first intermediate host (Mitchell and others 2000). Upon emergence from its egg, *Centrocestus formosanus* begins life as a few swimming larva that penetrates its first intermediate host, a snail. Within the first intermediate host the trematode will encyst, then metamorphose into free-swimming cercaria that emerge from the snail. The cercaria will then seek out a fish to serve as a secondary intermediate host. Various species of fish-eating waterfowl serve as the definitive host. Parasite monitoring via examination of presence on fountain darter gills to determine *Centrocestus formosanus* levels in the Comal and San Marcos rivers has been ongoing since the late 1990s by the U.S. Fish and Wildlife Service, Texas State University, and BIO-WEST, (partially funded by the Edwards Aquifer Authority). Brandt (U.S. Fish and Wildlife Service) speculates the parasite became well established in the Comal River in 1997, as 100 percent of collected fish were infected with an average of 100 cysts per fish. The parasite probably increased to fountain darter life-threatening levels in the Comal River during 1998 because dropping or slowly rising springflows between 1994 and 1998 allowed *Melanoides tuberculatus* numbers to build (Tom Brandt, personal communication). *Melanoides tuberculatus* does well in nutrient-rich, flowing environments, that are not subjected to spates (rapidly rising water levels—flash floods) (Giovanelli and others 2005). Brandt speculates the parasite numbers in the Comal River dropped during the 2000s because of floods during mid-1998, mid-2000, mid-2002, and above normal flows during 2003, 2004, and most of 2005. The drought beginning in 2007 allowed the numbers of *Melanoides tuberculatus* and *Centrocestus formosanus* to start building in both rivers (Tom Brandt, personal communication).

Bolick (2007) conducted her masters project in coordination with U.S. Fish and Wildlife Service, Texas State University, and BIO-WEST to evaluate the effect of the gill parasite with respect to flow in the Comal Springs system. Bolick (2007) concluded that neither total stream discharge (measured at the U.S. Geological Survey gage) nor wading discharge (measured at each transect when collections were taken) were found to be a useful predictor of cercarial abundance during the flow conditions (204 cubic feet per second to 441 cubic feet per second) present during her efforts. Cercarial abundance differed between sites and increased with distance downstream. Downstream sites received cercarial drift from their immediate area, as well as areas upstream. Abundance differed in relation to sun intensity as well, with higher cercarial counts on sunny days rather than cloudy days. Season also seemed to influence abundance of cercaria with the period from late fall to early spring having the highest abundance of the parasite. In order to reduce confounding effects of site, sunlight intensity, and season, the dataset was restricted to include only samples from the upstream-most site (Houston Street) on sunny days from late fall to late spring. However, even after removing these confounding effects, all measured variables (including moderate to high flows) were still found to be poor predictors of cercarial abundance. Results suggest that fountain darter populations in the Comal River will not experience increased infection pressures from *Centrocestus formosanus* within the range of total Comal Springs system discharges (204 to 441 cubic feet per second) observed during this study (Bolick 2007). The mean cross-section discharges at the three study sites over the study period ranged from 14 cubic feet per second (Upper Spring Run reach) to 50 cubic feet per second (Old Channel). Should moderate flow exist for several years without any flash floods followed by low flows due to drought conditions, it is anticipated that cercarial abundance may increase to a more severe level (Tom Brandt, personal communication).

Additional concerns include the presence of exotic species, water quality degradation, and recreation which all have consequences on the fountain darter populations in the Comal Springs system. Studies have shown that many fishes (especially small fish) have very similar food habitats (Hubbs and others 1978). If non-native species are added to the aquatic ecosystems, greater competition or overlap among species is possible. These non-native species may be able to acquire resources with greater efficiency than native species (USFWS 1984). Suckermouth catfishes (*Loricariidae*) are a non-native fish species that has become established in the waters of Texas including the Comal and San Marcos rivers (Howells 2005). In particular, suckermouth catfishes prefer to feed on periphyton and algae (Hoover and others 2006). The fountain darter lays eggs on algae and is believed to be threatened by the loss of spawning habitat and possibly egg predation. There is some concern that excessive numbers of suckermouth catfishes could cause direct (potential displacement) and indirect effects (disruption of food supply) to the fountain darter in the Comal and San Marcos rivers.

A non-native gastropod (giant ramshorn snail [*Marisa cornuarietis*]) also poses a threat to the Comal Springs ecosystem. The giant ramshorn snail, a species in the aquarium trade, was first discovered in Landa Lake in 1984 (McKinney and Sharp 1995). This snail grazes on aquatic plants and in the 1990s played a major role in reducing plant biomass in Landa Lake. This snail prefers clear streams and pools with temperatures of at least 66° F (19° C). When exposed to lower temperatures, the snails withdraw into their shells and only survive for short periods. The warmest temperature that the giant ramshorn snail can

withstand is 102° F (39° C). Although the population has diminished since the mid-1990s, the potential for future alteration of plant communities in these two ecosystems remains and could affect endangered species (McKinney and Sharp 1995, BIO-WEST 2007c). The strong preference of fountain darters for aquatic vegetation highlights the concern posed by the grazing activities of the giant ramshorn snail (BIO-WEST 2004a). Regardless of present numbers, this species needs to be monitored closely to assure that it does not significantly reduce the available fountain darter habitat.

Water quality encompasses a range of variables that can potentially impact fountain darters and other aquatic life if altered too far from the historic range to which the stream inhabitants have become accustomed. Most potential water quality problems are linked to nonpoint source pollution such as fertilizer runoff and chemicals washed in from adjacent streets; however, spills and leaks from industrial and municipal infrastructure along the heavily developed shorelines of the Comal River also present hazards. The potential for accidents and nonpoint source pollution to affect the organisms in the Comal River may be exacerbated during below average flows since chemicals and nutrients would be less diluted when a lower volume of water is present.

Recreational pressure is another concern regarding the protection of fountain darter habitat. Qualitative observations of increasing recreational activity have been noted for the Comal Springs system. However, on the Comal Springs system, the bulk of the recreational activity is fairly isolated to the New Channel, portions of the Old Channel and below the confluence of the Old and New channels. Being at the downstream extent of the Comal River, these areas support the lowest quality habitat for fountain darters and thus, recreation, as long as it does not increase in the higher quality habitat, is not nearly the concern as for the San Marcos River.

- Comal Springs riffle beetle (*Heterelmis comalensis*)

Comal Springs riffle beetles (*Heterelmis comalensis*) are found in areas where springflow is evident around Landa Lake in the Comal River (Figure 3). This includes spring runs 1, 2, 3, and 6 (Bosse and others 1988, Bowles and others 2002, Gibson and others 2008) and spring openings associated with shoreline habitat, upwelling areas surrounding Pecan Island, and deeper water within the lake (BIO-WEST 2002c, Gibson and others 2008). Bowles and others (2002) suggest that the primary requirements for Comal Springs riffle beetles relate to high-quality springflow and maintenance of physical habitat, and BIO-WEST (2004a–2010a) has documented the affinity for clear flowing water either horizontally or via upwelling.

One of the primary flow-related questions is associated with the survival of the species during the drought of the 1950s. No information is available to indicate how the species survived this period of prolonged drought and approximately five months of zero flow. However, recent discoveries of individuals in the lake suggest that individuals were likely in areas that maintained surface water during that period. Hypotheses regarding their survival include the persistence of a few individuals in Landa Lake and subsequent redistribution to spring run habitats, a localized retreat into the spring heads or hyporheos (between particles of the stream bottom substrate), or aestivation carried out in a specific life stage (Bowles and others 2002, BIO-WEST 2002d).

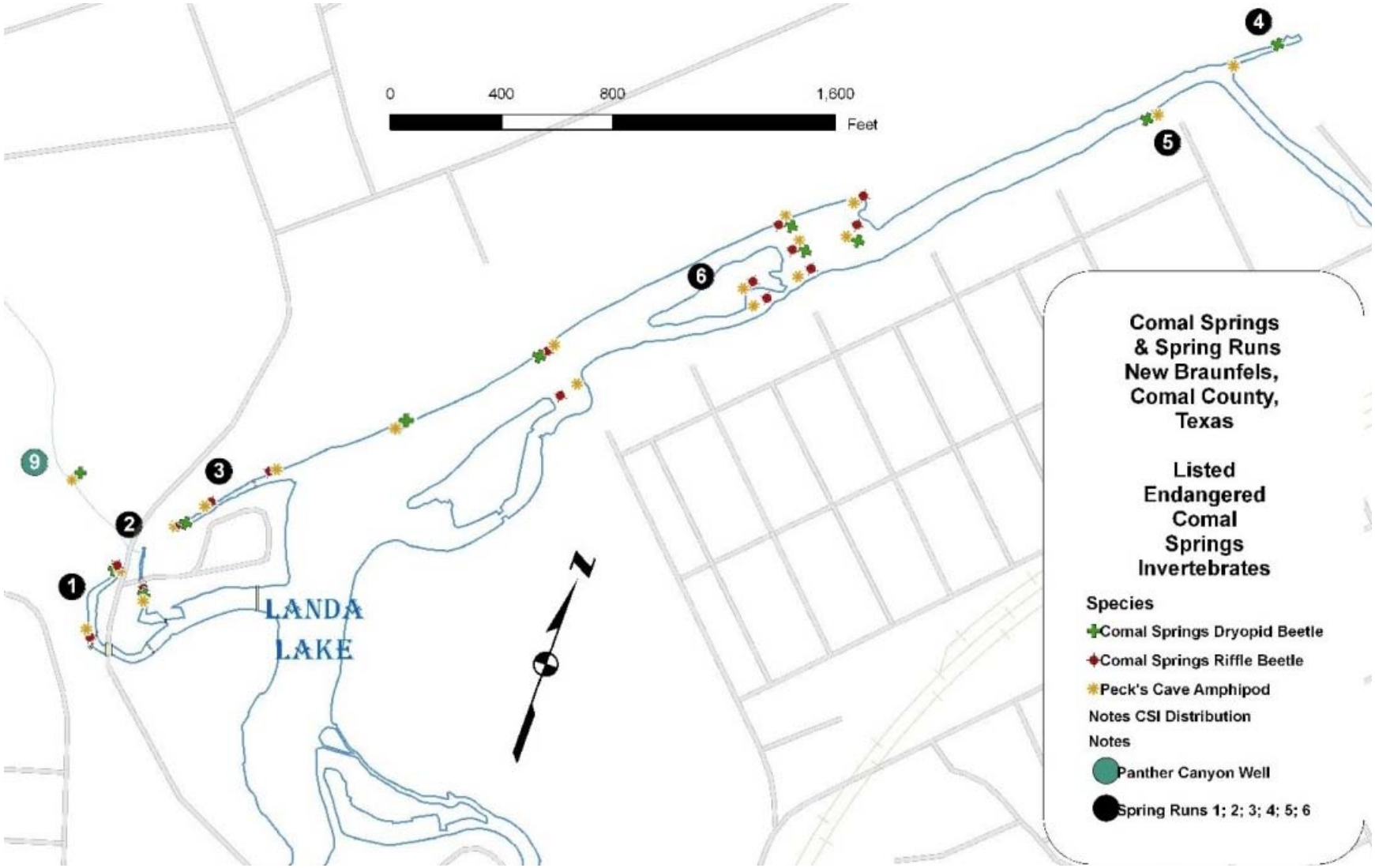


Figure 3: Collection locations of Comal Springs threatened and endangered invertebrates during the Edwards Aquifer Authority variable flow study.

One of the hypotheses, the use of the hyporheos during drought conditions, was tested under laboratory conditions. The findings suggest that Comal Springs riffle beetles associate strongly with springflow and move down into the substrate in response to upwelling (BIO-WEST 2002d). The study showed Comal Springs riffle beetle response to a shift in springflow direction and intensity (that is, individuals tended to move downward toward the source of water flow). This would lend credence to the hypothesis that the species retreats into spring heads during drought and possibly at other times. Although no published document has indicated that members of the genus *Heterelmis* use the hyporheos at times other than during drought, Poole and Stewart (1976) found that members of another riffle beetle genus, *Stenelmis*, were the most prevalent insects recovered from deeper strata in the Brazos River, Texas. This occurred despite the fact that no springs allowed for water circulation (that is, replenishment of oxygen, removal of waste products, etc.). In the spring-fed conditions within the range of the Comal Springs riffle beetle, factors such as low dissolved oxygen that typically limit vertical stratification in the hyporheos would be less prohibitive. This behavior in a similar taxon and research suggesting movement toward the source of water flow (downward) raises uncertainty about the proportion of the population that may be found below the upper layer of rocks that have been primarily sampled for the species.

To evaluate the surface flow or wetted area in the spring runs, Hardy (2009) modeled the three main spring runs of Landa Lake. The potentially suitable habitat for the Comal Springs riffle beetle was restricted to the main spring runs in water depths ranging from 0.02 to 2.0 feet and velocities of up to 2.0 feet per second. The simulated model runs for the surface area in the spring runs is presented in Figure 4.

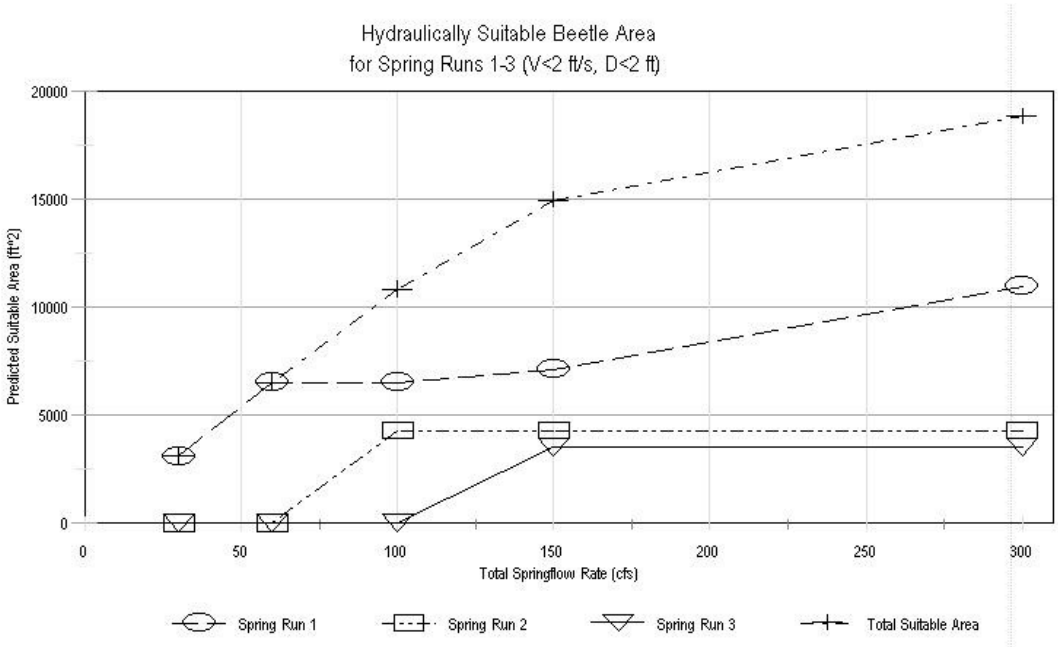


Figure 4: Simulated Comal Springs riffle beetle surface habitat in main spring runs at Comal Springs based on depth and velocity criteria (Hardy 2009).

Figure 4 shows approximately a 30 percent reduction in Comal Springs riffle beetle surface habitat within Spring Run 1 from 300 cubic feet per second to 150 cubic feet per second total discharge with no reduction in surface habitat for spring runs 2 or 3 at the same flow reduction. There is only a slight reduction predicted in surface habitat in Spring Run 1 going from 150 cubic feet per second to 100 cubic feet per second or 60 cubic feet per second total discharge. There is no reduction in surface habitat predicted at Spring Run 2 at 100 cubic feet per second. However, elimination of surface habitat is predicted at 100 cubic feet per second at Spring Run 3 and 60 cubic feet per second for Spring Run 2. Overall, there is approximately a 70 percent predicted reduction in Comal Springs riffle beetle surface habitat within Spring Run 1 from 300 cubic feet per second to 30 cubic feet per second total discharge. There is no surface habitat predicted for spring runs 2 or 3 at 30 cubic feet per second total discharge.

Although the modeling of surface habitat addresses changing conditions within the three main spring runs, it is important to reiterate that approximately 50 percent of Comal Springs riffle beetle habitat exists within Landa Lake (Figure 3) and was not considered in this modeling exercise. Additionally, the importance of subsurface habitat was not considered in this modeling exercise. Because specific springflow requirements cannot be accurately defined with these stated limitations in modeling, conservative management dictates that historic conditions should not be approached or exceeded. Bowles and others (2002) was unable to determine the appropriateness of current take and jeopardy limits set by the U.S. Fish and Wildlife Service but suggested that the springs should not be allowed to stop flowing for extended periods or become permanently dry. Hardy (2009) recommends that, “the most conservative approach to long term protection of this species would be to maintain surface flows in the various spring runs of Landa Lake”. Additional research is needed to assess the extent of population-level effects under low flows and to identify potential mechanisms for coping with drought that may have contributed to survival during the drought of record. However, until any such mechanisms are identified, it is assumed that conditions experienced in the drought of record were harmful to the species and exposing the population to zero flow for any longer than previously experienced would incur a high probability of detrimental impacts. This is supported by Gonzales (2008) who suggests a divergence in genetic diversity between the spring runs and Landa Lake populations of Comal Springs riffle beetles, potentially related to low flow extremes. It is also recognized that hydrological conditions experienced since the drought of the 1950s did not cause extirpation of the species as they continue to exist in the springs (although the species was not described until after the 1950s, it is assumed that it was present before or during the 1950s).

- Comal Springs dryopid beetle (*Stygoparnus comalensis*)

Very little information is available for the Comal Springs dryopid beetle (*Stygoparnus comalensis*), except that it is a subterranean, aquatic (stygobiotic) species that has been collected primarily from spring runs in the Comal Springs ecosystem and Fern Bank Spring in Hays County (Barr and Spangler 1992, Gibson and others 2008). Figure 3 shows the collection locations for the beetle during the Edwards Aquifer Authority variable flow study. The subterranean nature and restricted range of the species (to the headwaters of the springs and spring upwelling areas) suggests that it does not require substantial surface discharge from springs to survive. Therefore, it is presumed that

springflow (of sufficient water quality) that continually covers the spring orifice should prevent harm to the population.

- Peck's Cave Amphipod (*Stygobromus pecki*)

As with the Comal Springs dryopid beetle, very little is known of the habitat requirements of Peck's Cave amphipod (*Stygobromus pecki*). The species has been found in the spring orifices and upwelling areas throughout Comal Springs, and the Panther Canyon well (Figure 3). This species is often found in large numbers associated with the major spring runs at Comal (BIO-WEST 2004a–2010a). Assumptions regarding the species' requirements include sufficient springflow and water quality. In order to meet these assumptions, it is presumed that spring orifices should remain covered with flowing water to prevent harm to the species.

Historical flows at Comal Springs

To put the observed variable flow data from the past nine years and predicted model results in perspective and following the concept of the natural flow paradigm, we conducted an evaluation of the historical hydrology. The average discharge at Comal Springs during the period of record from 1927 to 2009 was approximately 291 cubic feet per second. The minimum recorded flow was zero when the springs stopped flowing for 144 consecutive days in 1956. This extreme flow condition, coupled with the likelihood that this event led to the extirpation of the fountain darter, is considered beyond the point of severe risk to the threatened and endangered species. Although all other endangered species were assumed to persist through this period, there is no evidence as to the state of health of any of these populations immediately following that event which provides an unknown relative to whether they would persist if those conditions were repeated.

Another historic period that is biologically meaningful for the Comal Springs system is the period of time since the fountain darter has been re-introduced into Comal Springs (post-1975). Sustained current populations (BIO-WEST 2002a–2010a) suggest that this period has been favorable for the fountain darter. It is important to note that spring discharge in the Comal Springs system in 1984 went below 60 cubic feet per second for over 100 consecutive days and below 40 cubic feet per second for over 40 consecutive days (dropping all the way down to 26 cubic feet per second). Since 1975, diminished flows at Comal Springs have occurred in 1984 (26 cubic feet per second), 1989 (62 cubic feet per second), 1990 (46 cubic feet per second), 1996 (83 cubic feet per second), and 2000 (138 cubic feet per second) with continued survival of the fountain darter, Comal Springs riffle beetle, Comal Springs dryopid beetle, and Peck's Cave amphipod.

Comal Springs flow regime recommendations

Figure 5 provides an overview of the information used to develop the flow regime recommendations for the Comal Springs system. To develop an ecologically protective flow regime, a balancing of species specific requirements was conducted where results did not align identically. In instances where there were competing species specific requirements, the higher flow requirement was conservatively chosen in each case following an analysis and understanding that this recommendation would not negatively impact the other species or overall ecosystem integrity.

Long-term average	Minimum 6-month average	Minimum 1-month average
Edwards Aquifer Authority Variable Flow Study (BIO-WEST 2002a-2010a) - Twenty-four comprehensive sampling events have been conducted on the Comal Springs system since 2000 over a total discharge range of 224 cfs to 446 cfs. Total Comal Springs system discharge greater than 225 cfs has been shown to provide high quality habitat throughout the range for the species present in this system. ***Hardy and others (2000)*** - No discernable change in modeled fountain darter habitat from 300 to 150 cfs total discharge. - Temperature conditions are suitable for fountain darter reproduction within its entire range at 150 cfs. ***Hardy (2009)*** - Approximately a 30 percent reduction in Comal Springs riffle beetle surface habitat within Spring Run 1 from 300 cfs to 150 cfs total discharge. - No reduction in Comal Springs riffle beetle surface habitat for Spring runs 2 or 3 at same flow reduction. ***Historical Hydrology*** - Average total discharge from 1927–2009 is 291 cfs. cfs = cubic feet per second	***Edwards Aquifer Authority Variable Flow Study (BIO-WEST 2002a-2010a)*** - Three critical period full monitoring events have been conducted since 2000 ranging in total discharge from 138 to 175 cfs. - Habitat reduction and subsequent reduction in fountain darter presence is noted in the Upper Spring Run reach at approximately 150 cfs when flow from Spring Run 5 ceases surface flow over the concrete structure. ***Hardy and others (2000)*** - Available fountain darter habitat reduced to approximately 90 and 75 percent of maximum available habitat at 100 and 60 cfs, respectively. - 77°F shown to cause reduced larval survival for fountain darters. At 60 cfs, this temperature is predicted to be exceeded in approximately 50 percent of the Upper Spring Run reach, 10 percent of the Old Channel, and 10 percent of the New Channel. At 60 cfs, Landa Lake below Spring Island is not predicted to be affected. ***Hardy (2009)*** - Only a slight reduction predicted in Comal Springs riffle beetle surface habitat in Spring Run 1 from 150 cfs to 100 cfs or 60 cfs total discharge. - No reduction at Spring run 2 predicted at 100 cfs. However elimination of surface habitat predicted at 100 cfs at Spring Run 3 and 60 cfs for Spring Run 2. ***Historical Hydrology*** - Minimum six month average discharge was 4 cfs from June to November 1956. - During 1984 total discharge went below 60 cfs for 103 consecutive days.	***Edwards Aquifer Authority Variable Flow Study (BIO-WEST 2002d, McDonald and others 2007)*** - Comal Springs riffle beetle laboratory studies suggest that the beetle has a strong affinity for upwelling flow and will retreat into artificial substrate during periods of low discharge. - Laboratory study suggests trematode gill parasite did not have a significant impact on fountain darter reproduction. ***Hardy and others (2000)*** - Available fountain darter habitat reduced to approximately 60 percent of maximum available habitat at 30 cfs. - 77°F shown to cause reduced larval survival for fountain darters. At 30 cfs, this temperature is predicted to be exceeded in approximately 100 percent of the Upper Spring Run reach, 40 percent of the Old Channel, and 60 percent of the New Channel. At 30 cfs, Landa Lake below Spring Island is not predicted to be affected. - Critical Thermal Maximum of 94.6°F established in Brandt and others 1993. The model suggests that this temperature would not be exceeded anywhere in the Comal Springs system at 30 cfs. ***Hardy (2009)*** - Approximately a 70 percent predicted reduction in Comal Springs riffle beetle surface habitat within Spring Run 1 from 300 cfs to 30 cfs total discharge. - No Comal Springs riffle beetle surface habitat predicted for Spring runs 2 or 3 at 30 cfs total discharge. ***Gonzales (2008)*** - Genetic differences of Comal Springs riffle beetle in spring runs versus Landa Lake suggest divergent populations and a bottleneck in the past. ***Historical Hydrology*** - Minimum one month average discharge was 0 cfs from July to October 1956. - During 1984 total discharge was below 40 cfs for 41 consecutive days dropping to a low of 26 cfs.

Figure 5: Overview of results used to inform flow regime recommendation on the Comal Springs system.

Based on the review of the best available science discussed throughout this report and summarized in Figure 5, we developed recommendations for the Comal Springs Flow Regime as presented in Table 2.

With the assumptions noted, it is our determination that maintaining all components of the proposed flow regime would meet the goal of long term survival of the threatened and endangered species of the Comal Springs system in the wild.

A long-term average value flow of 225 cubic feet per second is supported by long-term monitoring data and modeling results. At these total discharge levels, populations of each of the threatened and endangered species are anticipated to maintain or increase their respective populations. The most important aspect of maintaining the long-term average component of the flow regime is that the system would not be able to have repeated 6-month or 1-month events also prescribed in the flow regime. As such, the lower flow criteria were developed with the understanding that if they should occur, they would only be experienced a few times.

A minimum 6-month average flow of 75 cubic feet per second provides a condition that is sub-optimal for both the fountain darter and the Comal Springs riffle beetle. Water temperatures greater than those preferred for fountain darter larval survival would be exceeded throughout most of the Upper Spring Run reach and lower portions of the New and Old channels. This would have the potential to limit reproductive success within

Table 2: Comal Springs flow regime recommendations.

Comal Springs flow regime recommendation*		
Criteria	**Flow (cfs)**	**Notes**
Long-term average flow	225	
Minimum 6-month average	75	
Minimum 1-month average	30	No flows below 5 cfs

cfs = cubic feet per second

*Assumptions:

- Invasive species remain at current levels, both as to number of species and numbers of individuals/coverage.
- Gill parasite levels do not increase.
- Ramshorn snail populations do not increase.
- Amount of sediment in the river does not increase.
- Recreation remains at current levels (that is, no new tube/canoe/kayak rental facilities, no new water parks)
- Current in-channel structures remain unchanged.
- No additional mitigation activities beyond those currently in practice.

these portions of the system. However, at 75 cubic feet per second, the entirety of Landa Lake and upper portions of the Old and New channels would remain suitable to fountain darter reproduction. As fountain darter have been documented to reproduce year round in high quality habitat such as Landa Lake, a reduction in fountain darter reproduction is not anticipated to drive the population to a point from which it could not quickly rebound. Additionally, surface habitat for the Comal Springs riffle beetle is reduced in Spring Run 1 and predicted to be lost in Spring runs 2 and 3. It needs to be reiterated that although surface habitat is reduced for the riffle beetle in the spring runs, surface habitat at this discharge still exists at springs along the western shoreline of Landa Lake and spring upwelling areas near Spring Island and within the deeper portions of Landa Lake. Additionally, surface habitat is still predicted to be available at Spring Run 1 and subsurface habitat is still available at all spring runs.

A minimum 1-month average flow of 30 cubic feet per second is the lower threshold that we recommend the system not fall below with the current set of assumptions in place. At these levels, larger portions of fountain darter habitat relative to reproductive success are reduced in quality because of elevated water temperatures. However, even at 30 cubic feet per second, the majority of Landa Lake maintains suitable water temperatures for fountain darter reproduction. Additionally, it is not predicted that at 30 cubic feet per second any areas of fountain darter habitat exceed or even approach lethal temperatures for fountain darter survival. At 30 cubic feet per second, surface habitat for the riffle beetle is reduced nearly 70 percent in Spring Run 1 with no available surface habitat predicted in Spring runs 2 or 3. The possible genetic bottleneck in the Comal Springs riffle beetle spring run population suggested (Gonzales 2008) to occur during the 1950s drought makes going below this minimum threshold undesirable. The same understanding of available surface habitat at Spring Run 1, Spring Island, and Landa Lake, and subsurface habitat within the spring runs as described above for the minimum 6-month average flow applies at 30 cubic feet per second for the riffle beetle.

We reiterate earlier discussions in this report that emphasize that the flow regime recommendations for Comal Springs are based on the best available science and professional judgment at this time. We understand that these threatened and endangered species in the Comal Spring System can withstand short time periods of habitat loss and even some direct impact to the species themselves without resulting in long-term harm to the overall population. With that said, several unknowns still exist. One of the questions that remains is: What frequency or duration of these events could be tolerated by these species without long-term consequences? In the absence of that answer we have elected to recommend flows that are higher than the historically observed low flow statistics at Comal Springs because of the extirpation of the fountain darter following the 1950s drought. Although the remaining endangered species all presumably survived the 1950s drought, the condition of their populations prior to that event is unknown, and a possible genetic bottleneck is suggested to have occurred within the spring run population of Comal Springs riffle beetle.

A second major factor not incorporated into the habitat modeling results is the potential change to aquatic vegetation as flows decrease. The model assumes that the aquatic vegetation community will remain the same, which is certainly a false assumption to some unknown degree. Concern has also been raised by U.S. Fish and Wildlife Service

personnel that major die-offs and decomposition of aquatic vegetation during periods of low-flow may cause significant reductions in dissolved oxygen available for the fountain darter. The reduction in aquatic vegetation could also cause crowding or clumping of darters in remaining suitable habitat which could possibly make them more vulnerable to predation or increased competition (native and non-native). These are some of the factors associated with the professional judgment component of the review of model results that were considered by the Expert Science Subcommittee during deliberations. An additional factor in the Comal Springs system is the continued presence of an Asian trematode, *Centrocestus formosanus*. Should moderate flow exist for several years without any flash floods followed by low flows due to drought conditions, it is anticipated that cercarial abundance may increase to a more severe level (Thomas Brandt, personal communication).

All the unknowns logically lead one to a conservative mindset in the setting of flow-related requirements. However, we made a conscious decision not to incorporate a margin of safety into the proposed recommendations. It was our interpretation of the legislative charge that the subcommittee should evaluate the best available science objectively, clearly state the assumptions associated with the recommendations, and acknowledge the need for further study where appropriate. For instance, if it is later revealed that significant impacts are not captured in the model results or efforts to control the parasite or its host are not in place or successful in the future, then one needs to be cautious with strict implementation of the proposed flow recommendations. However, should information come forward that these species are able to aggregate in areas of suitable habitat more frequently or for longer durations than currently thought without significant consequence, or mitigation activities are in place that could be effective in providing additional levels of protection, then the proposed flow regime recommendations for the Comal Springs system would also need to be revisited. One thing is clear, long-term monitoring of this system is essential, and further study and research specifically during critical low flow periods (or simulated critical low-flows) are needed to accurately determine the potential impacts to the species at Comal Springs.

<u>San Marcos Springs analysis and assumptions</u>

- Fountain darter (*Etheostoma fonticola*)

Fountain darters were first collected in the San Marcos River in 1884 from immediately below the confluence with the Blanco River. Fountain darters have been found in the San Marcos River intermittently between downstream of Cumming's Dam and Martindale. The present distribution of fountain darters in the San Marcos River is from Spring Lake to an area between the San Marcos wastewater treatment plant outfall and the confluence with the Blanco River.

Biological monitoring for fountain darters conducted over the past nine years (BIO-WEST 2002b - 2010b) has focused on three main reaches of the San Marcos Springs system: Hotel Reach (Spring Lake), City Park, and Interstate 35 (Figure 6). Data collected via the Edwards Aquifer Authority variable flow study over the past nine years suggest that the highest quality fountain darter habitat is located within Spring Lake.

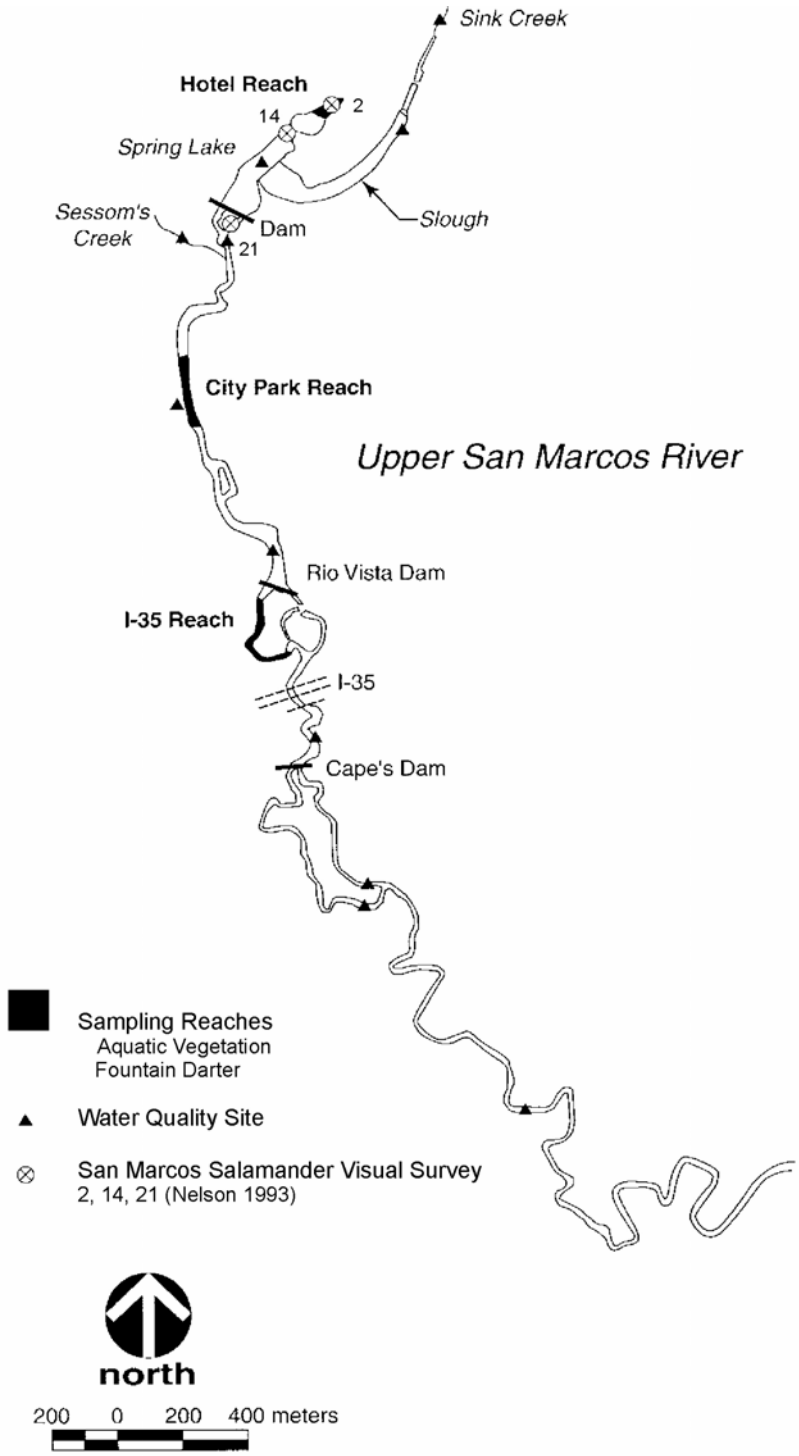


Figure 6: San Marcos River water quality and biological sampling areas for Edwards Aquifer Authority variable flow study (BIO-WEST 2009b).

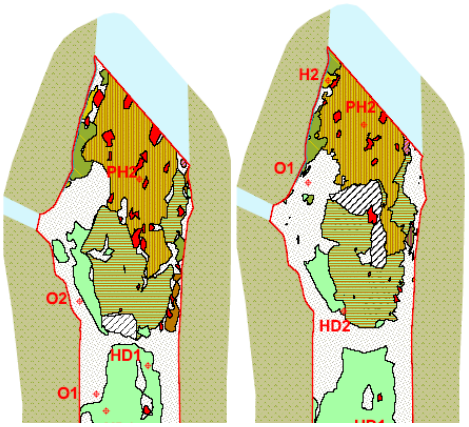
Spring Lake maintains a diverse aquatic vegetation community, supports year round reproduction of fountain darters, and exhibits exceptional water quality conditions. These factors contribute to the continuance of large populations of fountain darters within Spring Lake. The City Park and Interstate 35 reaches both maintain more variable habitat conditions for fountain darters relative to spring discharge (BIO-WEST 2002b–2010b). These reaches typically support seasonal fountain darter reproduction peaking during the spring. In comparison to habitat in Spring Lake or Landa Lake of the Comal Springs system, the habitat in these reaches is of lesser quality to fountain darters due to swifter currents, vegetation types, and recreational activities.

Over the past nine years of monitoring (BIO-WEST 2002b–2010b), total San Marcos Springs System discharge greater than 125 cubic feet per second has been shown to provide high quality fountain darter habitat throughout its range, excluding periods of high flow pulses. Indirect impacts associated with recreational activities in City Park occur each year regardless of flow condition but are magnified during flows less than 100 cubic feet per second as discussed below. Considerable habitat alteration has occurred several times over the years as a result of high flow pulses (heavy localized rain events) scouring out extensive areas of aquatic vegetation. These time periods are generally short-lived (hours to days) and the aquatic vegetation typically recovered and/or expanded in one to six months. BIO-WEST (2007c) has concluded that these represent flow events that have direct impacts on fountain darter habitat, but only on a temporary time scale.

During the nine years of monitoring at San Marcos Springs, it appears that the combination of sedimentation, low water levels, and intense recreation cause impacts to fountain darter habitat as total discharge declines to 110 cubic feet per second in the system. At this total discharge level, conditions within Spring Lake remain relatively unchanged; however, conditions within Sewell Park and City Park start showing considerable reductions in aquatic vegetation. Figure 7 shows the difference in vegetation impact in the City Park Reach between spring (April) and fall (October) during three flow conditions (A. 2005 [above average year—greater than 200 cubic feet per second], B. 2006 [below average year—near 110 cubic feet per second], and C. 2009 [below average year—below 100 cubic feet per second]). The colored polygons represent different types of aquatic vegetation within the upper portion of the City Park reach (for specific vegetation types and coverage, see BIO-WEST 2006b, 2007b, and 2010b). It is evident that even during higher than average flow conditions, recreation impacts occur to the central portion of the City Park reach (footpath across the river in the lower portion of each figure; Figure 7). However, the impacts remain relatively minor during 2006 even at much lower than average flow conditions. The effects of recreation are clearly magnified in this high access area when flow conditions go below 100 cubic feet per second total discharge (Figure 7).

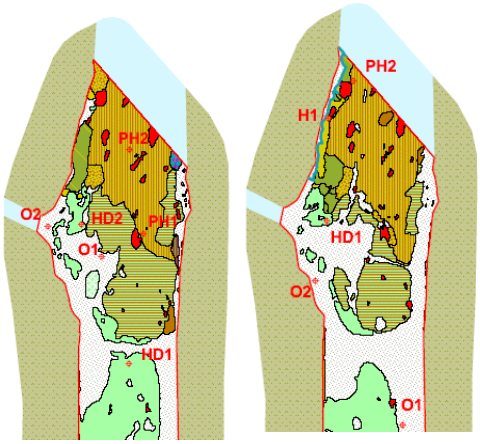
Table 3 shows the total aquatic vegetation area for the full City Park reach from these years and the differences recorded between spring and fall . Additionally, Table 3 shows the total aquatic vegetation area and seasonal differences for the Interstate 35 reach for the same years.

A.



Spring 2005 Fall 2005

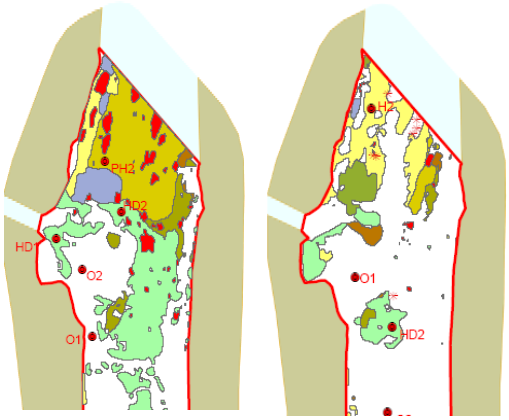
B.



Spring 2006 Fall 2006

	2005	2006	2009
Average Flow 6 months prior to spring	323 cfs	140 cfs	99 cfs
Average Flow between spring and fall	228 cfs	107 cfs	94 cfs

C.



Spring 2009 Fall 2009

San Marcos River – City Park Reach Aquatic Vegetation Maps

Figure 7: Aquatic vegetation maps for spring (April) and fall (October) (A) 2005, (B) 2006, and (C) 2009. Average flows for the San Marcos River for the six months preceding condition and between mapping efforts per year also shown (BIO-WEST 2006b, 2007b, 2010b) (cfs = cubic feet per second).

Table 3: Total aquatic vegetation area within City Park and Interstate 35 reaches during different flow conditions over time.

Reach	Total aquatic vegetation (m^2)		% Decline
	Spring (April)	Fall (October)	
City Park			
2005	4298	4319	0
2006	4620	4171	10
2009	4308	2690	38
Interstate 35			
2005	525	612	-17
2006	883	925	-5
2009	759	739	3

m^2 = square meters

Table 3 highlights the level of recreational impact in high access areas at lower flow conditions as the reduction in the City Park reach between spring and fall 2009 was 38 percent, while the total reduction in aquatic vegetation within the Interstate 35 reach during these same low flow conditions was only 3 percent. The greater amounts of aquatic vegetation in the Interstate 35 reach during lower flow conditions and in the fall versus spring (again, typically lower flow conditions in fall) are a result of reduced velocities throughout this reach. Higher velocities do not allow for establishment of large amounts of aquatic vegetation within the Interstate 35 reach at even long term historical average conditions. This highlights the importance of a flow regime and how maintaining variable flow benefits certain reaches at certain times in contrast with other segments of the river. Saunders and others (2000) make the same conclusion in their instream flow recommendation report for the San Marcos River (described below).

Moving beyond monitoring data into an evaluation of modeling results, the same habitat criteria employed in the Comal Springs ecosystem can be used to evaluate the suitable habitat available to fountain darters in the San Marcos Springs ecosystem. However, for the San Marcos River there have been two efforts for evaluation conducted by the U.S. Fish and Wildlife Service (Bartsch and others 2000) and Texas Parks and Wildlife Department (Saunders and others 2000), respectively. Rather than having the temperature data, vegetation composition, and wetted perimeter information combined into a single estimate of total usable fountain darter area as in Bartsch and others (2000), Saunders and others (2000) conducted a study that examined each component separately for the San Marcos Springs system. Again, only those primary conditions for suitable habitat are discussed; other potential influences may alter these estimations.

Temperature remains a variable of primary importance because individuals near the confluence of the Blanco River periodically experience temperatures that reach or exceed 77º F (25º C). The water temperature is typically in the range of 69.8–73.4º F (21.0–23.0º C) near the springs under historical average flows; the range broadens at the downstream edge of the fountain darter range (the confluence with the Blanco River). Groeger and others (1997) observed a range of approximately 68.0–75.2ºF (20.0–24.0º C) just

upstream of the confluence with the Blanco (4.8 kilometers downstream of headwaters of the San Marcos) during 1993–1994.

Saunders and others (2000) modeled water temperature from Spring Lake Dam down to the confluence with the Blanco River using the U.S. Fish and Wildlife Service's Stream Network Temperature Model (SNTEMP) developed by Theurer and others (1984). The model was applied to two flow scenarios: the historic mean and historic minimum for each month. This model provides information on daily mean and maximum temperatures for each month, and the two scenarios allow for a comparison between a typical year and the "worst case" scenario as derived from the recent historical record. The results indicate that the mean daily average should have exceeded the thermal maximum of 80.0º F (26.7º C) only under the historic minimum scenario and only at the downstream periphery of the fountain darter's range. Under historical average conditions, the more conservative mean daily threshold of 77.0º F (25.0º C) should not have been exceeded in the range of the fountain darter (Table 4). The study also examined the potential effects of elevated air temperatures on the model and found a slight increase in the amount of time during which water temperature would be at or above the threshold values. The investigators determined however, that "the model was fairly insensitive to changes in air temperature" (Saunders and others 2000).

Table 4: Number of months in which threshold water temperatures (77° F and 80° F) are exceeded in the San Marcos River as predicted by a SNTEMP model under normal (mean) and minimum springflow scenarios.

		Mean Air Temperature		Elevated Air Temperature	
	Station [a]	**77° F** [b]	**80° F** [b]	**77° F** [b]	**80° F** [b]
Normal Springflow	**1**	-	-	1	-
	3	-	-	5	-
	4	-	-	5	-
	5	-	-	5	-
Minimum Springflow	**1**	-	-	1	-
	3	2	-	5	4
	4	3	-	5	4
	5	4	2	5	5

Table created from data in Saunders and others (2000).
[a] Stations of increasing number are found further downstream.

[b] (77 º F = 25 º C; 80 º F = 26.7 º C.)

Saunders and others (2000) determined values of weighted usable area for several of the dominant vegetation types in the San Marcos River based on their importance in the ecosystem rather than to fountain darters. There were two components used in calculating weighted usable area for vegetation. First, habitat suitability criteria for each species were determined for both the main channel and natural channel (referring to the divergence that occurs downstream of Cape's Dam). These suitability criteria were then combined with hydraulic model output to determine weighted usable area estimates. The vegetation species included in this calculation were wild-celery (*Vallisneria americana*), delta arrow-head (*Sagittaria platyphylla*), Illinois pondweed (*Potamogeton illinoensis*), water stargrass (*Heteranthera liebmannii*), and Texas wild-rice (*Zizania texana*). Although information is lacking on the suitability of water stargrass as fountain darter habitat, the other species all provide fountain darter habitat at varying degrees (Schenck and Whiteside 1976, Bartsch and others 2000). The loss of habitat for these aquatic plant species, resulting in diminished areal coverage, may have indirect impacts on the fountain darter population.

The results of the weighted usable area calculations at various levels of discharge from 50 to 140 cubic feet per second can be found in Table 5. The modeling results indicate that wild-celery is minimally impacted by decreases in discharge and might benefit from flows down to 80 cubic feet per second in most of its range. When discharge approaches the historic minimum, the models show that weighted usable area for this species remains above 85 percent. According to the model, delta arrow-head is more significantly impacted in the upper reach with a steady decline in usable habitat (to just under 63 percent of the usable habitat available under maximum conditions) when flow is 50 cubic feet per second. As shown in the model, the usable area in the middle section remains highly resistant to decreases in flow, while in the lower reach usable area is maximized at 100 cubic feet per second and decreases at 50 cubic feet per second.

According to the model, Illinois pondweed and water stargrass have similar results to changes in discharge with usable habitat declining steadily as flows drop below 140 cubic feet per second in all reaches. Each declines to a low of 55 percent of the usable habitat under maximum conditions in the upper reach. The importance of Texas wild-rice to fountain darters is limited according to Schenck and Whiteside (1976), and little other information is available regarding the interaction between the two species; consequently, the results for Texas wild-rice are discussed separately and in more detail later in this report.

Information on wetted width is also presented in Saunders and others (2000). The information is presented by mesohabitat type: pools, runs, and riffles (Table 6). According to predictions, run habitat is lost in both the main and natural channels as flow decreases from 140 cubic feet per second to 50 cubic feet per second. Pools, another potential fountain darter habitat (though substantially less common in the system), had little change in wetted width as discharge decreased; virtually all of the habitat remained in the natural channel, and less than 5 percent was lost in the main channel. Riffles, also uncommon in this run-dominated system, experienced the greatest decline in wetted width as flow decreased, but they remained above 75 percent of normalized wetted width at 50 cubic feet per second.

Table 5: The weighted usable area (WUA)[a] for five dominant aquatic plant species in the San Marcos River.

VEGETATION TARGET SPECIES	Springflow (cfs)	Total % WUA in Segment 1	% of maximum	Total % WUA in Segment 2	% of maximum	Total % WUA in Segment 3	% of maximum
Wild-celery *Vallisneria americana*	140	33.0	75.0	20.0	100.0	33.0	89.2
	120	34.0	77.3	18.5	92.5	34.0	91.9
	100	39.5	89.8	18.0	90.0	35.5	95.9
	80	44.0	100.0	18.0	90.0	37.0	100.0
	60	41.0	93.2	17.0	85.0	34.0	91.9
	50	41.0	93.2	17.0	85.0	32.0	86.5
Delta arrow-head *Sagittaria platyphylla*	140	33.0	98.5	46.5	98.9	56.0	94.9
	120	31.0	92.5	46.0	97.9	53.0	89.8
	100	33.5	100.0	45.0	95.7	49.0	83.1
	80	31.5	94.0	45.0	95.7	47.0	79.7
	60	28.0	83.6	44.0	93.6	39.5	66.9
	50	26.0	77.6	43.0	91.5	37.0	62.7
Illinois pondweed *Potamogeton illinoensis*	140	61.0	96.8	53.0	98.1	72.5	94.2
	120	59.0	93.7	52.0	96.3	68.0	88.3
	100	56.0	88.9	49.0	90.7	61.0	79.2
	80	52.0	82.5	48.5	89.8	57.0	74.0
	60	45.5	72.2	47.5	88.0	48.5	63.0
	50	41.0	65.1	46.5	86.1	42.5	55.2
Water stargrass *Heteranthera liebmannii*	140	52.0	97.2	27.0	87.1	32.0	91.4
	120	51.0	95.3	25.0	80.6	30.0	85.7
	100	46.0	86.0	24.0	77.4	28.0	80.0
	80	41.0	76.6	21.5	69.4	25.0	71.4
	60	34.5	64.5	20.5	66.1	22.5	64.3
	50	32.0	59.8	19.5	62.9	19.5	55.7
Texas wild-rice *Zizania texana*	140	63.0	96.2	37.0	94.9	49.0	99.0
	120	64.0	97.7	36.5	93.6	49.5	100.0
	100	65.0	99.2	35.0	89.7	48.5	98.0
	80	65.5	100.0	35.0	89.7	46.0	92.9
	60	63.0	96.2	31.5	80.8	41.0	82.8
	50	63.5	96.9	31.0	79.5	39.0	78.8

Table created from data in Saunders and others (2000).

[a] The WUA is calculated as a percent of the total area in the segment and as a percent of usable area in that segment under optimal conditions. The percent of maximum is calculated by dividing the WUA per flow by the highest amount of WUA for that respective species and segment over the range of modeled flows. Segments are those defined by Saunders and others (2000) for the Upper San Marcos River: Segment 3 extends from Spring Lake Dam to Rio Vista Dam, Segment 2 extends from Rio Vista Dam to Millrace headgate downstream of the state fish hatchery outfall, and Segment 1 extends from the Millrace headgate to Cummings Dam.

Table 6: Normalized wetted width in pool, run, and riffle mesohabitats relative to discharge in the upper San Marcos River.

		Normalized Wetted Width			
Mesohabitats	Springflow (cfs)	Main Channel	% Loss	Natural Channel	% Loss
Pool	140	99.5	0.5	100.0	0.0
	120	98.5	1.5	100.0	0.0
	100	98.0	2.0	100.0	0.0
	80	97.0	3.0	100.0	0.0
	60	96.0	4.0	100.0	0.0
	50	95.5	4.5	100.0	0.0
Run	140	99.5	0.5	100.0	0.0
	120	98.5	1.5	99.0	1.0
	100	98.0	2.0	98.0	2.0
	80	95.0	5.0	96.5	3.5
	60	91.5	8.5	95.5	4.5
	50	89.0	11.0	94.0	6.0
Riffle	140	99.5	0.5	100.0	0.0
	120	99.0	1.0	99.5	0.5
	100	99.0	1.0	99.5	0.5
	80	90.0	10.0	99.0	1.0
	60	80.0	20.0	99.0	1.0
	50	76.0	24.0	98.5	1.5

Modified from Saunders and others (2000) to include calculated % loss.

The Hardy (2009) study results summarize both the original work (Bartsch and others 2000) conducted on habitat availability modeling for the fountain darter in the San Marcos River using 1997 channel geometries and the updated 2001 channel geometries. Both of these scenarios were modeled using the original habitat suitability criteria for fountain darters (Bartsch and others 2000). The 2009 model update used the 2001 channel geometries but utilized the updated habitat suitability criteria that were established following a detailed examination and analysis of existing data conducted by Dr. Tim Bonner of Texas State University.

The temperature modeling (Figure 8) shows that at 80 cubic feet per second total discharge, all areas of the San Marcos River are suitable for fountain darter reproduction. At 60 cubic feet per second, portions of the lower-most reaches slightly exceed the 77° F value. Temperature from Spring Lake to Rio Vista Dam supports fountain darter reproduction down to the lowest flow rate (30 cubic feet per second) modeled.

The relationships between available simulated habitat (weighted usable area) for fountain darters versus flow in the San Marcos River are shown in Figure 9. Figure 9 demonstrates that the measured channel changes between 1997 and 2001 resulted in a scaling of the predicted fountain darter habitat magnitude rather than a considerable change in the overall shape of the weighted usable area to discharge relationship (Hardy 2009). Again, it important to point out that these two scenarios do not incorporate revisions to the fountain darter habitat suitability functions. The Hardy (2009) results based on the 2001 channel geometries and updated fountain darter habitat suitability

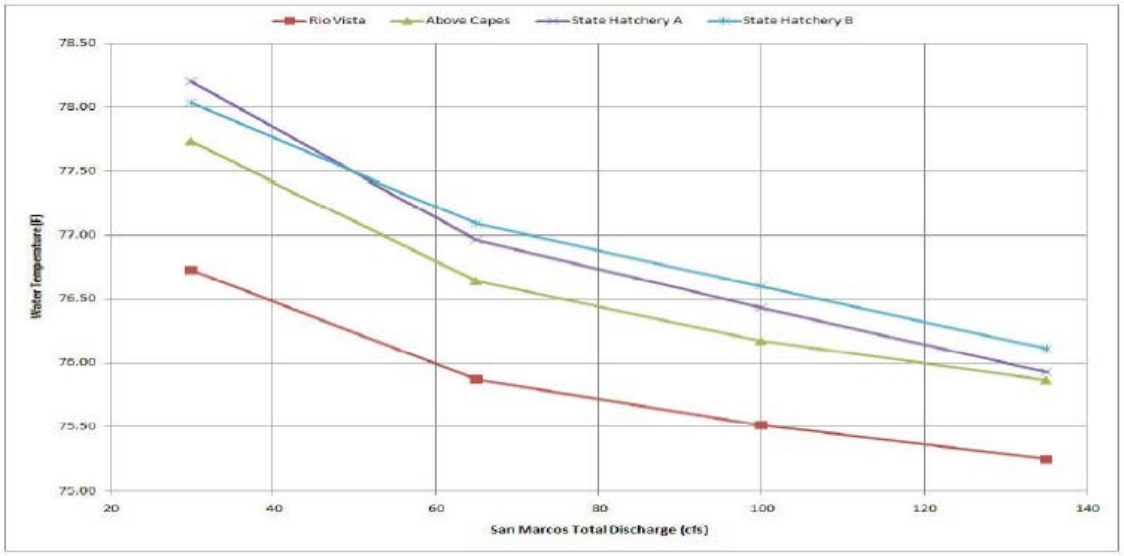


Figure 8: Relationship between total San Marcos River discharge (cubic feet per second [cfs]) and reach level maximum daily temperature (°F) (Hardy 2009).

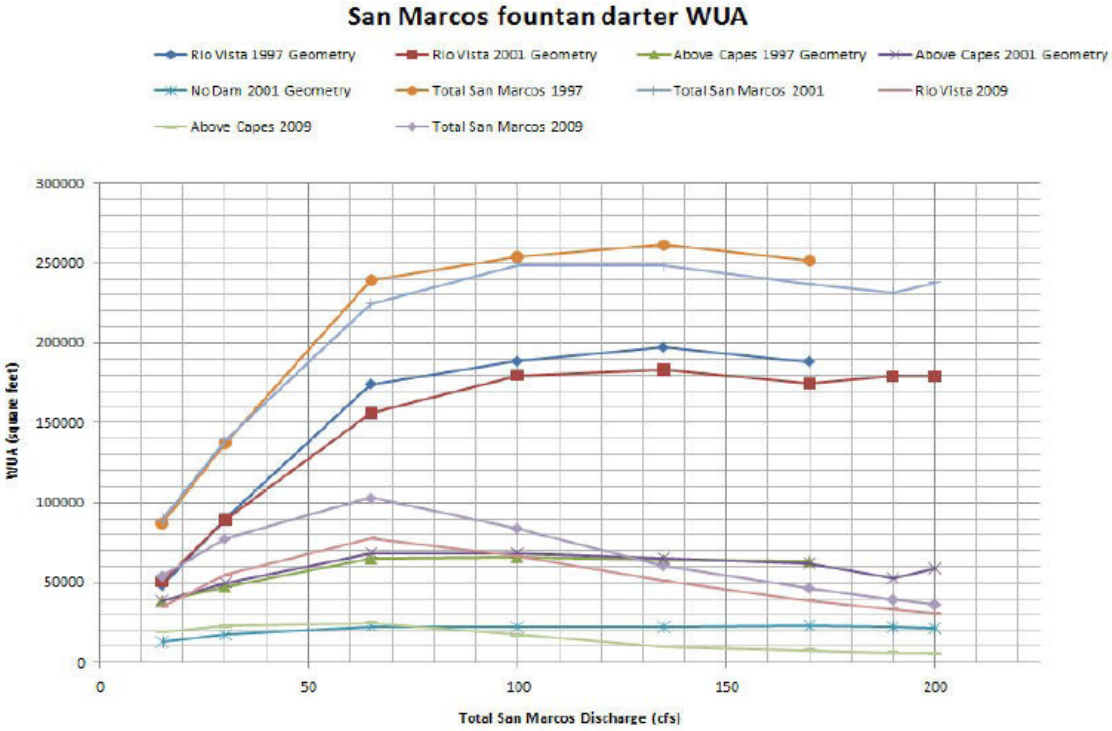


Figure 9: Simulated fountain darter available habitat in sections of the San Marcos River (Hardy 2009) (cfs = cubic feet per second; WUA = weighted usable area).

functions not only changed the magnitude of weighted usable area versus discharge but shifted the flow rate at which the maximum habitat values were predicted. As expected, this compares well with actual field data collected over the past nine years, in that areas of lesser flow tend to support more aquatic vegetation growth and higher utilization of fountain darters. This trend can only be supported down to some point as lowering flows subsequently cause the reduction in wetted area which in turn reduces the overall amount of available habitat for the fountain darter. When considering the total San Marcos River in 2009 (Figure 9), the maximum amount of available habitat predicted for the fountain darter occurs at 65 cubic feet per second. As flow declines to 30 cubic feet per second, approximately 75 percent of the maximum available habitat remains. As flow declines to 15 cubic feet per second, approximately 50 percent of the available habitat suitable for the fountain darter is predicted.

Overall, the species specific results of the Bartsch and others (2000) and Hardy (2009) modeling (both temperature and habitat) related to the fountain darter are similar to the ecosystem approach applied by Saunders and others (2000).

As discussed in the Comal Springs section, parasites, the presence of exotic species (primarily suckermouth catfishes and ramshorn snails), water quality degradation, and recreation all have consequences on the fountain darter populations. As in the Comal Springs system, the gill parasite (*Centrocestus formosanus*) is a potential threat that needs careful attention and study. Thomas Brandt (U.S. Fish and Wildlife Service, personal communication, 2009) speculates the parasite became well established, with 100 percent of collected fish infected with an average of 100 cysts per fish in the San Marcos River near Interstate 35, in 2009. Suckermouth catfishes are abundant in the San Marcos River and successfully reproducing (BIO-WEST 2007c). Ramshorn snails have been present in the San Marcos Springs system but at low levels since the inception of the Edwards Aquifer Authority variable flow study in fall 2000. Regardless of present numbers, this species needs to be monitored closely to assure that it does not significantly reduce the available fountain darter habitat.

As discussed in the Comal Springs section, water quality encompasses a range of variables that can potentially impact fountain darters and other aquatic life if altered too far from the historic range to which the stream inhabitants have become accustomed. Particularly on the San Marcos River, recreational activities have the potential to affect fountain darter populations directly (for example, trampling and displacing individuals) in addition to decreasing areal coverage of suitable habitat (various species of aquatic vegetation). These effects have been documented to be intensified during periods of lower spring discharge (BIO-WEST 2007c).

One additional factor for the San Marcos Springs system relevant to fountain darters and Texas wild-rice is increased sedimentation. Over the past decade, the upper San Marcos River has filled in considerably from just below Spring Lake Dam (near the mouth of Sessom Creek) to the reconstructed Rio Vista Dam. This statement is not based on a sediment transport study or model (as this type of effort has not been conducted to date) but rather on 20 years of visual observations and actually being in the river on a regular basis (Jackie Poole, personal communication; Ed Oborny, personal communication). The build-up of sediment in this stretch directly dictates the depth of water and substrate composition. Water depth and substrate are important components to maintaining the

proper aquatic vegetation for fountain darter habitat as well as suitable conditions for Texas wild-rice. Sedimentation relative to Texas wild-rice distribution has been studied (Griffin 2006). Griffin (2006) states that the sediment input to this upper reach derives from Sink Creek, Sessom Creek, and through overland flow. Griffin (2006) discusses the effectiveness of the five flood detention dams that have been built on tributary creeks draining into the San Marcos River and explains how reducing the frequency of higher flows has reduced the ability of the river to flush out the accumulated bed sediment (Griffin 2006).

- Texas wild-rice (*Zizania texana*)

Texas wild-rice was first collected in the San Marcos River in 1892. When the species was originally described in1933, it was reported to be abundant in the San Marcos River, including Spring Lake and its irrigation waterways (Silveus 1933). Beaty (1975) reported coverage of 240 square meters (2,580 square feet), but he did not provide distribution within the river or survey methodology. By 1967, only one plant remained in Spring Lake, no plants were found in the uppermost 0.8 kilometers (0.5 miles) of the San Marcos River, only scattered plants in the lower 2.4 kilometers (1.5 miles), and none below that (Emery 1967). In 1976, Emery began monitoring the coverage of Texas wild-rice within the San Marcos River on a regular basis (Table 7).

Currently, Texas wild-rice occurs in the upper 2.4 kilometers of the San Marcos River, above the confluence with the Blanco River. Texas wild-rice is generally found in high to moderate current velocities (0.4 to 3.3 feet per second [0.12 to 1.0 meters per second]) at shallow water depths (0.76 to 3.3 feet [0.23 to 1 meters]) on coarse and sandy substrates (Poole and Bowles 1999; Saunders and others 2000). Texas wild-rice is also frequently found in areas with dense growth of other aquatic macrophytes, including the native species *Potamogeton illinoensis, Vallisneria americana, Cabomba caroliniana, Ludwigia repens*, and the non-native species *Hygrophila polysperma, Hydrilla verticillata and Egeria densa* (Poole and Bowles 1999). Power (1996a) also found that substrate composition and current velocity affect plant biomass and stem density and argued that the decline in the population can be partially attributed to changes in habitat that have occurred through urbanization and impoundment. Since Texas wild-rice prefers shallow areas, significant reductions in streamflow could expose many plants to less than optimal depths, either reducing plant growth or desiccating and killing plants. Texas wild-rice will perish in moist soil or even less than a few inches of water (Vaughan 1986). Texas wild-rice seeds have a significantly better germination rate when grown in inundated soils versus moist, but not inundated, soil (Alexander 2008). Herbivory is a potential problem for Texas wild-rice; decreased flows leave the plants more susceptible to waterfowl, introduced nutria, and ramshorn snails (Rose and Power 1992). Lower flows also increase the likelihood of vegetation mats forming on top of Texas wild-rice plants. Vegetation mats interfere with culm emergence, block sunlight and interfere with photosynthesis, and slow current velocity (Power 1996b). Another concern is competition with exotics, which may gain a competitive advantage when conditions are sub-optimal for Texas wild-rice. Figure 10 depicts the mapping segments for Texas wild-rice employed by

Table 7: Annual coverage (square meters [m^2)]) of Texas wild-rice broken down by river segment (see Figure 10) (1976 and 1978 data from Emery; 1983-1986 from Vaughan; 1989-2009 from Texas Parks and Wildlife Department).

SEGMENT	YEAR												
	1976	1978	1983	1984	1985	1986	1989	1990	1991	1992	1993	1994	1995
A	0.00	0.00	0.00	0.00	0.00	0.00	23.10	77.63	83.39	34.23	38.66	34.43	35.93
B	0.00	0.00	0.00	0.00	0.00	0.00	76.73	162.44	237.80	207.72	267.35	417.17	513.07
C	554.00	463.50	251.00	228.00	217.00	209.00	326.83	477.94	392.02	449.23	540.70	442.62	514.34
D	0	0	0	0	0	0	0	0	0	0	0	0	0
E	55.00	26.00	29.00	27.00	19.00	19.00	81.33	72.40	109.81	71.86	77.05	62.85	81.16
F	164.00	no data	119.00	83.00	103.00	92.50	276.57	241.90	271.42	380.08	429.44	270.49	276.28
G	68.00	33.00	37.00	8.00	8.00	7.50	18.58	18.83	12.88	12.65	20.25	17.64	14.74
H	0.50	0.00	0.00	0.00	0.00	0.00	11.40	11.82	8.66	9.74	1.32	3.73	5.03
I	9.00	no data	4.00	3.00	4.50	4.00	12.86	5.55	1.40	0.21	0.32	0.17	0.11
X	0.00	0.00	0.00	0.00	0.00	0.00	1.04	0.00	0.00	0.00	0.00	0.00	0.00
J	49.00	no data	46.00	28.00	68.00	55.00	95.03	120.46	117.01	117.39	96.57	76.22	46.58
K	233.50	no data	55.00	15.00	69.50	67.00	77.14	191.02	171.52	122.56	136.21	129.50	136.24
L	0.00	0.00	0.00	0.00	0.00	0.00	2.84	0.43	0.29	0.33	0.52	1.52	0.52
M	0.00	0.00	0.00	0.00	0.00	0.00	0.52	0.00	0.00	0.00	0.00	0.00	0.00
	TOTAL												
	1132.50	522.50	541.00	412.00	489.00	454.00	1003.97	1380.42	1406.20	1406.00	1608.39	1456.34	1624.00

Table 7: Continued.

SEGMENT	YEAR													
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
A	31.70	48.99	57.43	75.77	77.58	104.41	141.58	256.35	285.63	325.72	410.47	361.15	354.07	327.24
B	555.06	519.68	766.48	661.81	745.09	991.22	1034.99	1312.01	1799.6	2299.5	2332.1	2529.3	2341.5	2299.4
C	459.95	416.09	422.61	493.08	553.34	399.16	425.74	716.91	655.57	830.9	735	726.55	668.7	710.44
D	0	0	0	0	0	0	0.00	4.51	7.22	12.19	8.42	8.69	14.95	7.71
E	72.83	76.34	67.75	38.67	24.25	19.98	11.80	19.66	21.15	6.13	5.05	6.08	2.94	1.49
F	275.97	335.40	327.62	339.49	350.52	359.42	286.41	429.13	460.16	426.07	550.99	539.37	425.39	386.8
G	10.64	11.98	20.80	23.26	20.85	4.78	6.69	9.69	12.08	16.8	18.23	16.95	24.3	13.75
H	4.35	2.43	2.84	2.92	3.67	0.98	0.90	12.59	20.36	25.54	15.88	20.2	16.58	28.67
I	0.064	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0
X	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0
J	36.96	36.99	48.82	7.33	6.22	6.70	3.00	5.36	0	7.27	6.39	5.94	3.58	0.61
K	202.60	134.39	234.94	2.55	9.56	8.97	5.14	9.83	127.85	37.38	71.9	57.36	53.53	46.91
L	1.95	1.87	0.00	0.00	0.00	0.00	0.00	0.00	0	5.21	6.74	5.84	4.2	5.28
M	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0
	1652.07	1584.16	1949.29	1644.88	1791.08	1895.62	1916.3	2776.04	3389.57	3992.7	4161.1	4277.5	3909.7	3828.3

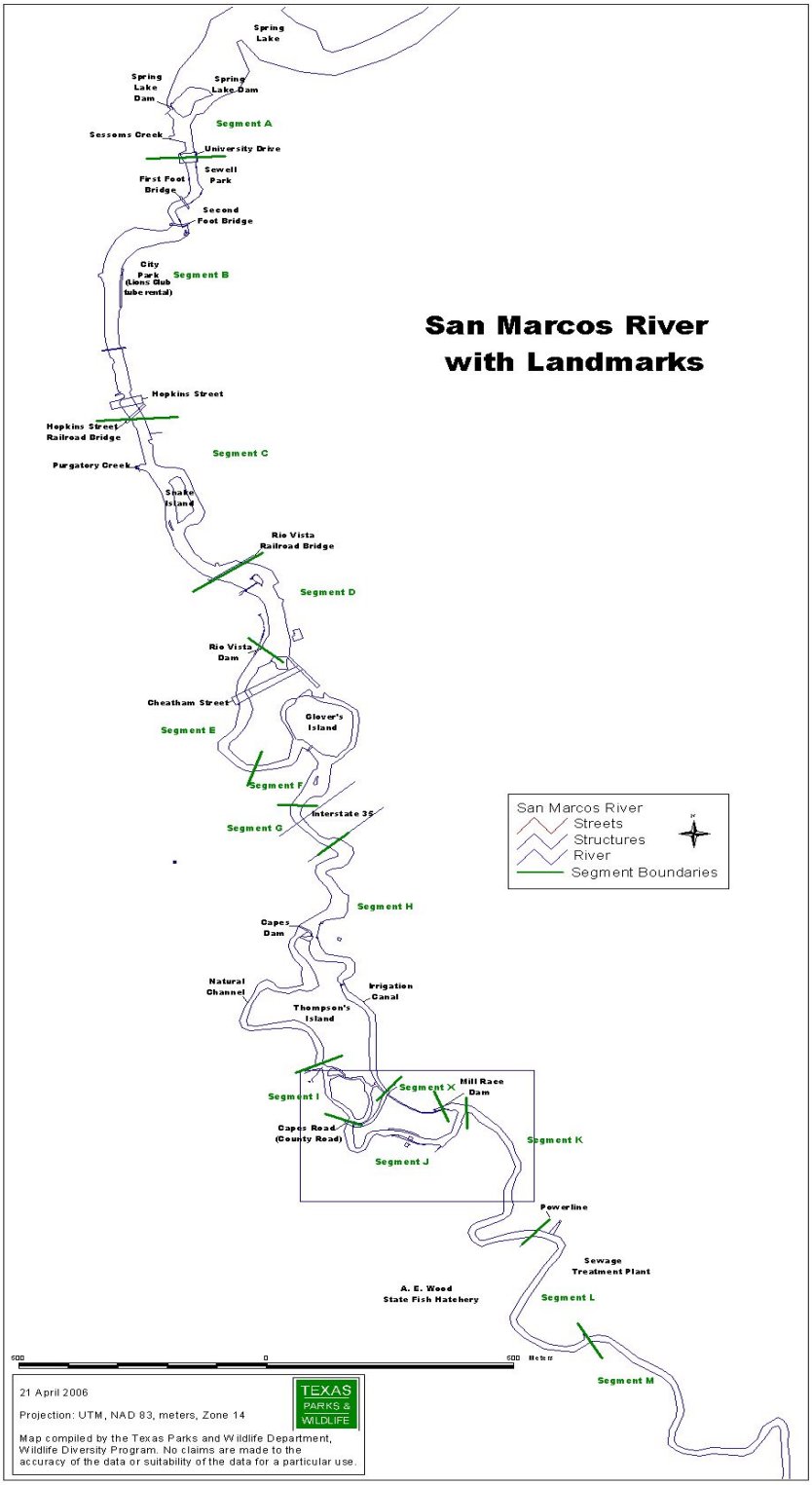


Figure 10: Texas wild-rice mapping segments used by Texas Parks and Wildlife Department for annual monitoring (Texas Parks and Wildlife Department unpublished data)

Texas Parks and Wildlife Department for their annual monitoring. Figure 11 represents the mapping sections used by the Edwards Aquifer Authority variable flow study of Texas wild-rice in the upper San Marcos River. Figure 12 depicts the total Texas wild-rice coverage in the San Marcos River as mapped annually in the summer by Texas Parks and Wildlife Department and for the Edwards Aquifer Authority variable flow study.

The variation between the Texas Parks and Wildlife Department values and the Edwards Aquifer Authority variable flow study results in Figures 12 and 13 and Table 7 may be due to slight differences in mapping techniques and procedures and/or timing of summer monitoring. Texas wild-rice rarely grows as a single-stemmed individual; normally, plants are composed of dozens or hundreds of rooted stems that may represent more than one genetic individual (Richards and others 2007). In the methodology employed by Texas Parks and Wildlife Department, plants that are in physical contact are grouped into stands. The stand location is measured from the stand's upstream-most end to a surveyed monument on the bank using a distance and bearing. The full extent of the stand's length and width are measured, and an aerial percent cover of Texas wild-rice within the length-width rectangle is estimated to provide aerial coverage. For the Edwards Aquifer Authority variable flow study, real-time GPS is used to map the perimeter of stands while kayaking or walking around the stands being measured. Stands smaller than 1 square meter are represented by a point without any associated aerial cover. However, despite the fact that there are many small plants, this probably represents less than 10 square meters of aerial coverage. For both efforts, annual mapping is done in the summer, usually in the month of July. The important aspect is not the slight differences in results but the consistency within sample methodology, with both methods providing a valuable double check for the other.

While it is true that Texas wild-rice coverage in the San Marcos River has more or less quadrupled in 20 years, if coverage is viewed on a segment-by-segment basis, a somewhat different picture emerges. Table 7 shows the annual coverage of Texas wild-rice broken down by Texas Parks and Wildlife Department river segment (Figure 10) from the earliest data collected by Emery in 1976 and 1978, Vaughan in 1983–1986, and Texas Parks and Wildlife Department (1989–2009) and Figure 13 shows the Edwards Aquifer Authority variable flow study total Texas wild-rice coverage per study section. Neither Emery nor Vaughan recorded Texas wild-rice in the uppermost segments (A and B) of the river. Until Texas wild-rice was listed as an endangered species, Texas State University and the City of San Marcos regularly dredged the bottom of the river in Sewell and City parks. Although Texas wild-rice was seen in Sewell Park in 1984 (Jackie Poole, personal observation), it is not known why Vaughan did not record it. The river segment that increased most in coverage is Segment B where the dredging occurred. Whether Texas wild-rice reestablished itself from seeds, surviving shoots and root balls, or from plantings is lost to history. However, Texas wild-rice made an impressive recovery in this segment of the river, going from 76.73 square meters in 1989 to a high of over 2,500 square meters in 2007, but much suitable habitat was available and unoccupied. In contrast, Segment K in the lower part of the San Marcos River had almost the same coverage in 1989 as Segment B and had increased (despite a few dips) in coverage until the 1998 flood when almost all the plants were destroyed. Although coverage shows a dramatic increase in this segment in 2004, this was due to U.S. Fish and Wildlife Service transplants that as the subsequent data shows did not fare well.

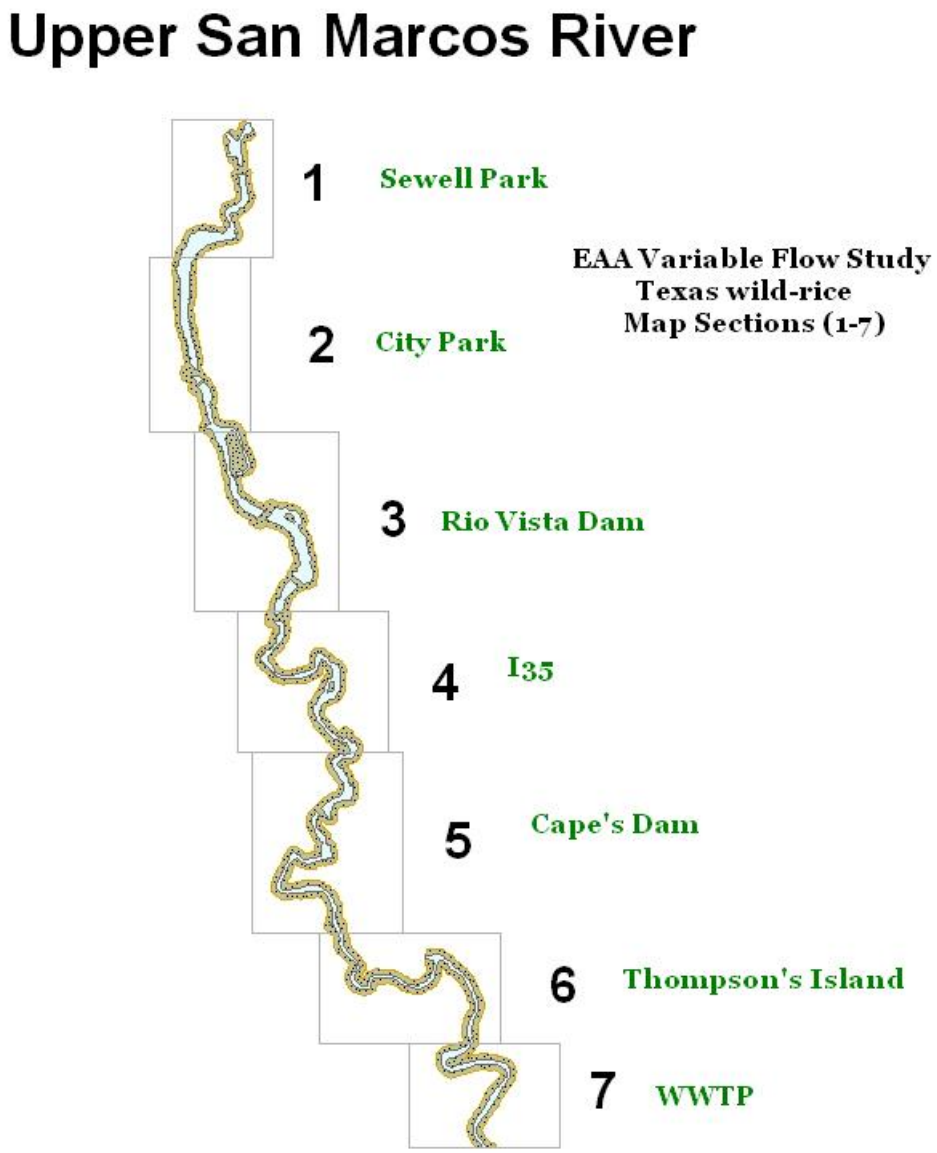


Figure 11: Texas wild-rice mapping sections for the Edwards Aquifer Authority variable flow study (BIO-WEST 2009b)

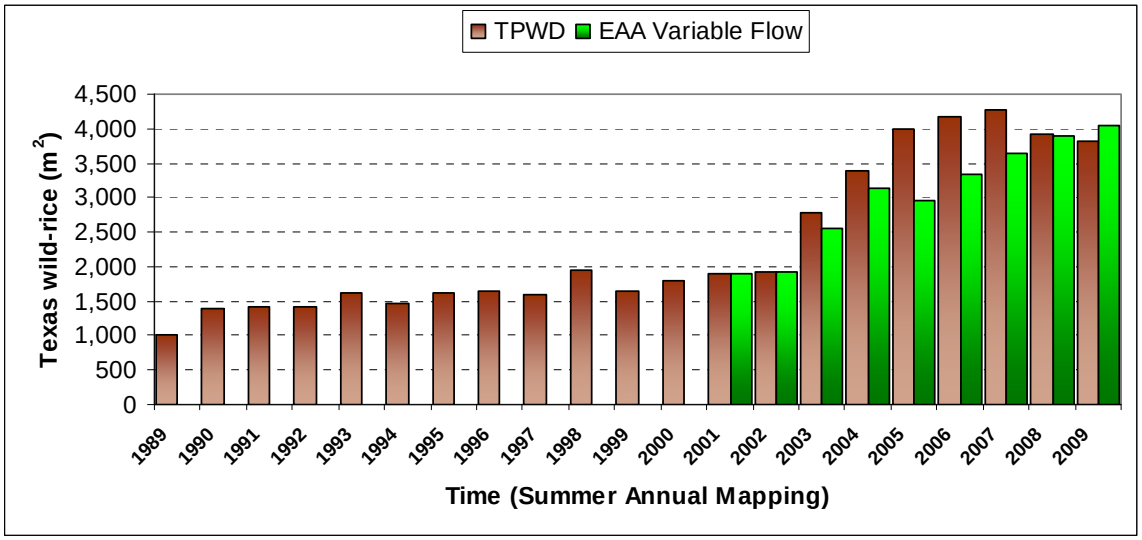


Figure 12: Total Texas wild-rice coverage (square meters [m^2]) on an annual basis as reported by Texas Parks and Wildlife Department and the Edwards Aquifer Authority variable flow study (only summer annual mapping results presented).

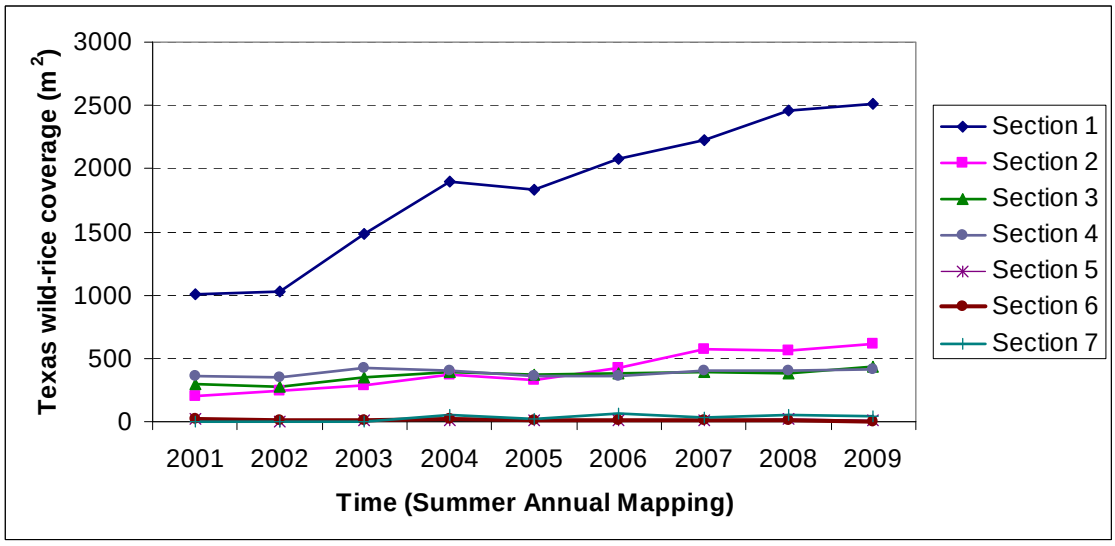


Figure 13: Total Texas wild-rice coverage (square meters [m^2]) per the Edwards Aquifer Authority variable flow study section (Figure 11) measured on an annual basis.

Other segments such as J and E have decreased as well with the Segment J decrease due to the 1998 flood and the Segment E decrease due to increased recreation below Rio Vista Dam. Thus, while coverage has increased in some areas, the overall range of Texas wild-rice has decreased—a troubling sign for a species with an already limited range. It should also be pointed out that increases in some segments of the river have been a result of human intervention via planting (Spring Lake; segments A, F, and K), seeding (Segment A), and appropriate management (that is, temporary removal of vegetation mats covering Texas wild-rice in the Sewell Park section of Segment B).

It should be pointed out that the annual summer monitoring data (Figure 12, Table 7) shows that during the low-flow conditions experienced during 2006, Texas wild-rice overall coverage as measured during the summer annual mapping (both Texas Parks and Wildlife Department and Edwards Aquifer Authority in 2006) actually increased compared to summertime results from 2005. While similar trends were exhibited in most sections or segments when viewed on that basis (Figure 13, Table 7), some sections (3, 4, and 6) or segments (C, D, H, and J) remained more or less stable or decreased. During the more extended low-flow conditions of 2009, Texas wild-rice overall coverage results were mixed, with Edwards Aquifer Authority showing a slight increase in coverage and Texas Parks and Wildlife Department showing a slight decrease. Coverage decreased in most of the Texas Parks and Wildlife Department segments, although coverage increased in segments C, H, and L. In the Edwards Aquifer Authority sections, coverage increased in all sections except where coverage remained stable in sections 6 and 7. However, during 2006 and 2009, it was very evident that lower water conditions affected Texas wild-rice stands during summer time conditions. In these years, annual measurements did not capture the entire picture of changing conditions in the wild. Therefore, Edwards Aquifer Authority conducted additional mapping of the whole river in early October in each of these years to quantify that impact. The average discharge from April through September 2006 and 2009 were approximately 107 cubic feet per second and 94 cubic feet per second, respectively.

—Summer (July)/fall (October) 2006

When the October 2006 mapping for Texas wild-rice was conducted, the average springflow in the previous six months was approximately 107 cubic feet per second. Springflow the six months prior to April 2006 was approximately 140 cubic feet per second which shows that for over a year the springflow conditions were below average and steadily decreasing. As discharge continued to decline to the lowest levels recorded in the previous 10 years, areas that were previously very shallow became exposed. As dry land became more prevalent, Texas wild-rice stands became fragmented and plants died. Other aquatic vegetation and in some cases terrestrial grasses began to replace habitat that had previously been dominated by Texas wild-rice. The shallow water also made it possible for more people to walk in these shallow areas creating paths and further fragmenting large Texas wild-rice stands. Low flows in combination with lack of flushing flow events also led to large, thick vegetation mats covering considerable areas of Texas wild-rice. The mats were especially prevalent in shallow areas, such as Sewell Park, where many Texas wild-rice plants either had submergent leaves close to the water's surface due to low flows or emergent blades that caught floating vegetation and trash coming from upstream and the surrounding area. These floating vegetation mats can

prohibit photosynthesis as evidenced by discoloring of leaves when these mats are cleared off. In addition, as vegetation floats over the Texas wild-rice, it can pull out or shred the leaves (Power 1996b).

Figure 14 provides photographs of conditions in Sewell Park in September 2006. The photographs show the healthy stands in the deeper portion on river left (left) and the poor health of the stands intertwined with the emergent vegetation along the river right (right). The greatest impacts observed during 2006 were the indirect effects of the lower discharge conditions on Texas wild-rice. The most prominent indirect effects were from extensive sedimentation that has occurred over the past decade and increased recreation in these shallow areas. For example, in the upper end of Sewell Park, "paths" developed in the shallow areas where Texas wild-rice was located as it was easier for people to wade in these areas during lower discharge conditions. People were observed walking in these areas and parking their kayaks/tubes/inflatable floats on top of plants, leading to plants being pulled out or trampled.

Figure 14: Texas wild-rice in Sewell Park, September 2006.

The greatest single impact was observed in the eastern spillway below Spring Lake Dam where a 73 percent decrease in total Texas wild-rice area was observed in October 2006 (Figure 15). Upon visual observation during a field investigation, it was evident that large patches of Texas wild-rice had been physically pulled out with only solitary leaves and root-mats to indicate where these plants had been.

Further evidence of manipulation of the river by people was present immediately downstream of Spring Lake Dam. Artificially created walls of rocks emerging from the water column served to further channelize this area, blocking flow to several Texas wild-rice plants and perhaps disturbing San Marcos salamanders.

To put the Spring Lake Dam physical disturbance into perspective, the overall coverage of Texas wild-rice in the San Marcos River, according to the Edwards Aquifer Authority variable flow study, increased by 50 square meters from July 2005 to October 2006. Texas Parks and Wildlife Department data also shows a similar small increase in total coverage between 2005 and 2006 as well as an increase in Segment A of 26 percent (Texas Parks and Wildlife Department 2006 data was gathered in June before the

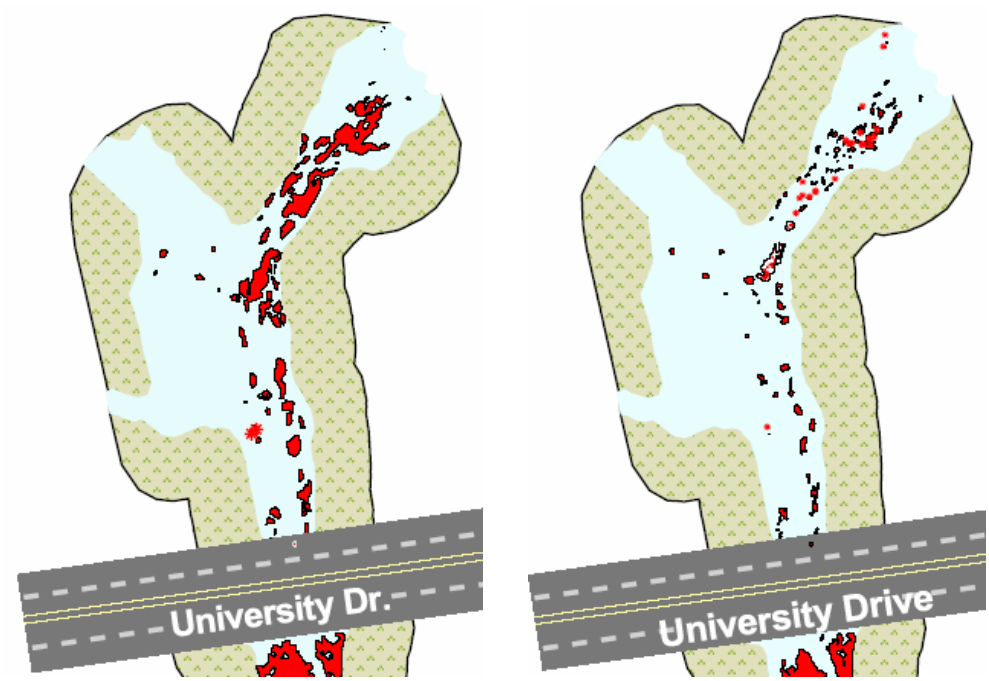


Figure 15: Texas wild-rice aerial coverage (July 2006, left; October 2006, right).

recreational damage in September). From July 2006 to October 2006, the overall (river wide) Texas wild-rice coverage declined by 335.3 square meters or approximately 10 percent. Subtracting the 234 square meters that was clearly human-related disturbance, this leaves an overall 2006 decline (101 square meters—approximately 3 percent) that might be directly attributable to lower discharges or other causes.

—Summer (July)/fall (October) 2009

When the October 2009 mapping for Texas wild-rice was conducted, the average springflow since that preceding spring (April) was approximately 94 cubic feet per second. During 2008-2009, the lowest 6-month average was approximately 91 cubic feet per second; the lowest 12-month average was approximately 96 cubic feet per second; and the lowest l6-month average was approximately 103 cubic feet per second. This highlights the extended nature of the drought in 2008 and 2009. Table 8 shows the decline in Texas wild-rice that accompanied lower than average flow conditions in the San Marcos River from July to October of 2006 and 2009.

Figure 16 provides photographs of conditions in Sewell Park in August 2009. The photographs show the shallow water and stands of Texas wild-rice along the river left (left) and the emergent vegetation and almost non-existent Texas wild-rice stands along the river right (right).

Although summer-to-summer annual Edwards Aquifer Authority variable flow study coverage of Texas wild-rice increased from July 2005 through June 2009 (Texas Parks and Wildlife Department annual coverage decreased almost 11 percent from 2007 to

Table 8: Total coverage and percentage decline of Texas wild-rice in the San Marcos River during 2006 and 2009 (BIO-WEST 2007b, BIO-WEST 2010b).

Year	Total Texas wild-rice (m^2)		% Decline
	Summer (July)	Fall (October)	
2006 Total	3,335	3,000	10
2006 (not including physical uprooting in Spring Lake Dam Reach)	3,335	3,234	3
2009 Total	4,034	3,350	17

Figure 16: Texas wild-rice in Sewell Park, August 2009.

2009), impacts during 2006 and 2009 did occur. Including the 234 square meter area below Spring Lake Dam which was documented to be direct physical disturbance, there was a 10 percent decrease in Texas wild-rice from July to October 2006. The impacts observed in 2009 were much greater, with an overall 17 percent decrease from July to October. Table 9 highlights the declines or increases in each of the Edwards Aquifer Authority variable flow study sections, again demonstrating that 2009 was more severe than 2006. According to the Edwards Aquifer Authority data, only Section 1 (Sewell Park section) exhibited declines during 2006 (total area of Texas wild-rice decreased 384.1 square meters, an 18 percent decrease in coverage from July to October 2006 [Table 9]). Texas Parks and Wildlife Department also showed a 12 percent decrease in aerial coverage in Segment A between 2006 and 2007. However, as discussed previously, much of this decrease occurred just below Spring Lake Dam where a large area of Texas

Table 9: Total Texas wild-rice coverage (square meters [m^2]) for each Edwards Aquifer Authority variable flow study section during summer and fall 2006 and 2009.

Year / Section	Total Texas wild-rice (m^2)		% Decline		
	July	September			
2006					
Section 1	2,080	1,695	18		
Section 2	429	431	-1		
Section 3	386	386	0		
Section 4	357	400	-12		
Section 5	9	10	-10		
Section 6	10	11	-10		
Section 7	66	67	-2		
2009	June/July	October		Decrease (m^2)	% of overall TWR decreased
Section 1	2,517	2,071	18	446	65
Section 2	610	522	14	88	13
Section 3	433	363	16	71	10
Section 4	413	341	17	72	11
Section 5	14	10	25	3	<1
Section 6	2	3	-45	-1	0
Section 7	46	42	10	5	1

wild-rice was manually removed by recreationists in early September. The majority of this decline was the physical disturbance below Spring Lake Dam followed by the river right portion of Sewell Park that became exposed causing fragmentation of stands. However, Texas Parks and Wildlife Department segment data from 2006 to 2007 also showed declines in segments C (1 percent), F (2 percent), G (7 percent), J (12 percent), K (20 percent), and L (3 percent).

During 2009, each of the sections (with the exception of Section 6) exhibited declines in coverage of Texas wild-rice from July to October (Table 9). This overall reduction can be translated as the entire river was experiencing low enough flow conditions to leave Texas

wild-rice stands exposed or in extremely shallow water. As in 2006, the greatest decrease in area (446 square meters) was in Section 1 which represented 65 percent of the Texas wild-rice lost during this period. This data clearly illustrates that as flows approach 100 cubic feet per second, total discharge impacts to Texas wild-rice become more pronounced. As total discharge declines to 90 cubic feet per second, impacts are magnified in that Texas wild-rice stands in shallow water become exposed and stranded. Texas Parks and Wildlife Department 2009 monitoring data (Jackie Poole, unpublished data) revealed 99 Texas wild-rice stands (15 percent of the total stands) at less than optimal depths, with 56 Texas wild-rice stands (almost 9 percent of the total stands) in water less than 6 inches deep, and some stranded. Many such plants were moved to deeper water, but lack of personnel meant that not all stranded plants would be rescued. Additional losses occurred throughout the river at these flows, but again were magnified within areas that encounter high recreation pressure.

The durational component experienced in 2009 must also be considered in this evaluation. In 2006, the lower flow conditions were only experienced for approximately three months, whereas in 2009 the low flow conditions were experienced for greater than one year. The potential magnification of effects by extended durations of low flow was a key factor in our determination to have a minimum 6-month criterion within the recommended flow regime.

As flows have not been observed at levels nearer to historical minimums, modeling efforts have been conducted to evaluate the potential for impacts to Texas wild-rice at lower flow conditions. An evaluation of the Saunders and others (2000) report shows that approximately 10 percent and 20 percent of weighted usable area would be lost when springflow drops from 140 cubic feet per second to 80 cubic feet per second and 50 cubic feet per second, respectively (Table 10). For these estimates, the weighted usable area approach was described in Saunders and others (2000) and summarized below.

The Saunders and others (2000) approach includes combining habitat suitability (only depth, substrate, and velocity for Texas wild-rice were included) and hydraulic modeling components to determine weighted usable area. In the lower San Marcos River (Segment 1—millrace headgate to Cumming's Dam), weighted usable area for Texas wild-rice was lowest above 140 cubic feet per second and increased slightly as discharge decreased from 140 to 80 cubic feet per second, but weighted usable area did not fall below 96 percent of optimal conditions as discharge declined to 50 cubic feet per second. Unfortunately, most of the Texas wild-rice in this segment was lost in the 1998 flood (two years after the Saunders and others data was taken). Despite at least two attempts to reintroduce Texas wild-rice to this area, coverage remains extremely low. In the farthest upstream portion (Segment 3—Spring Lake Dam to Rio Vista Dam), the most weighted usable area is available around 120 cubic feet per second; this drops to around 78.8 percent of that number at 50 cubic feet per second. Segment 2 (Rio Vista Dam to millrace headgate) is similar to Segment 1, and weighted usable area declines steadily from 140 cubic feet per second to 79.5 percent of optimal conditions at 50 cubic feet per second.

Table 10: Weighted usable area (WUA) simulated for Texas wild-rice in the San Marcos River (Saunders and others 2000). Segment 3 extends from Spring Lake Dam to Rio Vista Dam, Segment 2 extends from Rio Vista Dam to Millrace headgate downstream of the fish hatchery outfall, and Segment 1 extends from the Millrace headgate to Cumming's Dam (see Saunders and others 2000) (cfs = cubic feet per second).

VEGETATION TARGET SPECIES	Springflow (cfs)	Total % WUA in Segment 1	% of maximum	Total % WUA in Segment 2	% of maximum	Total % WUA in Segment 3	% of maximum
Texas wild-rice *Zizania texana*	140	63.0	96.2	37.0	94.9	49.0	99.0
	120	64.0	97.7	36.5	93.6	49.5	100.0
	100	65.0	99.2	35.0	89.7	48.5	98.0
	80	65.5	100.0	35.0	89.7	46.0	92.9
	60	63.0	96.2	31.5	80.8	41.0	82.8
	50	63.5	96.9	31.0	79.5	39.0	78.8

An additional modeling effort to evaluate Texas wild-rice was conducted by Bartsch and others (2000) and recently revised by Hardy (2009). Figure 17 shows the simulated Texas wild-rice available habitat in the San Marcos River based on 1997 channel geometries, 2001 channel geometries, and geometries based on assumed removal of Cape's Dam.

Regarding Figure 17, Hardy (2009) states that "The results suggest that Texas wild-rice habitat availability is maximized in both these sections of the San Marcos River as flow rates increase above approximately 100 cubic feet per second." The results also suggest that rapid decreases in suitable area occur below the 65 cubic feet per second simulated flow. At 65 cubic feet per second, approximately 75 percent of maximum habitat is maintained and drops to approximately 50 percent at 30 cubic feet per second. Loss in available habitat occurs rapidly as flows drop below 30 cubic feet per second." Hardy (2009) summarizes the technical team's review of the model results as follows: "As part of the technical team evaluation, the spatial distribution of predicted cell suitabilities were examined on a computational cell by cell basis and compared to actual wild rice distributions based on 1989 to 2008 monitoring data at each simulated discharge. Observed versus use frequency distributions at flow above 60 cubic feet per second are very similar to that reported above for 60 cubic feet per second while the results for 30 cubic feet per second are indicative of the results at simulated flow lower than 30 cubic feet per second. This appears to be a systematic bias in the modeling results at lower flows that should be examined in more detail with the revised modeling currently underway."

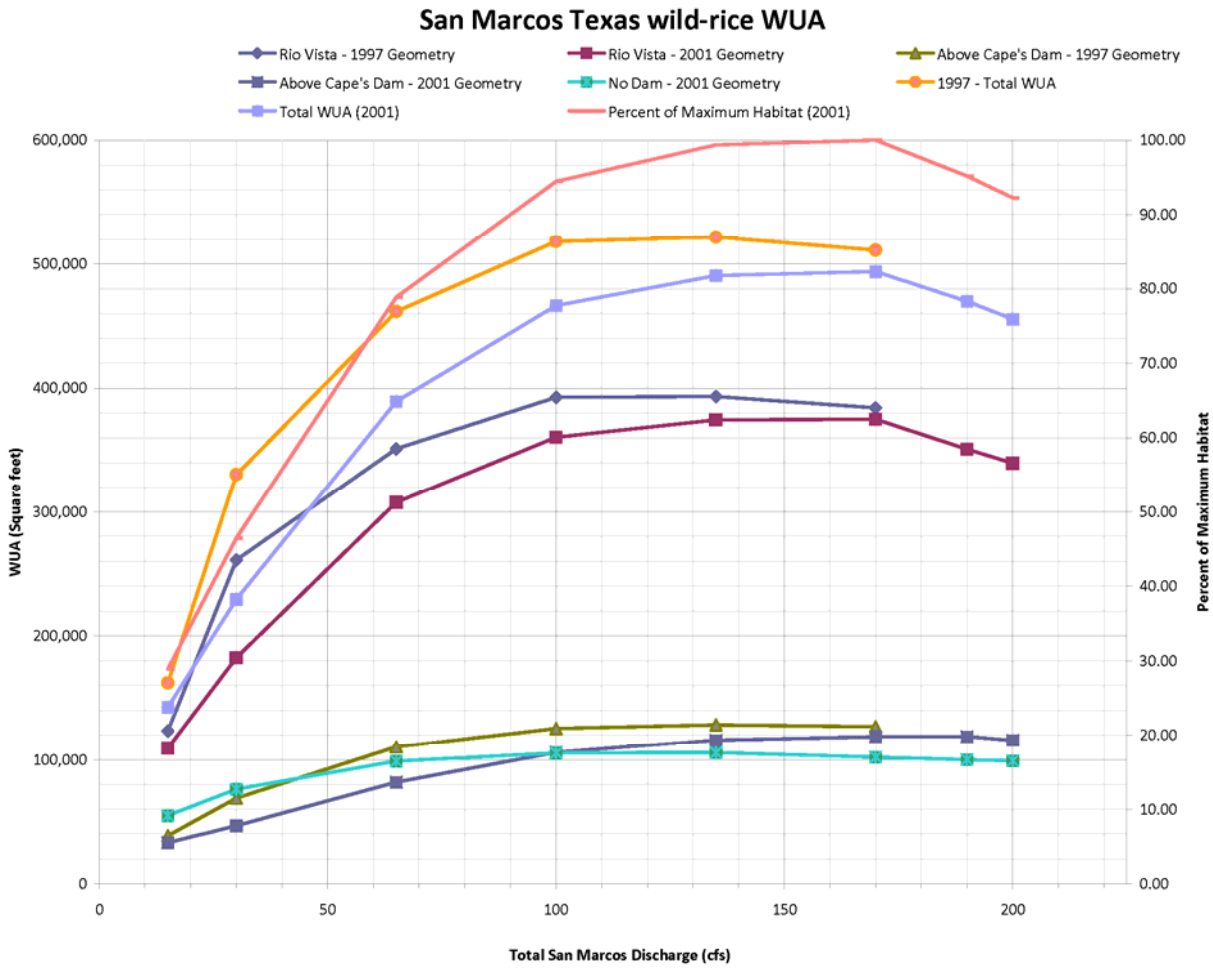


Figure 17: Simulated Texas wild-rice available habitat in sections of the San Marcos River (Hardy 2009) (cfs = cubic feet per second' WUA = weighted usable area).

As with all such models there is a difference between suitable cells (potential habitat) and the actual occupied cells. Also, the San Marcos River is fairly dynamic, with frequent changes in bathymetry related to flooding and sedimentation. Changes in bathymetry have occurred since the Saunders and others model was run. Bathymetry was redone in 2001 and used in the Hardy model (Hardy 2009). In order to compare potential or predicted vs. occupied habitat, the Texas wild-rice annual monitoring data from 2001 (Poole 2002) was overlaid on the Hardy model's computational grid. Flows in 2001 during the time of monitoring were similar to the 190 cubic feet per second flow that Hardy modeled. There was a 17 percent and 9 percent match between predicted habitat and occupied habitat in the Rio Vista and Above Capes sections, respectively. As a rooted plant, Texas wild-rice is not able to move quickly to areas of potential habitat as they become available. Thus, such models are of limited use in determining the decline of the population. The models are more useful in determining potential habitat for future reintroductions of Texas wild-rice.

As previously mentioned, an additional concern to this species is recreational use of the river, which is heavy (Bradsby 1994) and known to have measurable impacts on Texas wild-rice (Breslin 1997). Breslin (1997) details the relative impacts of various activities to Texas wild-rice, and Bradsby (1994) discusses the relative quantity of use of the river during different levels of flow, but there are no quantifiable impacts detailed at various discharge levels. Presumably, as discharge decreases, a greater percentage of the plants are exposed to tubers, canoeists, kayakers, and dogs, which increases potential negative consequences. As discussed for recreational impacts to the fountain darter, minimizing periods of low springflow provides a conservative approach to overcoming the problem of recreational impacts.

- San Marcos gambusia (*Gambusia georgei*)

The San Marcos gambusia has not been collected since 1982 (USFWS 1996) and is most likely extinct. As a precaution, the U.S. Fish and Wildlife Service (USFWS 1993) has issued take and jeopardy levels corresponding to those for the fountain darter in the San Marcos Springs System where the San Marcos gambusia was previously found. Major concerns for any existing San Marcos gambusia include elevated temperatures and the presence of quiet, shallow, open water with partial shading adjacent to fast-moving current. The exact cause for the decline of the species in the early 1980s is unknown, but hybridization with the western mosquitofish (*G. affinis*) is believed to have contributed. Although hybridization occurred in relatively small numbers historically, for unknown reasons collections in the early 1980s indicate hybrids had become many times more abundant than the pure strain of San Marcos gambusia. Another likely cause for the decline of this species is that suitable habitat is severely limited in the system; virtually all locations with the necessary conditions to support this species have been invaded by and overgrown with the exotic macrophyte, elephant ears (*Colocasia esculenta*). Because of the probability that this species is no longer found in the system, specific components of a flow regime aimed at its protection are not considered here. As indicated in the U.S. Fish and Wildlife Service Recovery Plan (USFWS 1996), the measures adopted to support the continued existence of the fountain darter are assumed to be sufficient to support any remaining San Marcos gambusia without incurring harm to the species.

- Texas blind salamander (*Eurycea rathbuni*)

Texas blind salamanders (*Eurycea rathbuni*) are found in the subterranean waters of the San Marcos area of the Edwards Aquifer. They live in water-filled cavernous areas, and are neotenic (reproduce in the larval form) and aquatic throughout their life. Primary concerns to the Texas blind salamander are depth of the water table and water temperature (Longley 1978, Berkhouse and Fries 1995). The latter is an assumption based on the constant temperatures of the water in which the species is found; more research is needed to address the affects of temperature changes to the species. Regardless, the temperature of the water stored in the aquifer is constant at approximately 69.8º F (21º C), which is unaffected by temperatures aboveground or fluctuations in discharge from spring openings. Depth of the water table fluctuates depending on recharge to the aquifer and withdrawals made from it. Despite concern for a decline in the water table, the springs feeding the San Marcos River (in Spring Lake) have not ceased flowing in recorded history. Concerns with water quality include human activities (that is, nonpoint source runoff, sewage leaks, and other chemical contamination) in the recharge

zone and lowered aquifer levels preventing adequate dilution to these contaminants. There is also concern with encroachment of the "bad water" line into spring areas; however, evidence indicates that minimal salinity changes occur only in the transition zone, not at the springs under historical aquifer level changes. Springflow issuing from the major springs within Spring Lake might be sufficient for the protection of this species within the aquifer. However, with the unknowns surrounding the "bad water" line, the conservative approach would be to maintain springflow at no less than historically recorded values.

- San Marcos salamander (*Eurycea nana*)

San Marcos salamanders (*Eurycea nana*) are found throughout Spring Lake (at the headwaters of the San Marcos River) where rocks are associated with spring openings and in rocky areas up to 150 meters below Spring Lake Dam (Nelson 1993, BIO-WEST 2007c). The primary concerns facing the San Marcos salamander are water temperature, available physical habitat, and water quality.

Temperature requirements are known only from research conducted to determine critical thermal maximum for the species: 96.4º F (35.8º C) and 99.1º F (37.3º C) for juveniles and adults, respectively (Berkhouse and Fries 1995). Because of the constancy of the water temperature issuing from the springs (Groeger and others 1997), it is extremely unlikely that this temperature maximum will ever be reached. Temperatures at which sub-lethal effects, such as decreased fecundity and growth rates, begin to occur are unknown. A cautious approach is preferred in such instances, but the temperature of the water issuing from the springs fluctuates very little and the springs have not ceased to flow in known history. Downstream of Spring Lake Dam, there is a greater potential for water temperatures to increase; however, studies have shown that the temperature in this portion of the San Marcos salamander's range remains virtually unchanged from the temperature at the spring orifice (Groeger and others 1997, Saunders and others 2000, Hardy 2009). Thermal requirements of the San Marcos salamander should be met as long as water continues to flow from the spring openings in Spring Lake and over Spring Lake Dam.

One of the habitat requirements of the San Marcos salamander is silt free rocks around the spring openings within Spring Lake and downstream of the dam (Tupa and Davis 1976, Nelson 1993, BIO-WEST 2007c). Because the rocks utilized by the salamanders are located adjacent to spring openings, they are kept silt free as long as water is issuing from the springs. Rocks within the habitat downstream of the dam are more susceptible to being covered with detritus or silt that washes over the dam. No research is available to determine what discharge levels are necessary to prevent build up of silt and detritus in this reach. This area is close to the headwaters (Spring Lake); thus, little silt enters the system before it reaches this section. In addition, flow is generally rapid (sufficient to prevent siltation) in this reach as water travels over the dam and through this relatively shallow region just downstream.

In addition to using silt free rocks, the San Marcos salamanders are abundant in the filamentous algae found in the upper end or "hotel reach" section of Spring Lake (Tupa and Davis 1976, Nelson 1993, BIO-WEST 2007c). Investigators hypothesize that San Marcos salamanders find abundant food in the algae as well as increased protection from

predators. Because of the stable water temperature, dissolved oxygen, and nutrients found in Spring Lake (McKinney and Sharp 1995), algae is abundant in this section of the lake. Within the period of record, changes in discharge from the springs have had very little affect on these water quality parameters.

Wetted perimeter is another concern for the San Marcos salamander, though the relative constancy of the water level in Spring Lake, even with changes in discharge, minimizes this concern. Unlike habitat in the lake itself, portions of the San Marcos salamander range found downstream of Spring Lake are subject to changes in wetted perimeter as discharge fluctuates. At a site immediately downstream of the San Marcos salamander's range (just upstream of University Drive Bridge), information gathered from Saunders and others (2000) reveals that a wetted width of 60.8 feet occurs when flows reach 172 cubic feet per second. At a discharge of 125 cubic feet per second, 56.8 feet (93 percent) of the wetted width remains, and at 81 cubic feet per second, 50.4 feet (83 percent) remains.

Recreation and water chemistry are other factors that can impact the San Marcos salamander population. Recreation is regulated and generally prohibited on Spring Lake, although archeological excavations and other scientific investigations may disturb sites where San Marcos salamanders are found. Downstream of the dam, the river is open to the public and portions are heavily used by recreationists, but impacts in the area immediately below the dam during higher flow conditions are limited because of the depth (west spillway) and underwater hazards (remains of old dam; east spillway). However, during lower flow conditions, the depth in the western spillway is reduced and the underwater hazards are exposed which causes the recreational use in this area to intensify.

There were no noted direct impacts from springflow to the San Marcos salamander population at the locations sampled for the Edwards Aquifer Authority variable flow study during the low-flow periods experienced in 2006 and 2009 (BIO-WEST 2007b, BIO-WEST 2010b). However, habitat conditions in the riverbed portion of Spring Lake in July 2009 were reduced due to extensive vegetation growth and corresponding siltation. This was not experienced during the reduced flow period in 2006. The shallower water depths below Spring Lake Dam as a result of the low discharge conditions in 2006 and 2009 did cause some indirect effects on San Marcos salamander habitat via increased recreational activity. Recreation in the immediate areas below the dam increased during these periods with many rocks being physically moved by people to create structures, dams, underwater rock art, and artificial channels (Figure 18). Although not captured in the snorkel surveys, the physical perturbation associated with this recreation as well as the habitat modification likely had some impacts on the resident salamander population below Spring Lake Dam.

Springflow issuing from the major springs within Spring Lake to the degree necessary to overflow Spring Lake dam and inundate the western spillway is anticipated to be sufficient for the protection of the San Marcos salamander. However, with the unknowns surrounding habitat conditions within Spring Lake under flows less than the historical record, the conservative approach would again be to maintain springflow at no less than historically recorded values.

Figure 18: Physical disturbance below Spring Lake Dam, September 2006.

- Comal Springs riffle beetle (*Heterelmis comalensis*)

Comal Springs riffle beetles (*Heterelmis comalensis*) have been found near spring orifices within Spring Lake (Gibson and others 2008). Unlike Comal Springs, there is no spring run habitat (for example, surface habitat) for modeling in Spring Lake, and only upwelling habitat areas are maintained. Similar to the salamanders, springflow issuing from the major springs within Spring Lake is anticipated to be sufficient for the protection of this species within upwelling areas and subsurface habitat. However, as mentioned for the salamanders, the conservative approach would be to not allow springflow to fall below historically observed flow conditions.

Historical flows at San Marcos Springs

Similar to the Comal Springs system, an evaluation of the historical hydrology was conducted to put the observed variable flow data from the past nine years, the Texas Parks and Wildlife Department Texas wild-rice annual monitoring data of more than 20 years, and predicted model results in perspective. The average discharge at San Marcos Springs during the period of record from 1940 to 2009 was approximately 164 cubic feet

per second. The minimum recorded flow was 46 cubic feet per second on August 15 and 16, 1956. The minimum monthly average springflow of 53.5 cubic feet per second also occurred in August 1956. For an 18-month period (September 1955 through February 1957), monthly average springflow was 68.6 cubic feet per second and ranged from 76.8 cubic feet per second (September 1955) to 53.5 cubic feet per second (August 1956). This springflow condition, coupled with the duration of this event, resulted in an extreme low flow condition that no doubt had direct impacts on threatened and endangered species habitat and most likely directly on the species as well (especially Texas wild-rice). While all the listed San Marcos species (with the exception of the Comal Springs riffle beetle and the San Marcos gambusia) were known from the San Marcos ecosystem before and after the extreme low flow conditions of the 1950s, there is no evidence as to the size, distribution, or health of any of their populations immediately prior to or after that extended event. Additionally, conditions in the watershed of the San Marcos River have changed dramatically over the last 50 years, with increases in both urban and rural population, aquifer pumping, impervious cover and runoff, sedimentation, non-native invasive species, recreation, roads, bridges, and dam failures. The system is more stressed today than 50 years ago. Therefore, there is less confidence that the threatened and endangered species would necessarily persist if those extreme low flow conditions were repeated.

San Marcos Springs flow regime recommendations

Figure 19 provides an overview of the information used to develop the flow regime recommendations for the San Marcos Springs system. To develop an ecologically protective flow regime, a balancing of species specific requirements was conducted where results did not align identically. In instances where there were competing species specific requirements, the higher flow requirement was conservatively chosen in each case following an analysis and understanding that this recommendation would not negatively impact the other species or overall ecosystem integrity.

Based on the review of the best available science discussed throughout this report and summarized in Figure 19, we developed the San Marcos Springs Flow Regime as presented in Table 11.

With the assumptions noted, it is our determination that maintaining all components of the proposed flow regime would meet the goal of long term survival of the threatened and endangered species of the San Marcos Springs system in the wild.

The long-term average value flow of 140 cubic feet per second is supported by long-term monitoring data and modeling results. At these total discharge levels, populations of each of the threatened and endangered species are anticipated to maintain or increase their respective populations. The most important aspect of maintaining the long-term average component of the flow regime is that the system would not be able to have repeated 6-month or 1-month events also prescribed in the flow regime. As such, the lower flow criteria were developed with the understanding that if they should occur, they would rarely be experienced in the future.

Long-term average	Minimum 6-month average	Minimum 1-month average
Poole (2002, unpublished data) - 21 annual demographic monitoring surveys have been conducted since 1989, at discharges ranging from 78 cfs to 400 cfs. ***Edwards Aquifer Authority Variable Flow Study (BIO-WEST 2002b-2010b)*** - 22 comprehensive sampling events have been conducted since 2000 over a total discharge range of 105 cfs to 417 cfs. Total San Marcos Springs system discharge greater than 140 cfs has been shown to provide high quality habitat throughout the range for the species present in this system. ***Saunders and others (2000)*** - Diverse aquatic vegetation maintained at 140 cfs. - Maximum Texas wild-rice habitat predicted at 120 cfs in Segment 3 (Sewell Park reach) ***Bartsch and others (2000)*** - No discernable change in modeled fountain darter habitat from 135 to 100 cfs total discharge. - Temperature conditions are suitable for fountain darter reproduction within its entire range at 80 cfs. ***Hardy (2009)*** - Maximum predicted available habitat for fountain darter at 65 cfs. - Maximum predicted available habitat for Texas wild-rice at 170 cfs. - Approximately 95% of maximum predicted available habitat for Texas wild-rice at 100 cfs. ***Historical Hydrology*** - Average total discharge from 1956 – 2009 is 173 cfs. cfs = cubic feet per second	***Poole (2002, unpublished data)*** - 4 annual demographic monitoring surveys conducted during low flow (<110 cfs) periods. - Monitoring and transplanting Texas wild-rice during flows <100cfs in 2006 and 2009 as well as Cape's Dam breach in January 2000. ***Edwards Aquifer Authority Variable Flow Study (BIO-WEST 2002b, 2007b, 2010b)*** - 6 Critical period full monitoring events have been conducted since 2000 ranging in total discharge from 92 cfs to 108 cfs. - Aquatic vegetation reductions in highly recreated areas magnified below 100 cfs. - Slight siltation of San Marcos salamander habitat within riverbed area of Spring Lake below 100 cfs in 2009. - Nearly 20% reduction in Texas wild-rice coverage in 2009 following a 12-month duration of approximately 96 cfs. ***Saunders and others (2000)*** - Greater than 80% of maximum run, riffle, and pool habitat maintained at 60 cfs. - Greater than 60% of modeled aquatic vegetation maintained at 60 cfs throughout all segments. - Approximately 90% or greater and greater than 80% of maximum predicted available habitat for Texas wild-rice at 80 cfs and 60 cfs, respectively. ***Bartsch and others (2000)*** - Approximately 90% of maximum available fountain darter habitat predicted at 65 cfs. - Temperature conditions are suitable for fountain darter reproduction to Cape's Dam at 55 cfs. ***Hardy (2009)*** - Maximum available habitat for fountain darter predicted at 65 cfs. Approximately 85% and 75% of maximum predicted available habitat for Texas wild-rice at 80 cfs and 65 cfs, respectively. ***Historical Hydrology*** - Minimum 6-month average discharge was 61 cfs from May to November 1956.	***Edwards Aquifer Authority Variable Flow Study (BIO-WEST 2002d, McDonald and others 2007)*** - Comal Springs riffle beetle laboratory studies suggest that the beetle has a strong affinity for upwelling flow and will retreat into artificial substrate during periods of low discharge. - Laboratory study suggests trematode gill parasite did not have a significant impact on fountain darter reproduction. ***Saunders and others (2000)*** - Greater than 75% of maximum run, riffle, and pool habitat maintained at 50 cfs (lowest flow modeled). - Greater than 55% of modeled aquatic vegetation maintained at 50 cfs throughout all segments. - Approximately 96% (Segment 1), 79% (Segment 2), and 78 % (Segment 3) of maximum available habitat for Texas wild-rice predicted at 50 cfs. ***Bartsch and others (2000)*** - Approximately 90% and 55% of maximum available fountain darter habitat predicted at 65 cfs and 30 cfs, respectively. - Temperature conditions are suitable for fountain darter reproduction from Spring Lake to Rio Vista Dam at 30 cfs. ***Hardy (2009)*** - Approximately 75% of maximum available fountain darter habitat predicted at 30 cfs. - Approximately 75% and 55% of maximum available habitat for Texas wild-rice predicted at 65 cfs and 30 cfs, respectively. ***Historical Hydrology*** - Minimum 1- month average discharge was 53.5 cfs in August 1956. - Lowest flow recorded was 46 cfs in August 1956. - 18-month period (September 1955 through February 1957), monthly average springflow was 68.6 cfs.

Figure 19: Overview of results used to inform initial flow regime recommendation on the San Marcos Springs system.

Table 11: San Marcos Springs flow regime recommendation.

San Marcos Springs flow regime recommendation*		
Criteria	**Flow (cfs)**	**Notes**
Long-term average flow	140	
Minimum 6-month average	75	
Minimum 1-month average	60	No flow below 52 cfs

cfs = cubic feet per second

*Assumptions:

- Invasive species remain at current levels, both as to number of species and numbers of individuals/coverage.
- Gill parasite levels do not increase.
- Amount of sediment in the river does not increase.
- Recreation remains at current levels (that is, no new tube/canoe/kayak rental facilities, no new water parks)
- Current dam configuration remains unchanged.
- Flow recommendations do not reflect the U.S. Geological Survey discharge measurement accuracy range of up to plus or minus 10 percent based on physical and anthropogenic factors affecting stream velocity (that is, no buffers are added).
- Texas wild-rice survived the drought of record and recolonized the river without human assistance.
- No additional mitigation activities beyond those currently in practice.

The minimum 6-month average flow of 75 cubic feet per second is supported by a combination of observed data, model results, and aspects of historical hydrology woven together with professional judgment. Actual data collected and observed at flows slightly higher than this (about 80 to 90 cubic feet per second) show that effects to the fountain darter are minimal but decreases in Texas wild-rice areal coverage have been documented to be approximately 20 percent (BIO-WEST 2010b). The Expert Science Subcommittee is in agreement that dropping to 75 cubic feet per second would not greatly affect fountain darter habitat but would result in greater reductions in total areal coverage of Texas wild-rice, likely 25 to 30 percent or potentially greater.

Habitat model results (Saunders and others 2000 [Texas wild-rice], Hardy 2009 [fountain darter and Texas wild-rice]) show that greater than approximately 80 percent of available habitat is predicted at 75 cubic feet per second (note: 75 cubic feet per second was not actually modeled by either effort; thus, this approximation was made on the flow levels modeled above and below this value). At first glance, these percentages seemed high for this flow regime component, which is likely the case for the fountain darter. However, the interpretation of these results relative to Texas wild-rice is more complicated as it is a plant and cannot simply move to areas of predicted suitable habitat like the fountain darter. To check the predictive ability of these models, Texas wild-rice annual demographic data was used to compare occupied versus predicted habitat. A comparison was made using the Hardy 2001 bathymetry model (Hardy 2009) with the Texas Parks and Wildlife Department's 2001 Texas wild-rice GIS shapefiles (Poole 2002) at a flow of

190 cubic feet per second, as this was the average flow when the Texas Parks and Wildlife Department data was recorded. Using cells from the Hardy (2009) model with a greater than 0.45 suitability rating, 17 percent of the predicted suitable habitat from Spring Lake to Rio Vista was occupied and 9 percent of the predicted suitable habitat from Rio Vista to Cape's Dam was occupied. In addition to the low percentage of predicted habitat that was indeed occupied, it is important to point out that only depth, velocity, and substrate were considered as input parameters to the Texas wild-rice habitat model. As such, an area of river that met these three parameters was predicted to be suitable irrespective if the area was already occupied with another type of aquatic vegetation or shaded by bridges or riparian canopy. Based on these factors, the Expert Science Subcommittee determined that high (greater than 80 percent) percentages of modeled habitat were necessary to be protective of Texas wild-rice.

Finally, we reviewed the historical hydrology for the San Marcos River. The historic minimum 6-month average was approximately 61 cubic feet per second during the 1950s drought. Although the historical minimum 6-month average was less than the proposed 75 cubic feet per second, changing conditions in the San Marcos Springs system since the drought of record, especially increased sedimentation and recreation, coupled with the effects of the 1998 flood and the significant reduction in Texas wild-rice below Interstate 35, guided our determination that a shift upward from the historically observed average was warranted.

There was considerable discussion amongst subcommittee members over the interpretation and integration of the observed data, model results, historical hydrology, changing conditions in the river, and potential frequency of occurrence of this flow component within the context of implementing the flow regime. As with the Comal Springs recommendations, we used best professional judgment to interpret and integrate these components and determined that 75 cubic feet per second for a minimum 6-month average would be protective with the associated assumption that the flow regime is implemented as designed, which would mean that this 6-month average would be experienced very infrequently in the future.

The minimum 1-month average flow of 60 cubic feet per second with a minimum flow of 52 cubic feet per second is the threshold that we recommend the system not fall below with the current set of assumptions in place. The minimum 1-month average flow recommendation was based primarily on professional judgment and habitat modeling as this flow has not been observed by scientists on the biological workgroup or our subcommittee. Although data has not been collected at these flows, we used professional judgment to determine that if 25 to 30 percent reductions in Texas wild-rice are likely at 75 cubic feet per second, reductions at 60 cubic feet per second would be greater. How much more is unknown at this time but, with the refinement of existing habitat models (currently underway), more accurate estimates may be obtained in the near future.

Habitat model results (Saunders and others 2000 [Texas wild-rice], Hardy 2009 [fountain darter and Texas wild-rice]) show that greater than approximately 70 percent of available habitat is predicted at 60 cubic feet per second (note: 60 cubic feet per second was modeled by Saunders and others [2000] but not Hardy [2009]); thus, the interpretation of the latter was made on the flow levels modeled above and below 60 cubic feet per second). Although both models (with all their associated assumptions) still show

relatively high percentages of available habitat at 60 cubic feet per second, Hardy (2009) does show a sharp decline below 65 cubic feet per second and Saunders and others (2000) only modeled down to 50 cubic feet per second. As 60 cubic feet per second is below the level of observed hydrology, modeling at this level represents an exercise in extrapolation that inherently creates greater uncertainty around model results. This, coupled with the additional analysis described above regarding occupied area of Texas wild-rice versus predicted area, led us to recommend that greater than 70 percent of modeled habitat was necessary to be protective of Texas wild-rice.

The historical hydrology (U.S. Geological Survey gage data) was again reviewed and revealed that the minimum 1-month average was approximately 54 cubic feet per second during the 1950s drought. Although the historical minimum was lower than the recommended 60 cubic feet per second, we determined that a shift upward from the historically observed monthly minimum was warranted based on the changing conditions in the San Marcos Springs system since the drought of record, especially increased sedimentation and recreation, coupled with the effects of the 1998 flood and the significant reduction in Texas wild-rice below Interstate 35. A component of the historical hydrology we examined closely was the relative gaps between historical events (during periods of drought and falling spring discharge) as represented by the proposed flow regime. For instance, the gap between the historical minimum 6-month average and the historical 1-day minimum was approximately 16 to 23 cubic feet per second. We used this analysis to help describe the 1-day minimum (75 cubic feet per second [6-month average] - 23 cubic feet per second = 52 cubic feet per second (proposed 1-day minimum). Additionally, the gap between the historical minimum 1-month average and historical 1-day minimum was approximately 8 to 15 cubic feet per second. We included an 8 cubic feet per second gap from the proposed minimum 1-month average (60 cubic feet per second) to the 1-day minimum (52 cubic feet per second).

As with the 6-month average recommendation for San Marcos, there was considerable discussion amongst subcommittee members over the interpretation and integration of the model results and embedded uncertainty, historical hydrology, changing conditions in the river, and potential frequency of occurrence of this flow component within the context of implementing the flow regime. We again used best professional judgment to interpret and integrate these components and determined that 60 cubic feet per second for a 1-month average with a minimum flow of 52 cubic feet per second would be protective with the associated assumption that the flow regime is implemented as designed resulting in a 1-month average that would be experienced very infrequently in the future.

We reiterate discussions throughout this report that emphasize that the flow regime recommendations for San Marcos Springs are based on the best available science and professional judgment at this time. We understand that the threatened and endangered species in the San Marcos Spring system can withstand short time periods of habitat loss and even some direct impact to the species themselves without resulting in long-term harm to the overall population. With that said, several questions remain: What frequency or duration of these events could be tolerated by these species without long-term consequences? How many individuals (or cover) can be lost before recovery is impeded or impossible? How long does recovery take, particularly in a population with diminished reproductive capacity? How much can the range be contracted before the probability of a

stochastic event wiping out the species becomes significant? In the absence of those answers, we have chosen to exceed the historically observed flow statistics at San Marcos Springs because the condition of the threatened and endangered species populations following the 1950s drought is unknown.

Additional major factors discussed in the Comal Springs recommendations section but very much applicable in the San Marcos Springs recommendation as well are that (1) aquatic vegetation changes are not incorporated into the habitat modeling results, (2) U.S. Fish and Wildlife Service biologists have expressed concern that major die-offs and decomposition of aquatic vegetation during periods of low-flow may cause significant reductions in dissolved oxygen available for the fountain darter, and (3) reduction in aquatic vegetation could also cause crowding or clumping of darters in remaining suitable habitat which could possibly make them more vulnerable to predation or increased competition (native and non-native). These were factors addressed by our professional judgment during the review of model results.

Three additional factors standout in the San Marcos Springs system:

- Asian trematode (*Centrocestus formosanus*)

Should moderate flow exist for several years without any flash floods followed by low flows due to drought conditions, it is anticipated that cercarial abundance may increase to a more severe level (Tom Brandt, personal communication).

- Increased sedimentation

Over the past decade, the upper San Marcos River has filled in considerably from just below Spring Lake Dam (just downstream of the mouth of Sessom Creek) to the reconstructed Rio Vista Dam. If sedimentation is not controlled to some degree, it will likely continue to impact endangered species habitat or the species directly, as in the case of Texas wild-rice.

- Increased recreational pressure

Similar to the trends witnessed with sedimentation, qualitative observations of increasing recreational activity have been noted for the San Marcos Springs system. The main focus of the recreation on the San Marcos River starts immediately below Spring Lake Dam and extends to Cheatham Street Bridge below Rio Vista Dam. Recreational impacts are also increasing in the area below this. The upper stretch of the San Marcos River includes high quality habitat for the San Marcos salamander and fountain darter as well as supporting the highest areal coverages of Texas wild-rice. As with sedimentation, if not addressed, this will likely continue to impact San Marcos salamander and fountain darter habitat, and Texas wild-rice directly.

All the unknowns logically lead one to a conservative mindset in the setting of flow-related requirements. However, we made a conscious decision not to build in cushion to the proposed recommendations. It was our interpretation of the legislative charge to evaluate the best available science objectively, clearly state the assumptions associated with the recommendations, and acknowledge the need for further study where appropriate. For instance, if it is later revealed that significant impacts are not captured in the model results or efforts to control the parasite or its host, sedimentation, or recreation

are not in place or successful in the future, then one needs to be cautious with strict implementation of the proposed flow recommendations. However, should information come forward that these species are able to tolerate short periods of lower flow conditions or more frequent occurrences without significant consequence, or mitigation activities are in place that could be effective in providing additional levels of protection, then the proposed flow regime recommendations for the San Marcos Springs System would also need to be revisited. One thing is clear, long-term monitoring is essential and further study and research specifically during critical low flow periods (or simulated critical low-flows) are needed to accurately determine the potential impacts to the species at San Marcos Springs.

Further studies

Several studies have already been funded by the Edwards Aquifer Recovery Implementation Program and are in progress, so only a summary of the studies with biological relevance will be provided in this section. One such study is the update of hydraulic and habitat models for both the Comal and San Marcos Springs systems. The update will include measuring current bathymetry of the systems where appropriate, updating aquatic vegetation maps for the entirety of each system, and an evaluation of canopy cover (shading) and its effect on Texas wild-rice habitat. This study is currently under contract with Dr. Thomas Hardy of the Texas State University, River Systems Institute. The Edwards Aquifer Recovery Implementation Program has also funded a feasibility study of potential Intensive Management Areas on the Comal Springs system. The two main components of this study are evaluating the potential for (1) in-situ refugia—the ability to maintain habitat and endangered species within the Comal Springs/River system itself under severely reduced discharge conditions—and (2) applied research—the ability to explore low and high flow responses of the endangered species and their habitats to better inform future (adaptive) management decisions. This study is currently under contract with BIO-WEST, Inc. The U.S. Fish and Wildlife Service's San Marcos National Fish Hatchery and Technology Center is also under contract with the Edwards Aquifer Recovery Implementation Program to conduct low-flow evaluations of habitat use and genetic diversity of fountain darters within the Comal and San Marcos springs systems.

We support ongoing monitoring efforts being conducted by Texas Parks and Wildlife Department and Edwards Aquifer Authority relative to the evaluation of flow rates on the threatened and endangered species in these systems. We recommend that the following studies be considered to address data gaps relative to flow responses of species requirements not currently being captured within either of those programs.

- Fountain darter
    - *Centrocestus formosanus* is an introduced gill parasite, in the Comal and San Marcos rivers that has the potential to affect resident populations of fountain darters. The research should see if correlations exist among springflow, *Melanoides tuberculatus* (snail host of *Centrocestus formosanus*) numbers, and parasite numbers within each system. Determination of correlations among flow, snail host, parasite, and fountain darter will permit the

development of a model to predict future effects of the parasite on fountain darter survival.

  - Research is needed to evaluate management alternatives for the control of *Centrocestus formosanus* and/or *Melanoides tuberculatus* within the Comal and San Marcos springs systems. Elimination of the parasite from the rivers is not likely. However, physical removal of the parasite's host snail, *Melanoides tuberculatus*, by dredging and using turbulence (dams, riffles, and air bubbles) to kill drifting parasites, needs to be evaluated as a possible method to manage the effects of the parasite on the fountain darter.
  - The effect of water temperature on fountain darter reproduction has been determined. The effects of temperatures between 81° F (27.2° C) and 95° F (35° C) have on fountain darter growth and survival has not been determined. This information is needed to model the stress placed on the population as water temperatures rise within the systems.

- Texas wild-rice
  - Determine the minimum buffer size, both horizontally and vertically within the water column, needed to protect Texas wild-rice from recreational damage.
  - Determine why Texas wild-rice has not re-established well in the San Marcos River below Interstate 35. Specifically investigate CO_2 levels as well as water clarity.
  - Determine the rate at which Texas wild-rice may recolonize following dry periods or floods. This would be an essential component of determining the frequency and duration of low flow events that result in population decline.
- Comal Springs riffle beetle
  - Study the use of subsurface habitat during normal and low-flow conditions to evaluate the size and importance of this habitat type during periods of low flow.
  - Evaluate the potential for maintaining successful reproduction of this species in captivity.
- Comal Springs dryopid beetle and Peck's Cave amphipod
  - Conduct laboratory studies on the life history requirements of these species.
  - Evaluate the potential for maintaining successful reproduction of this species in captivity.
- Invasive species monitoring
  - Monitoring of the Comal and San Marcos rivers to identify newly introduced species. Twice yearly surveys of the plants, invertebrates, and fishes should be done to identify newly introduced species and to determine if significant changes in native species have occurred. Introduced species need to be

removed immediately. Causes of significant changes in native species numbers or distributions need to be determined and addressed.

  - We also recommend that special studies targeted at potential management plans be conducted to protect the listed species directly or through the protection of water quality and/or physical habitat within the San Marcos and Comal rivers.

- Recreation
  - Conduct a study to quantify recreational use and economic benefit on the Comal and San Marcos rivers.
  - Conduct an evaluation to quantify impacts that recreational activity has on threatened and endangered species habitat or directly on the species in both the Comal and San Marcos ecosystems.
  - Develop a recreational management plan for both systems.
- Sedimentation
  - Conduct a study to quantify sediment transport within the San Marcos River.
  - Conduct an evaluation to quantify impacts of sedimentation on fountain darter, San Marcos salamander, and Texas wild-rice within the San Marcos River.
  - Develop a sedimentation management plan for the San Marcos River.

We support the San Marcos River and Comal River restoration committees. Both entities have conducted several meetings and have prepared restoration plans for their respective systems. Within these proposed restoration plans, it is our understanding that each committee will be making recommendations for further studies and/or potential management activities to explore. Finally, we also support interaction and coordination with the Edwards Aquifer Recovery Implementation Program during the preparation of the Habitat Conservation Plan and the Southern Edwards Aquifer Recovery Team during their process of developing a recovery plan for the listed species independent of the Edwards Aquifer Recovery Implementation Program. It is anticipated that the Habitat Conservation Plan and Recovery Plan development will involve several consistent objectives for which we might be able to provide valuable input.

Task 2: Analyze withdrawal reductions and stages for critical period management

Results: The following withdrawal reductions and stages for critical period management resulted from the species requirements in relation to spring discharge rates:

San Antonio Pool

Comal (cfs)	San Marcos (cfs)	J-17 (feet)	Stage -	Reduction (%)
<225	<96	<665	I	85

Uvalde Pool

J-27 (feet)	Stage -	Reduction (%)
< 865	I	85

where cfs is cubic feet per second.

Our interpretation of the task

This task is focused on developing withdrawal reductions and stages for critical period management based on the flow requirements from Task 1. Specifically, statute required us to:

> "*Based on*…[the results of Task 1]…*and the elements required to be considered by the authority under Section 1.14 of this article, the expert science subcommittee shall, through a collaborative process designed to achieve consensus, develop recommendations for withdrawal reduction levels and stages for critical period management including, if appropriate, establishing separate and possibly different withdrawal reduction levels and stages for critical period management for different pools of the aquifer needed to maintain target spring discharge and aquifer levels.*" (see Appendix B for the full text).

Among other items, Section 1.14 of the Edwards Aquifer Authority Act (Appendix B) states that the Edwards Aquifer Authority shall (1) protect the water quality of the aquifer, (2) protect the water quality of the surface streams to which the aquifer provides springflow, (3) achieve water conservation, (4) maximize the beneficial use of water available for withdrawal from the aquifer, (5) recognize the extent of the hydrogeologic connection and interaction between surface water and groundwater, (6) protect aquatic and wildlife habitat, (7) protect species that are designated as threatened or endangered under applicable federal or state law, and (8) provide for instream uses, bays, and estuaries.

Based on the wording of the act, we assumed that our task was limited to adjusting withdrawal (pumping) reduction levels and stages for critical period management. We did not suggest changes to the overall permitting cap or how the act or the authority

implements withdrawal reductions or permitting (although we did request model runs at different levels of constant pumping to better understand how the aquifer responds to different levels of pumping). Therefore, we restricted ourselves to considering adjustments of (1) the current number of stages; (2) the current trigger levels for J-17, J-27, Comal Springs, and San Marcos Springs; and (3) reductions in pumping at each of the stages.

Based on our interpretation of the task, we developed withdrawal reductions and stages for critical period management that met or exceeded the flow requirements for the endangered species from Task 1—we did not consider minimum pumping (or additional water supply infrastructure) needed to maintain health and human safety or any management actions that could be taken to lower springflow requirements. Our understanding is that these policy issues will be considered by the Steering Committee during the development of a habitat conservation plan.

With respect to the charge, we did not extensively address all elements under Section 1.14 of the Edwards Aquifer Authority Act. Although we considered the need to protect the water quality of the aquifer and that of the aquatic and wildlife habitats in and near the springs with respect to movement of the bad water line and potential contamination, water quality in general was not explicitly considered. We did not consider the protection of aquatic and wildlife habitat in the downstream reaches of the river and its the associated bay and estuary. We did not explicitly consider provisions for instream uses (Senate Bill 3 created a separate process—the environmental flows process—to evaluate the flow requirements for bays and estuaries, a process that is just starting for the Guadalupe-San Antonio River Basin and the Guadalupe Estuary).

Approach

We used an existing numerical groundwater flow model of the Edwards Aquifer to develop withdrawal reductions and stages for critical period management. We used the model to consider different “scenarios”, where a scenario included adjustments to critical period management, maximum pumping, or a model parameter such as an initial condition. After deciding on a scenario we wanted to investigate or consider, we filed a request with staff at the Edwards Aquifer Authority to run the model to simulate the scenario, what we refer to as a “model run request”. Edwards Aquifer Authority staff used the model developed by Lindgren and others (2004) using MODFLOW-NR (Southwest Research Institute 2007). We used this model because it is (1) the best available tool at this time to evaluate the effects of pumping and recharge on water levels at J-17 and J-27 and springflows at Comal and San Marcos springs, (2) it is used by the Edwards Aquifer Authority for managing the aquifer, and (3) it is recognized by the Texas Water Development Board as a groundwater availability model for the San Antonio segment of the Edwards (Balcones Fault Zone) Aquifer. Where appropriate, the Edwards Aquifer Authority’s management module was used to evaluate scenarios. The management module applies withdrawal reductions based on the triggers placed into the module. Edwards Aquifer Authority staff wrote a report of the results and, after internal review at the Edwards Aquifer Authority, delivered the report and output files to the chair of the subcommittee. This report includes our run requests, model run reports from the

Edwards Aquifer Authority, and the model run output files (appendices F, G, and H, respectively).

Based on the results of Task 1, we used the model to look at meeting or exceeding three flow criteria for each of the two springs: a 1-month minimum, a 6-month minimum, and a long-term average for Comal Springs and a 1-month minimum, a 6-month minimum, and a long-term average for San Marcos Springs. Our requested model runs (simulations) fell into three broad categories: (1) runs at constant pumping, (2) runs to investigate the sensitivity of the model to various parameters and scenarios, and (3) runs to attempt to meet springflow requirements while maintaining the permitted pumping cap recognized in Senate Bill 3. We also requested a simulation to serve as a baseline application of current critical period management.

We requested various model runs at constant pumping (that is, no critical period management) to gain an understanding of springflow at different levels of pumping (that is, no critical period management reductions; runs 002, 003, 004, 005, 006, 007, 008, 014, 015, 030, and 032) to help estimate pumping reductions to meet springflow requirements. Although one could come to policy conclusions based on these runs, our intent was not to suggest a modification to the permitting cap or the removal of critical period management.

We requested various model runs to investigate the sensitivity of different parameters and scenarios (runs 009, 010, 016, 017, 018, 019, 020, 021, 022, 023, 024, 028, 029, and 031) to gain an understanding of how springflows might respond to changes in these parameters. Although one could come to policy conclusions based on these runs, our intent was not to suggest modifications to the management of the aquifer based on the runs. For example, Run 031 specified no pumping in Comal and Hays counties. We requested this run to assess the sensitivity of pumping near the springs on springflow and not to suggest that pumping should not be allowed in these counties.

A number of the sensitivity runs examine the effects of limiting the non-critical period pumping at 437,000 acre-feet per year. This number represents what we believe to be the actual recent past maximum amount of permitted pumping given current management policies and current critical period management. Because our model runs generally assume that the maximum permitted volume that can be pumped will be pumped, we wanted to assess how springflow might respond to current levels of maximum pumping. Note that when we refer to pumping amounts (for example, 572,000 acre-feet per year), we are referring to the maximum permitted volumes pumped by permitted users. These numbers do not include exempt uses, which are estimated to be about 20,000 acre-feet per year (Hamilton and others 2009) but are included in the model (although at a level of 13,000 acre-feet per year) and, therefore, all of the model runs discussed in this report.

Based on draft springflow requirements and what we learned from the constant pumping and sensitivity runs, we requested runs intended to meet or exceed the minimum springflow requirements for the endangered species of concern (runs 011, 012, 013, 030, and 034). These runs are in two groups, the first was in response to the initial draft springflow requirements presented on July 8, 2009, (runs 011, 012, and 013), and the second was in response to the revised draft numbers presented on September 21, 2009, (runs 030, 031, 032, 033, 034, 035a, 036a, and 037a). Runs 025, 026, and 027 were

withdrawn once the biologists on the subcommittee revised springflow requirements. Consensus on the springflow requirements was not reached until early December 2009.

Below is a brief description of each run:

Run 001: Current critical period management (maximum 40 percent reduction in pumping for the San Antonio Pool and maximum 35 percent reduction in pumping for the Uvalde Pool)

Run 002: No pumping

Run 003: Constant pumping at 100,000 acre-feet per year

Run 004: Constant pumping at 200,000 acre-feet per year

Run 005: Constant pumping at 300,000 acre-feet per year

Run 006: Constant pumping at 400,000 acre-feet per year

Run 007: Constant pumping at 500,000 acre-feet per year

Run 008: Constant pumping at 572,000 acre-feet per year

Run 009: Pumping at Stage IV not lower than 320,000 acre-feet per year with pumping not allowed to exceed 437,000 acre-feet per year

Run 010: Pumping at Stage IV not lower than 340,000 acre-feet per year with pumping not allowed to exceed 437,000 acre-feet per year

Run 011: Adjustments in pumping reductions for stages III and IV (maximum 50 percent reduction in pumping for the San Antonio Pool and maximum 50 percent reduction in pumping for the Uvalde Pool)

Run 012: Adjustments in pumping reductions for stages III and IV (maximum 60 percent reduction in pumping for the San Antonio Pool and maximum 60 percent reduction in pumping for the Uvalde Pool)

Run 013: Adjustments in pumping reductions for stages III and IV (maximum 70 percent reduction in pumping for the San Antonio Pool and maximum 70 percent reduction in pumping for the Uvalde Pool)

Run 014: Constant pumping at 250,000 acre-feet per year

Run 015: Constant pumping at 350,000 acre-feet per year

Run 016: Current critical period management (Run 001) but starting the simulation with no initial pumping

Run 017: Current critical period management (Run 001) but starting the simulation with twice the initial pumping

Run 018: Adjustments in pumping reductions for stages III and IV (Run 011) but with pumping not allowed to exceed 437,000 acre-feet per year

Run 019: Adjustments in pumping reductions for stages III and IV (Run 012) but with pumping not allowed to exceed 437,000 acre-feet per year

Run 020: Adjustments in pumping reductions for stages III and IV (Run 013) but with pumping not allowed to exceed 437,000 acre-feet per year

Run 021: Adjustments in pumping reductions for stages III and IV; in J-17 triggers for stages I, II, III, and IV; and in J-27 triggers for stages II, III, and IV (maximum 70 percent reduction in pumping for the San Antonio Pool and maximum 70 percent reduction in pumping for the Uvalde Pool)

Run 022: Adjustments in pumping reductions for stages III and IV and in Comal triggers for stages I, II, III, and IV (maximum 70 percent reduction in pumping for the San Antonio Pool and maximum 70 percent reduction in pumping for the Uvalde Pool)

Run 023: Adjustments in pumping reductions for stages III and IV and in J-27 triggers for stages I, II, III, and IV (maximum 70 percent reduction in pumping for the San Antonio Pool and maximum 70 percent reduction in pumping for the Uvalde Pool)

Run 024: Adjustments in pumping reductions for stages I, II, III, and IV for the San Antonio Pool and for stages II and III for the Uvalde Pool (maximum 70 percent reduction in pumping for the San Antonio Pool and maximum 70 percent reduction in pumping for the Uvalde Pool)

Run 025: Withdrawn

Run 026: Withdrawn

Run 027: Withdrawn

Run 028: Adjustments in pumping reductions for stages I, II, III, and IV for the San Antonio and Uvalde pools and adjustments in J-17 and J-27 triggers for stages I, II, III, and IV (maximum 60 percent reduction in pumping for the San Antonio Pool and maximum 70 percent reduction in pumping for the Uvalde Pool)

Run 029: Adjustments in pumping reductions for stages I, II, III, and IV for the San Antonio and Uvalde pools and adjustments in J-17 and J-27 triggers for stages I, II, III, and IV (maximum 70 percent reduction in pumping for the San Antonio Pool and maximum 70 percent reduction in pumping for the Uvalde Pool)

Run 030: Adjustments in pumping reductions for stages I, II, III, and IV for the San Antonio and Uvalde pools and adjustments in J-17 and J-27 triggers for stages I, II, III, and IV (maximum 90 percent reduction in pumping for the San Antonio Pool and maximum 90 percent reduction in pumping for the Uvalde Pool)

Run 031: Adjustments in pumping reductions for stages I, II, III, and IV for the San Antonio and Uvalde pools; adjustments in J-17 and J-27 triggers for stages I, II, III, and IV (maximum 90 percent reduction in pumping for the San Antonio Pool and maximum 90 percent reduction in pumping for the Uvalde Pool); and no pumping in Hays and Comal counties.

Run 032: Constant pumping at 40,000, 55,000, 65,000, and 75,000 acre-feet per year

Run 033: Adjustments in pumping reductions for stages I, II, III, and IV for the San Antonio and Uvalde pools and adjustments in J-17 and J-27 triggers for stages I, II, III, and IV (maximum 80 percent reduction in pumping for the San Antonio Pool and maximum 80 percent reduction in pumping for the Uvalde Pool)

Run 034a: Adjustments in pumping reductions for stages I, II, III, and IV for the San Antonio and Uvalde pools and adjustments in J-17 and J-27 triggers for stages I, II, III, and IV

Run 034b: Adjustments in pumping reductions for stages I, II, III, and IV for the San Antonio and Uvalde pools and adjustments in J-17 and J-27 triggers for stages I, II, III, and IV (Run 034a) but with pumping not allowed to exceed 437,000 acre-feet per year (maximum 100 percent reduction in pumping for the San Antonio Pool and maximum 100 percent reduction in pumping for the Uvalde Pool)

Run 035a: Removal of stage IV and adjustments in pumping reductions for stages I, II, and III for the San Antonio and Uvalde pools and adjustments in J-17 and J-27 triggers for stages I, II, and III (maximum 100 percent reduction in pumping for the San Antonio Pool and maximum 100 percent reduction in pumping for the Uvalde Pool)

Run 036a: Removal of stages III and IV and adjustments in pumping reductions for stages I and II for the San Antonio and Uvalde pools and adjustments in J-17 and J-27 triggers for stages I and II (maximum 100 percent reduction in pumping for the San Antonio Pool and maximum 100 percent reduction in pumping for the Uvalde Pool)

Run 037a: Removal of stages II, III, and IV and adjustments in pumping reductions for stage I for the San Antonio and Uvalde pools and adjustments in J-17 and J-27 triggers for stage I (maximum 100 percent reduction in pumping for the San Antonio Pool and maximum 100 percent reduction in pumping for the Uvalde Pool)

Run 038: Removal of stages II, III, and IV and adjustments in pumping reductions for stage I for the San Antonio and Uvalde pools and adjustments in J-17 and J-27 triggers for stage I

Assumptions

As with any scientific study, we made a number of assumptions that may affect our results, which are ultimately related to predicting springflow. While some assumptions probably overestimate springflow, other assumptions probably underestimate springflow. With this task, we assumed that:

- all reductions and increases in pumping due to critical period management were instantaneous,

- the maximum amount of groundwater that could be pumped under any given scenario would be pumped,
- climate and drought in the future would look like climate and drought in the past (specifically from 1947 through 2000),
- there was no movement in the location of pumping,
- the model accurately simulates springflows at Comal and San Marcos springs and water levels at J-17 and J-27, and
- the subcommittee did not consider either the minimum amount of pumping needed to maintain human health and safety requirements or potential strategies to meet those requirements.

The management module for the model does not allow for the non-instantaneous implementation of the critical period management plan. The assumption on instantaneous pumping reductions probably leads to underestimated impacts to springflow. In practice, entering or exiting any given critical period management stage is dictated by a 10-day average of springflow or water-level elevation. While we believe municipal and industrial pumping reductions are nearly instantaneous (for example, San Antonio quickly reduced its use over the past summer), agricultural reductions may be delayed depending on the timing of the drought and when critical period management triggers are crossed. There may, in fact, be as much as a one-year delay to reductions in agricultural pumping. We assumed instantaneous reductions and increases in pumping because the management module for the groundwater model operates under this assumption. In other words, the model assumes instantaneous pumping reductions and increases when going into and out of critical period management.

The assumption that the maximum amount of groundwater that could be pumped under any given scenario would be pumped probably leads to overestimated impacts to springflow. For example, the most that has been annually pumped from the aquifer was 542,500 acre-feet in 1989 and, in the last 10 years, 454,500 acre-feet per year (compare that to the permitted amount of 572,000 acre-feet; both estimates are from Hamilton and others 2009, and include estimated exempt and unreported use). However, the maximum amount pumped will likely increase over time as agricultural use converts to municipal use, municipal use increases, and municipal users conjunctively manage water from the Edwards Aquifer. We do not have a projection of how much of the permitted use might be realized in the future. Although pumping is likely to increase, it is not likely to reach the maximum permitted amount.

The assumption that climate and drought in the future will statistically resemble climate and drought in the past probably leads to overestimated springflow. Global climate models used by the International Panel on Climate Change suggest that Texas will be warmer and most suggest that Texas will be drier (Kundzewicz and others 2007). Warmer temperatures increase evapotranspiration which decreases runoff (all other factors remaining the same), an important factor for recharge to the Edwards Aquifer. A recent study commissioned by the Lower Colorado River Authority and the San Antonio Water System showed that even with increased rainfall, runoff was expected to decrease in the contributing basins to the Highland Lakes (CH2M Hill 2008).

The assumption that there is no movement in the location of pumping may underestimate or overestimate springflow. Pumping that moves closer to the springs will tend to have a greater effect on springflow (LBG-Guyton Associates 2008) while pumping that moves away from springs will tend to have a lesser effect on springflow. Note that about 66,000 acre-feet per year of pumping rights have been transferred since completion of the base pumping distribution files in 2005 for the Edwards Aquifer model used in the preparation of this report (EAA 2009). In addition, leases of withdrawal rights have increased from about 98,000 acre-feet per year to about 138,000 acre-feet per year (EAA 2009). To the extent that additional pumping would be expected to occur closer to Comal and San Marcos springs as a result of such transfers, model results presented herein would tend to overestimate springflow during drought periods. Also note that the distribution of pumping in the model reflects the location of permits as of 2005. In December 2009, the Edwards Aquifer Authority approved rules to limit the transfer of Edwards Aquifer withdrawal rights east of Cibolo Creek.

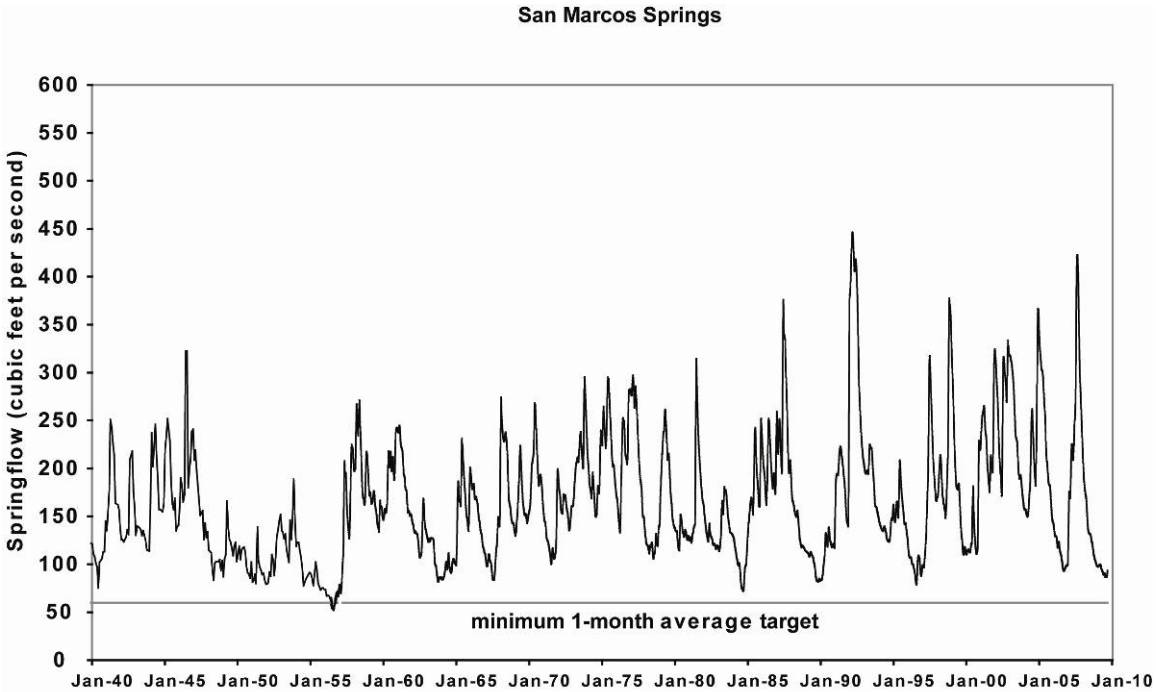
The assumption that the model accurately simulates springflows at Comal and San Marcos springs and water levels at J-17 and J-27 probably leads to underestimates and overestimates in springflows. According to calibration statistics in Lindgren and others (2004), flows at Comal and San Marcos springs have a small bias toward overestimating flows, mostly due to simulating higher flows between 1958 and 1961 and the late 1980s. Although it appears that flows at San Marcos Springs are generally overestimated by the model for the calibration period, the model does a good job of matching flows during the drought of record (1947 through 1956). For J-17, the model generally does a good job of matching observed values although it underestimates levels during the deepest part of the drought of record and a few other extreme droughts and slightly overestimates some high levels. For J-27, the model consistently underestimates water levels until about 1970 when it mostly overestimates levels.

The assumption that the subcommittee could not consider the minimum amount of pumping needed to maintain human health and safety requirements or strategies to meet those requirements comes from an interpretation of the language in Senate Bill 3.

Analysis and results

A comparison of the springflow requirements from Task 1 to historical flows at San Marcos and Comal springs (figures 20 and 21, respectively) shows that, at least with historical levels of pumping, the springflow requirements are met except at the end of the drought of the 1950s in the summer of 1956. However, it is important to note that during the drought of the 1950s pumping increased from about 167,000 acre-feet per year in 1947 to about 321,000 acre-feet per year in 1956 (Hamilton and others 2009). At present time, we would expect the opposite: that pumping would decrease in response to drought and critical period management.

The Edwards Aquifer Authority manages water levels and spring flows in the aquifer with two basic approaches: (1) a cap on total permitted pumping of 572,000 acre-feet per year and (2) protecting springflows during drought periods with critical period management rules. These rules require different classes of users to reduce pumping by a



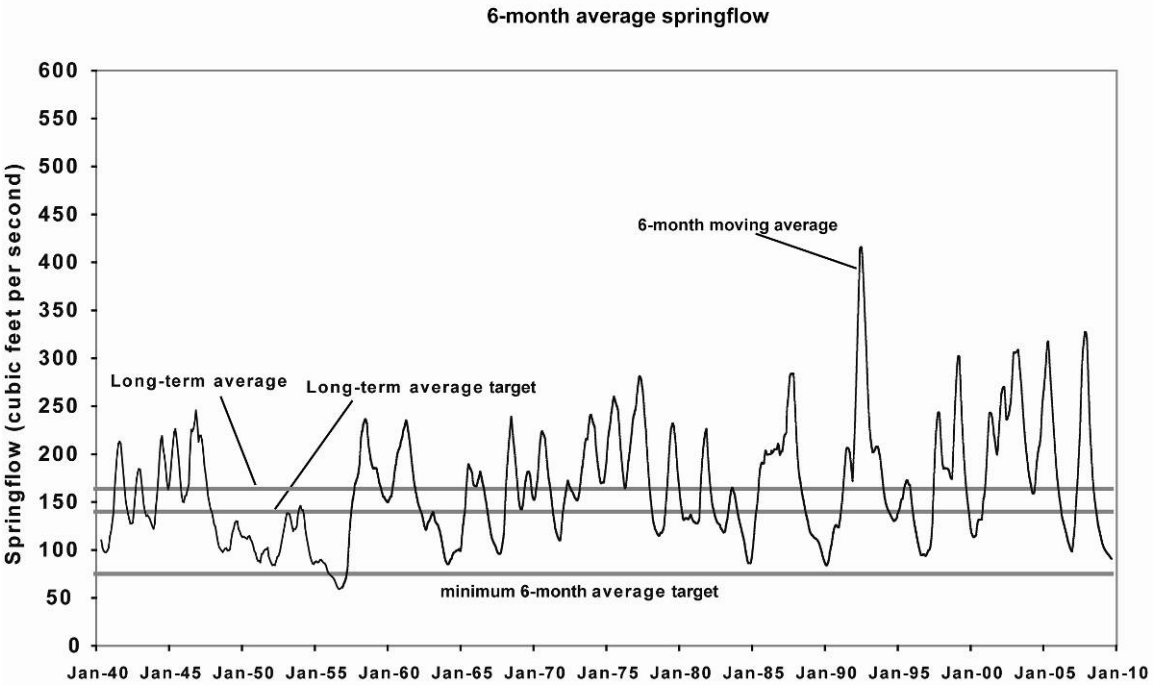
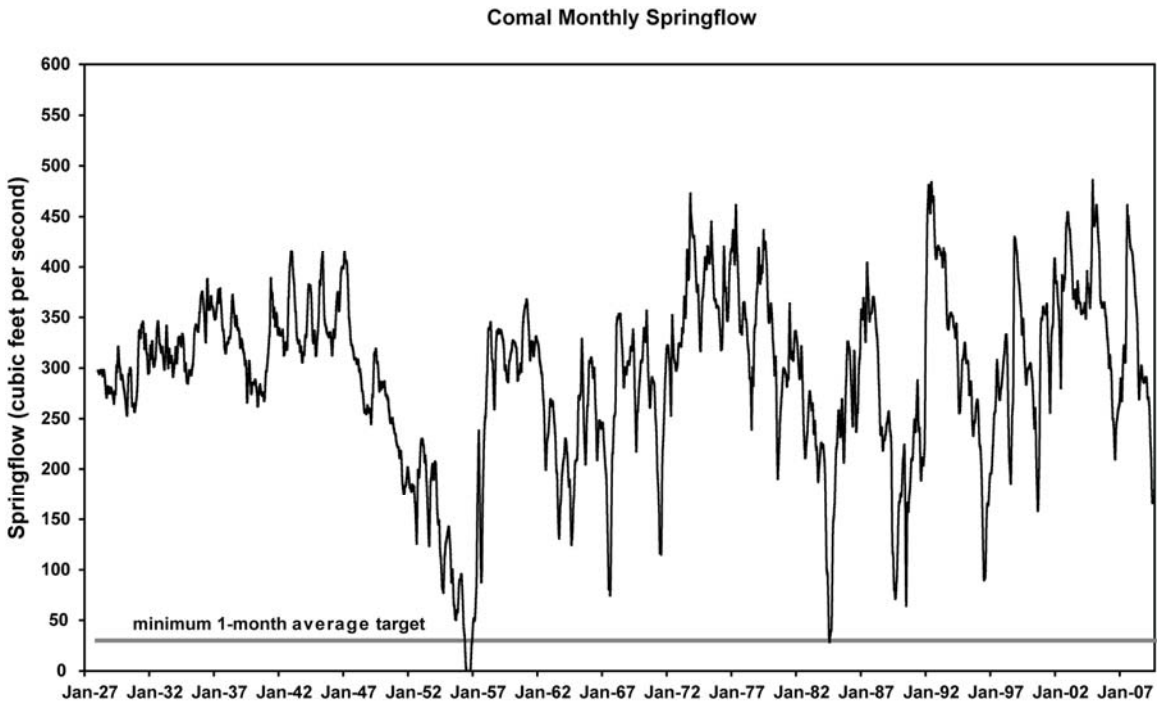


Figure 20: Record of historical discharge from San Marcos Springs compared to the biological flow regime requirements (data before 1956 from GBRA 1988, data for 1956 and later from USGS 2009).



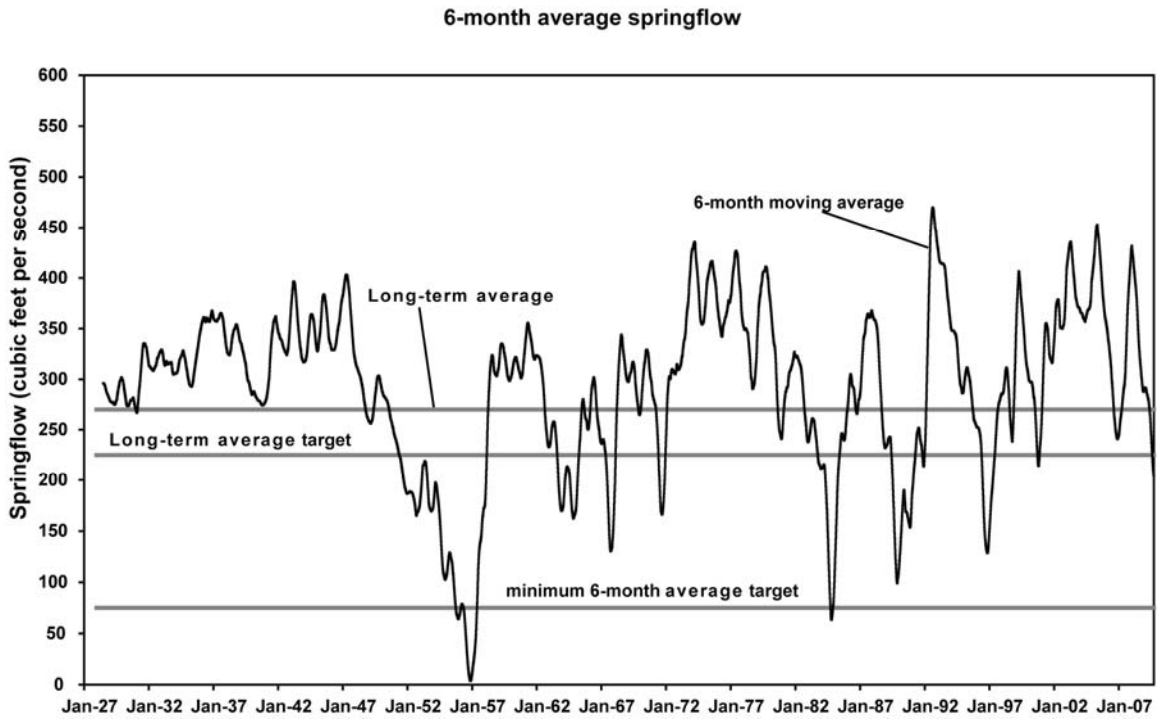


Figure 21: Record of historical discharge from Comal Springs compared to the biological flow regime requirements (data from Miller, 2009).

percentage of their total water right as springflows decline below an established springflow or water levels in index wells decline below an established level. Declining springflows (or water levels) may pass through different trigger levels as a drought worsens. The current critical period management rules define four triggers or stages. Upon reaching each trigger, the percent cut back increases. In the San Antonio Pool, for example, Stage I requires a 20 percent reduction; Stage II requires a 30 percent reduction; Stage III requires a 35 percent reduction, and Stage IV requires a 40 percent reduction (Table 12). The purpose of these cutbacks is to preserve springflow (and therefore the endangered species). We evaluated the potential effectiveness of this critical period management approach by using the Edwards MODFLOW model with critical period management module to simulate several different management scenarios to determine which trigger approach gets us through the "drought of record".

The current critical period management plan in the Edwards Aquifer Authority Act (Table 12) does not achieve the springflow requirements in Task 1 (Table 13; figures 22 and 23). In fact, the groundwater model (Run 001) suggests that Comal Springs would stop flowing for 13 consecutive months and 29 months total. Under this scenario, pumping decreases from the maximum permitted amount (572,000 acre-feet per year) to about 362,000 acre-feet per year (EAA 2009).

Model runs assuming different levels of constant pumping (that is, no critical period management) suggest that the minimum 6-month flow average for San Marcos Springs would be the primary driver in achieving the springflow requirements and would require pumping reductions in the neighborhood of 85 percent (Figure 24).

Given that there are six different springflow criteria, it is not surprising that one would be the controlling criterion depending on the value of that criterion and the predicted effects of pumping on springflows. For example, based on constant levels of pumping (no critical period management), the 1-month minimum flow criterion for San Marcos Springs would allow for about 200,000 acre-feet per year of pumping; however, the 6-month minimum flow criteria would only allow for about 90,000 acre-feet of pumping (Table 13 and Figure 24).

In evaluating the sensitivity of simulated springflow to various adjustments and assumptions, we learned that:

- restricting the maximum amount of pumping to 437,000 acre-feet per year instead of 572,000 acre-feet per year generally, but not always, increased 1-month, 6-month, and long-term average springflows (from comparing runs 009 and 010 to Run 001, Run 018 to Run 011, Run 019 to Run 012, and Run 020 to Run 013; Table 13);
- raising or lowering the amount of pumping that defines the initial condition of the transient simulations lowers or raises the springflows, respectively (from comparing Run 017 to Run 001 and Run 016 to Run 001, respectively);
- raising the triggers for J-17 and J-27 by five feet increased 1-month, 6-month, and long-term average springflows from 0 to 2 cubic feet per second (from comparing Run 021 to Run 013; Table 13);

Table 12: The current critical period management plan in the Edwards Aquifer Authority Act.

San Antonio Pool				
Comal (cfs)	**San Marcos (cfs)**	**J-17 (feet)**	**Stage -**	**Reduction (%)**
<225	<96	<660	I	20
<200	<80	<650	II	30
<150	N/A	<640	III	35
<100	N/A	<630	IV	40

Uvalde Pool		
J-27 (feet)	**Stage -**	**Reduction (%)**
-	I	0
<850	II	5
<845	III	20
<842	IV	35

- raising the triggers for Comal Springs by 15 cubic feet per second increased some springflow statistics, decreased some springflow statistics, and did not affect other springflow statistics (from comparing Run 022 to Run 013; Table 13);
- having larger pumping reductions in stages I and II raises long-term average springflow and allows smaller pumping reductions in stages III and IV (from comparing Run 024 to Run 013 and Run 033 to Run 030; Table 13); and
- decreasing pumping in the areas near the springs increases springflow, especially for San Marcos Springs (from comparing Run 031 to Run 030; Table 13).

Run 34 represented the start of a series of model runs to obtain a critical period management plan that met all the draft biological flow requirements from Task 1. Runs 34 through 37a include 100 percent reductions in pumping during progressively fewer critical period management triggers. We did this as a screening exercise to determine how few triggers we would need to meet the draft springflow requirements. In other words, if a model run showed that we could not achieve or surpass all of the springflow targets with a 100 percent reduction in pumping, we knew we could not achieve or surpass the draft targets with a smaller reduction.

Consensus on the final springflow requirements, which differed from previous numbers under consideration, was not reached until early December 2009. Out of the existing model runs, we had 11 that met or exceeded all of the springflow requirements (Table 13). One of the 11 had no pumping (Run 2), 4 had fixed pumping equal to or less than 75,000 acre-feet per year (runs 32-40, 32-55, 32-65, and 32-75), 1 had two critical period management stages (Run 36a), and 5 had one critical period management stage with varying pumping reductions (runs 37a-100, 37a-98, 37a-97, 37a-96, and 37a-94).

Table 13: Springflow statistics resulting from the model runs.

			Comal springflow (cubic feet per second)			San Marcos springflow (cubic feet per second)		
Run	**Maximum pumping (AFY)**	**Description**	**Min. 1-month avg.**	**Min. 6-month avg.**	**Long-term avg.**	**Min. 1-month avg.**	**Min. 6-month avg.**	**Long-term avg.**
Historical	NA	1947-2000	***0***	***4***	270	***54***	***61***	158
Criteria	**NA**	**Task 1**	**30**	**75**	**225**	**60**	**75**	**140**
1	572,000	SB3	***0***	***0***	***184***	***10***	***20***	153
2	**0**	**fixed Q**	**288**	**290**	**526**	**89**	**92**	**203**
3	100,000	fixed Q	183	190	436	72	***74***	187
4	200,000	fixed Q	75	87	367	60	***63***	177
5	300,000	fixed Q	***0***	***1***	294	***36***	***45***	167
6	400,000	fixed Q	***0***	***0***	***212***	***0***	***0***	155
7	500,000	fixed Q	***0***	***0***	***129***	***0***	***0***	***137***
8	572,000	fixed Q	***0***	***0***	***72***	***0***	***0***	***116***
9	437,000	sensitivity	***0***	***0***	229	***26***	***35***	158
10	437,000	sensitivity	***0***	***0***	***222***	***15***	***25***	157
11	572,000	CPM adjust.	***0***	***3***	***195***	***40***	***48***	154
12	572,000	CPM adjust.	***22***	***38***	***200***	***54***	***57***	155
13	572,000	CPM adjust.	57	***73***	***202***	***59***	***62***	155
14	250,000	fixed Q	***19***	***35***	331	***54***	***57***	172
15	350,000	fixed Q	***0***	***0***	254	***10***	***20***	162
16	572,000	sensitivity	***0***	***0***	***189***	***16***	***25***	153
17	572,000	sensitivity	***0***	***0***	***176***	***0***	***6***	151
18	437,000	sensitivity	***0***	***3***	***217***	***41***	***48***	157
19	437,000	sensitivity	***23***	***39***	***222***	***55***	***57***	157
20	437,000	sensitivity	38	***60***	***224***	***57***	***59***	157
21	572,000	sensitivity	59	***74***	***207***	***59***	***61***	155
22	572,000	sensitivity	55	78	***208***	60	***61***	155
23	572,000	sensitivity	*29*	***64***	***199***	***59***	***61***	155
24	572,000	sensitivity	58	***74***	***207***	***59***	***61***	155
28	572,000	sensitivity	41	***70***	***224***	***59***	***61***	157
29	572,000	sensitivity	47	75	***213***	***59***	***61***	156
30	572,000	sensitivity	33	83	***216***	***53***	***61***	156
31	572,000	sensitivity	38	87	***223***	70	***73***	178
32-40	**40,000**	**fixed Q**	**244**	**246**	**475**	**78**	**80**	**193**
32-55	**55,000**	**fixed Q**	**230**	**233**	**466**	**77**	**79**	**192**
32-65	**65,000**	**fixed Q**	**220**	**224**	**459**	**76**	**78**	**191**
32-75	**75,000**	**fixed Q**	**210**	**214**	**452**	**75**	**77**	**190**
33	572,000	CPM adjust	42	84	225	***54***	***62***	157
34a	572,000	CPM adjust	41	98	227	***55***	***62***	157
35a	572,000	CPM adjust	57	118	238	***55***	***64***	158
36a	**572,000**	**CPM adjust**	**84**	**161**	**259**	**67**	**76**	**161**
37a-100	**572,000**	**CPM adjust**	**87**	**203**	**284**	**70**	**82**	**165**
37a-98	**572,000**	**CPM adjust**	**63**	**200**	**282**	**67**	**80**	**164**
37a-97	**572,000**	**CPM adjust**	**73**	**199**	**282**	**73**	**80.1**	**164**
37a-96	**572,000**	**CPM adjust**	**83**	**201**	**283**	**73**	**79.9**	**164**
37a-94	**572,000**	**CPM adjust**	**80**	**205**	**282**	**73**	**79**	**164**
38	**572,000**	**CPM adjust**	**109**	**196**	**278**	**72**	**75**	**164**

Runs 25, 26, and 27 were withdrawn. Runs in **bold red** and shaded meet all of the springflow criteria shown in **bold blue**. Springflows in ***bold italics*** do not meet the springflow criteria. adjust. = adjustment; AFY = acre-feet per year; avg. = average; CPM = critical period management; Min. = minimum; NA = not applicable; Q = pumping; SB3 = Senate Bill 3. See p. 72–74 and Appendix F for more complete descriptions of each run.

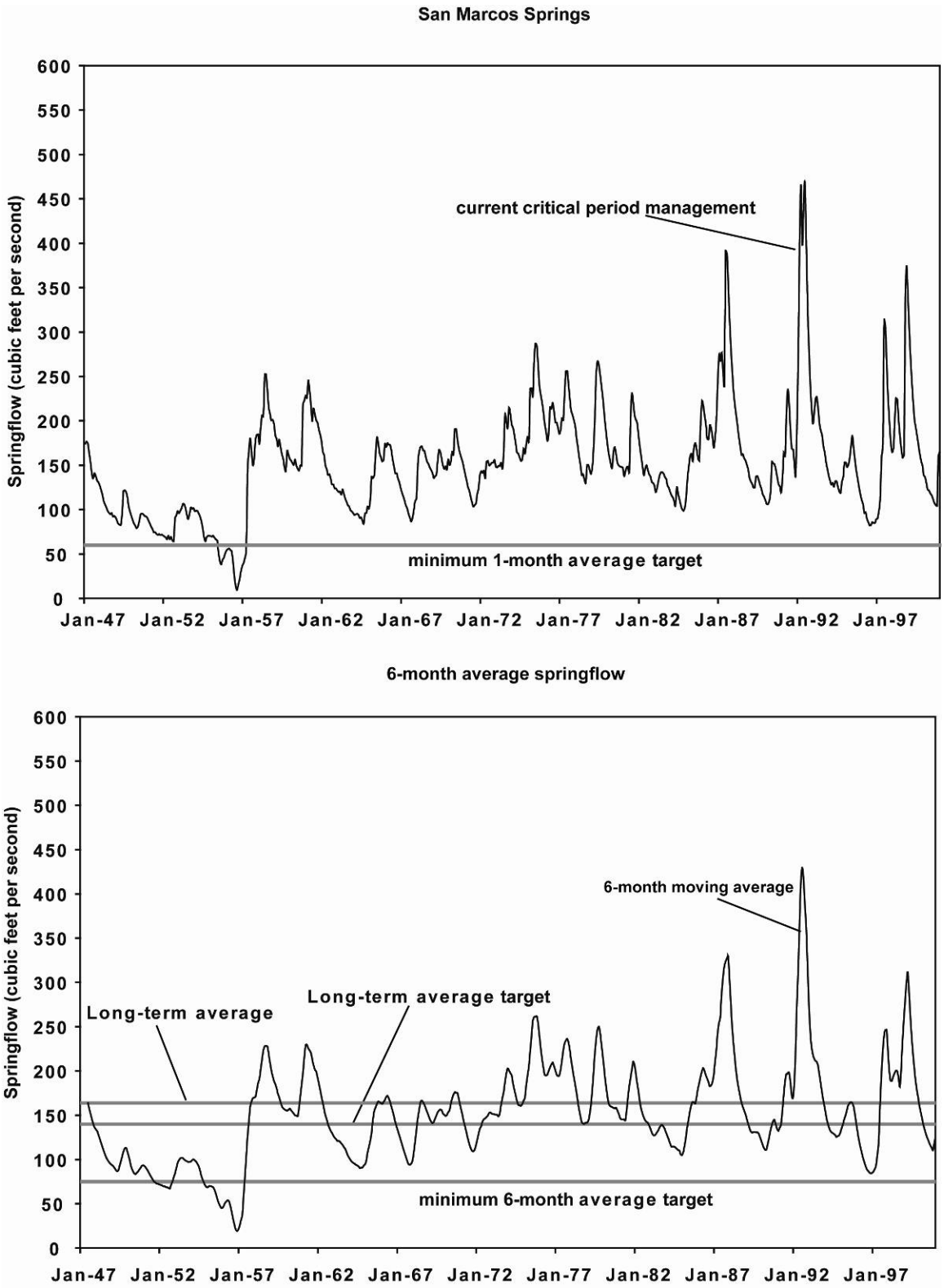


Figure 22: Predicted discharge statistics for San Marcos Springs under the current critical period management plan compared to the biological flow regime requirements (Run 1).

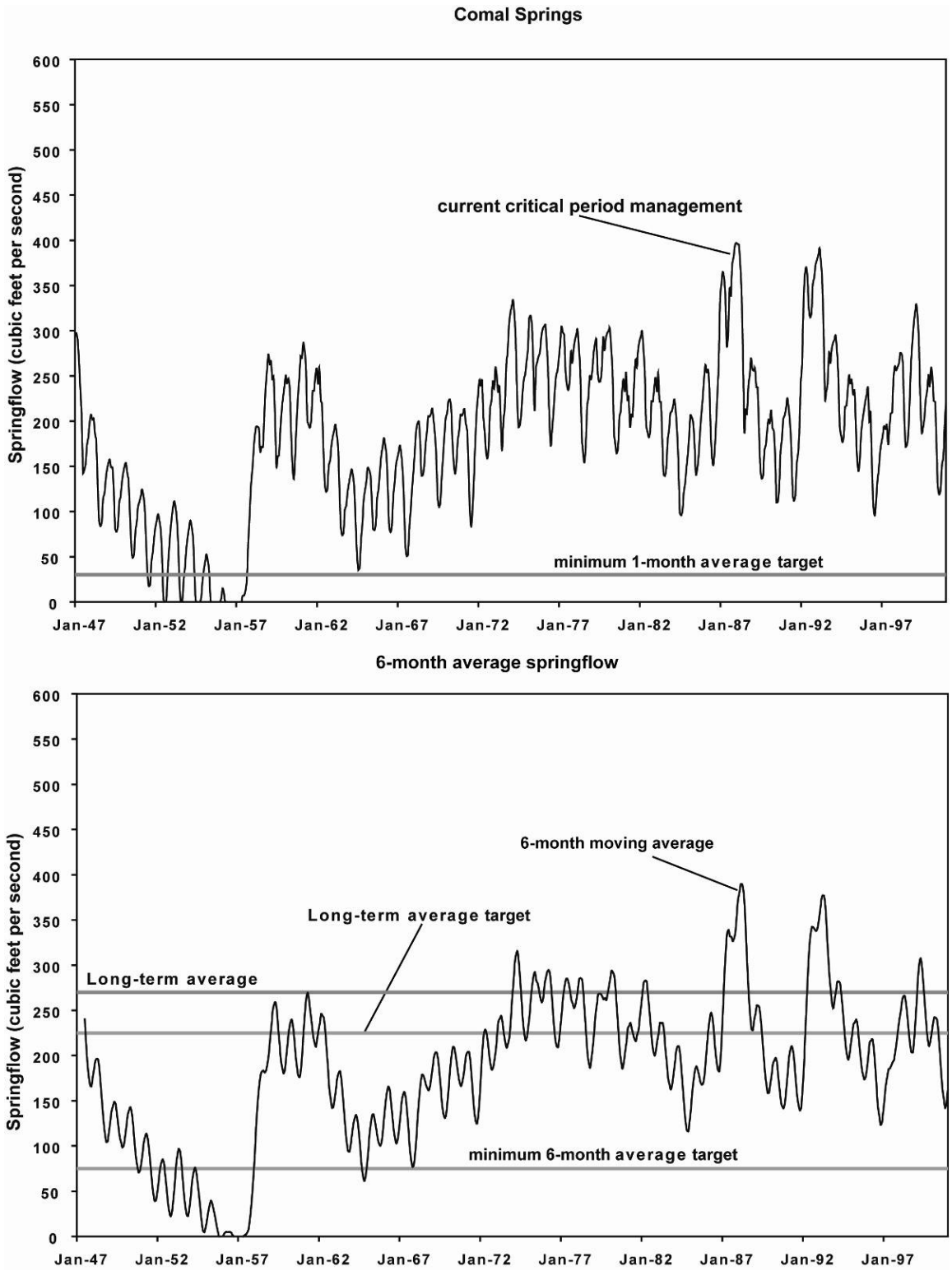


Figure 23: Predicted discharge statistics for Comal Springs under the current critical period management plan compared to the biological flow regime requirements (Run 1).

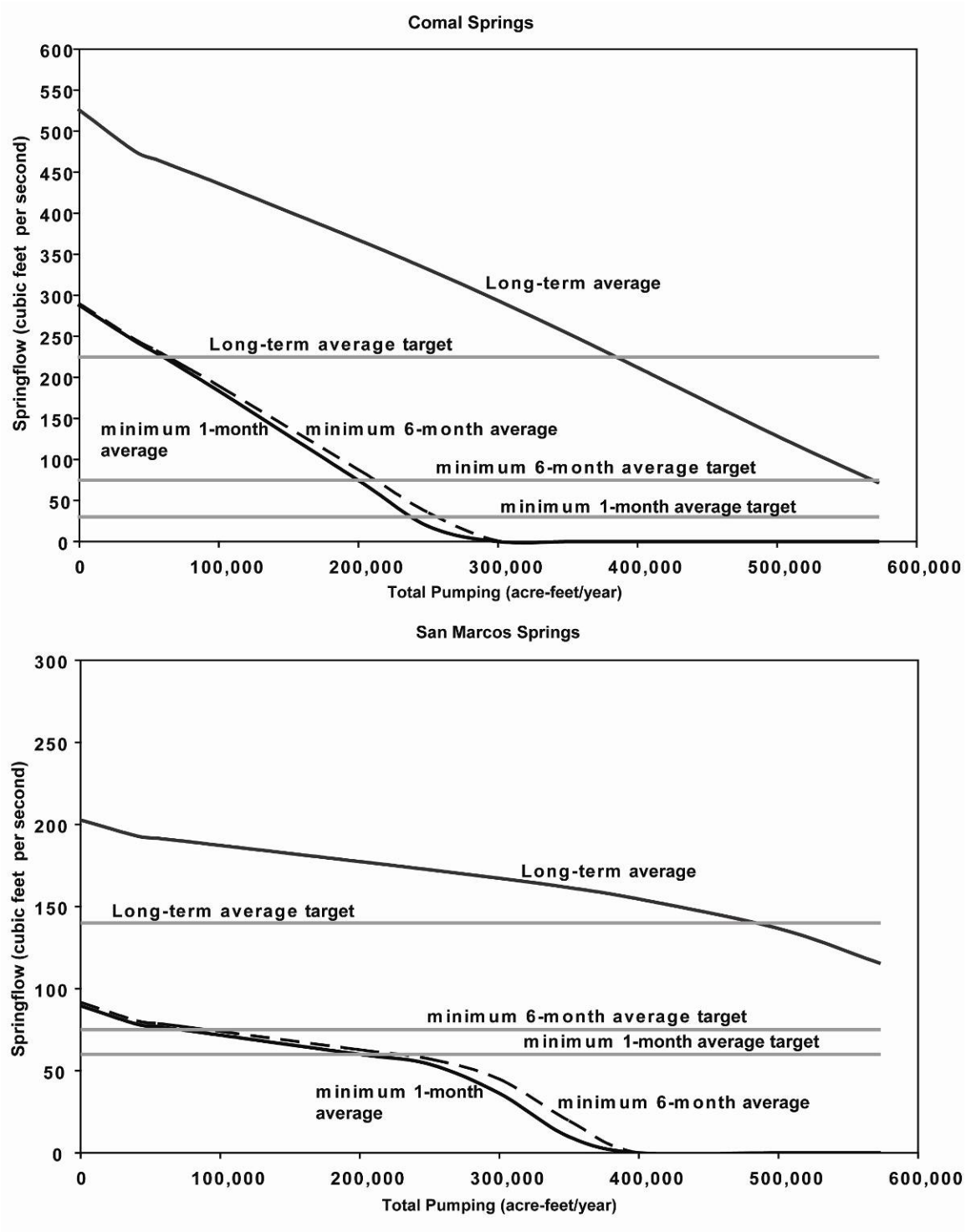


Figure 24: Predicted discharge statistics for Comal and San Marcos springs with different levels of constant pumping compared to the biological flow regime requirements. These plots are based on the results of model runs 2, 3, 4, 5, 6, 7, 8, 14, 15, and 32.

Run 36a actually came the closest to meeting the 6-month minimum flow requirement for San Marcos Springs at 76 cubic feet per second; however, this was achieved with a 30 percent reduction of pumping in Stage I and a 100 percent reduction of pumping in Stage II.

Because we did not want to suggest a 100 percent reduction in pumping, we requested an additional run (Run 38) with a single stage critical period management and a pumping reduction to achieve the minimum 6-month average flow at San Marcos Springs (with the assumption, supported by Run 37, that the other springflow criteria would be met if this criterion was met). The results of this run—Run 38—showed that pumping needed to be reduced 85 percent to meet the minimum 6-month average flow at San Marcos Springs (Table 13; figures 25 and 26; Run 38). Therefore, the final critical period management scenario that meets or exceeds the final springflow recommendations is

San Antonio Pool

Comal (cfs)	**San Marcos (cfs)**	**J-17 (feet)**	**Stage -**	**Reduction (%)**
<225	<96	<**665**	I	**85**

Uvalde Pool

J-27 (feet)	**Stage -**	**Reduction (%)**
< **865**	I	**85**

where cfs is cubic feet per second. The cumulative distribution function of simulated flow at Comal and San Marcos springs for Run 038 (Figure 27) shows that simulated springflow achieves the minimum 6-month-average flow target at San Marcos Springs only one time for the simulation period and that the other flow targets are never achieved.

We recognize that this final run that reduces permitted pumping by 85 percent at Stage I does not take advantage of the Edwards Aquifer Authority's current critical period management approach in which higher percentage withdrawal reductions are phased in as springflows and water levels decline and drought becomes more severe. While a multi-stage critical period management approach is possible, the magnitude of withdrawal reductions necessary to meet springflow criteria would require very rapid passage through the initial stages and/or complete cessation of permitted pumping beyond the initial stages.

Given the legislatively mandated deadline for the report, we did not have time to investigate multi-stage critical period management with the final springflow requirements. For example, Run 36a had two stages, the first with a 30 percent reduction in pumping and the second with a 100 percent reduction. An increase in the Stage I pumping reduction should allow a decrease in the Stage II pumping reduction. Additional stages might also be possible. Also, note that Run 31—a run with four stages ending with a 90 percent reduction in pumping—nearly met all of the springflow requirements; however, this run had no pumping in the Edwards Aquifer in Comal and Hays counties.

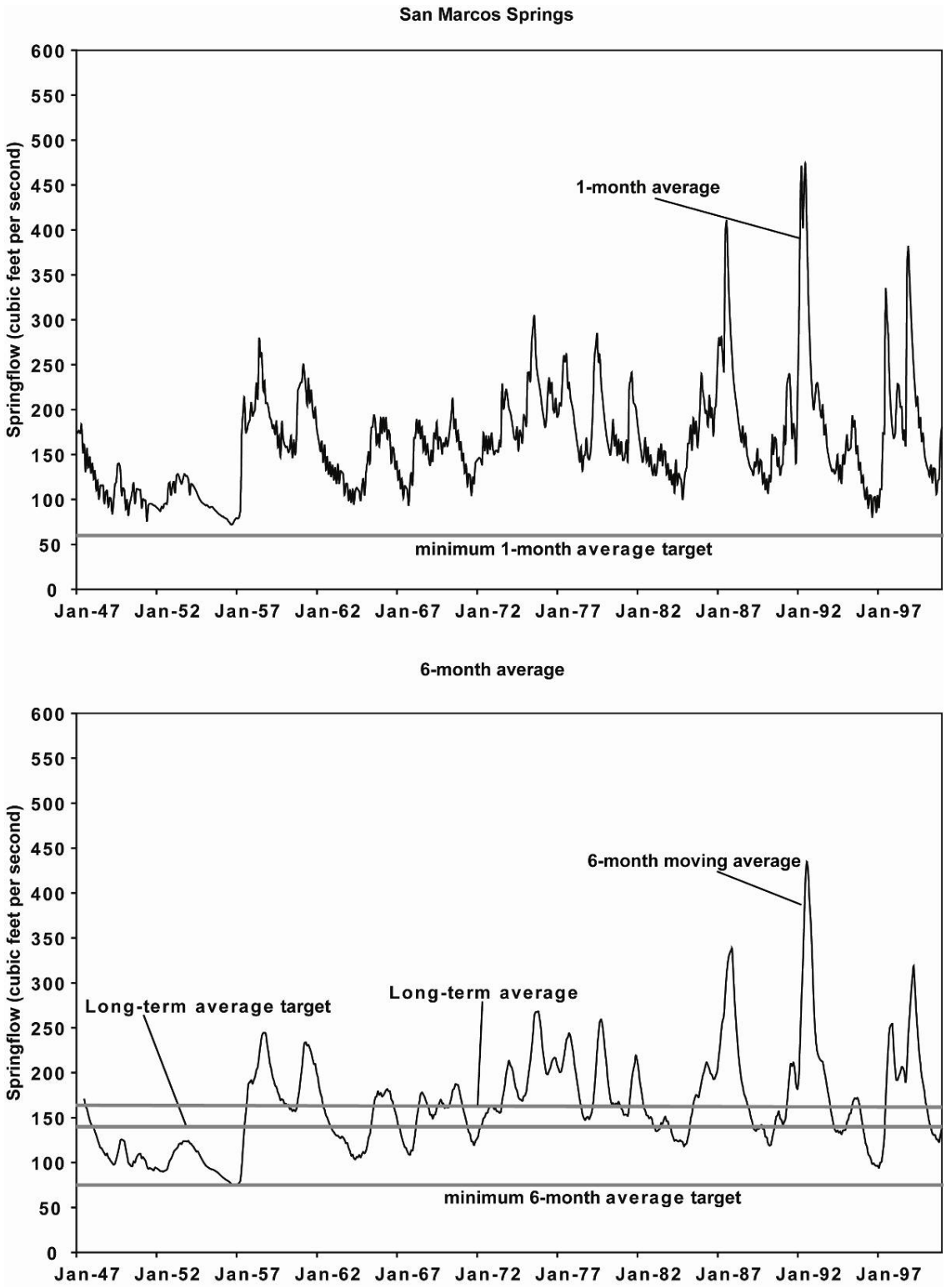


Figure 25: Predicted discharge statistics for San Marcos Springs with one critical period management stage with an 85 percent reduction in pumping (Run 38).

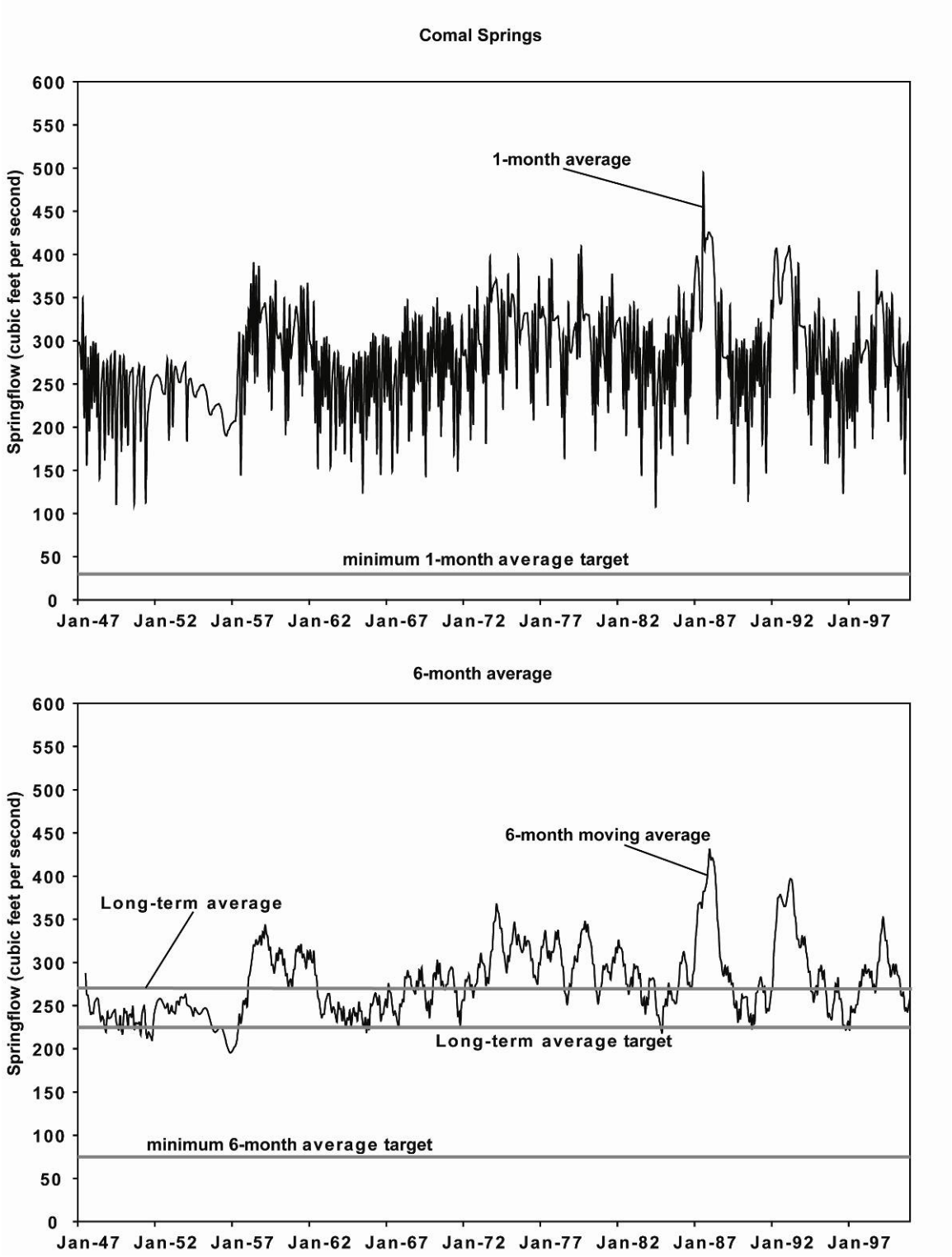


Figure 26: Predicted discharge statistics for Comal Springs with one critical period management stage with an 85 percent reduction in pumping (Run 38).

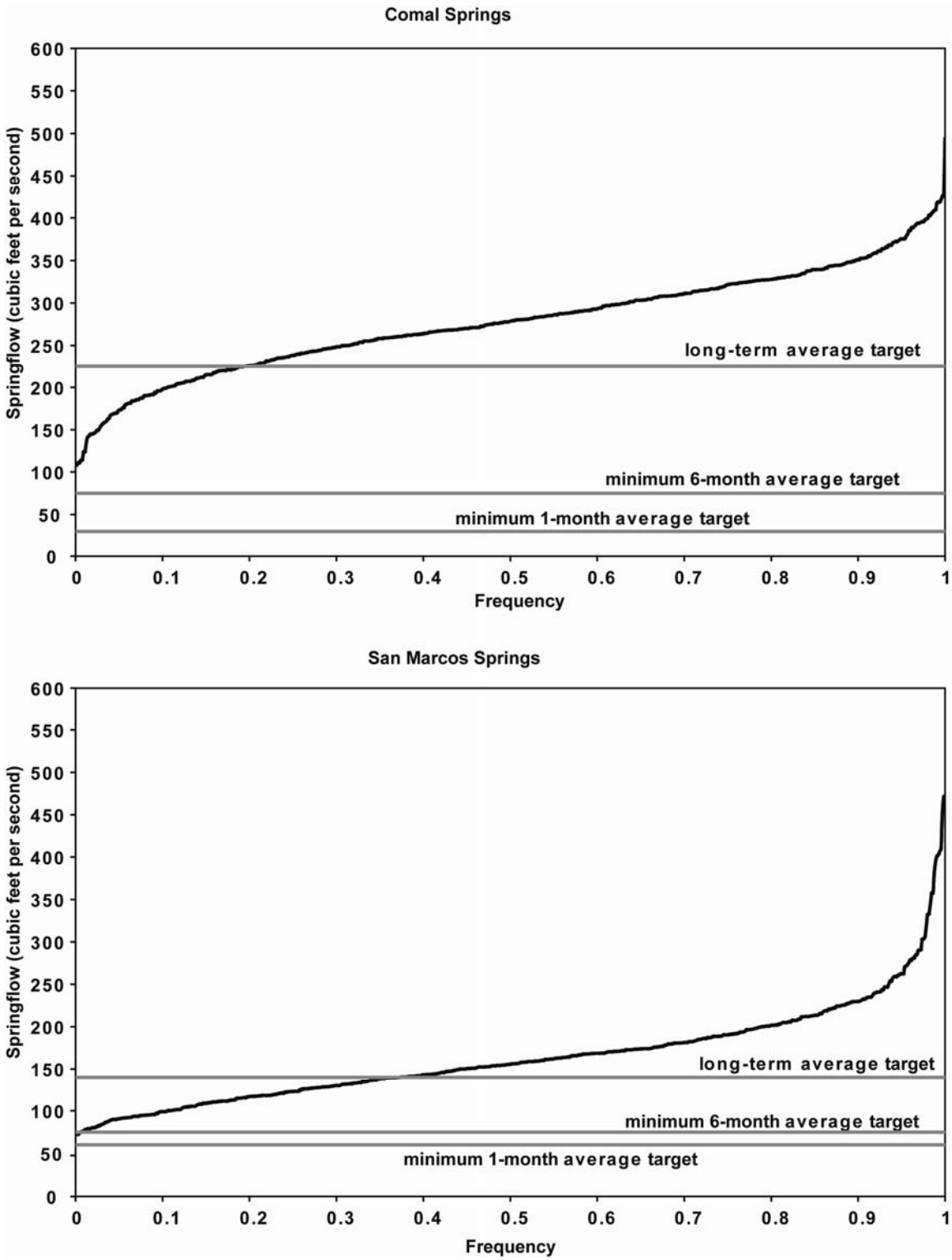


Figure 27: Cumulative distribution function of simulated flow at Comal and San Marcos springs for Run 38. This plot shows the frequency at which any given springflow is exceeded.

Springflow at San Marcos Springs appears less sensitive to San Antonio Pool pumping and the Senate Bill 3 critical period management pumping reductions when compared to similar times and similar simulations for Comal Springs. Much of the pumping reductions for the San Antonio Pool result in greater increases in springflow at Comal Springs than at San Marcos Springs. In other words, Comal Springs responds with much greater springflow changes than does San Marcos Springs. Because of this relative lack of sensitivity of San Marcos Springs to western regional pumping reductions, greater pumping reductions are needed from the general aquifer to cause any significant increase in flow at San Marcos Springs. Run 34a (Appendix G) for Comal Springs shows a wide range of springflows as the aquifer goes in and out of high percent pumping reductions. A similar plot for San Marcos Springs (Appendix G) does not show these wide oscillations. This indicates that the pumping changes west of Comal Springs are significantly dampened by the time they reach San Marcos Springs as springflow. In addition, deleting the pumping in Comal and Hays counties in the model significantly raises the minimum 1-month average, the minimum 6-month average, and the long-term average for San Marcos Springs by 17, 12, and 22 cubic feet per second, respectively (Table 12). When pumping is removed from Comal and Hays counties, an additional 14 to 20 cubic feet per second of springflow is added at San Marcos Springs during the 1950s and 20 to 25 cubic feet per second of springflow is added from 1960 to 2000. These two observations indicate that much larger pumping cuts have to be made in Bexar, Medina, and Uvalde counties than in Comal and Hays counties to have similar increases in springflow at San Marcos.

A single critical period management stage and the size of the reduction during this stage results in some large and abrupt fluctuations in water levels and springflows in response to the aquifer entering and exiting critical period management (see Figure 26 as well as various figures in Appendix G). Outside of critical period management, 572,000 acre-feet per year are being pumped from the aquifer. As declining water levels or springflows cause the simulated aquifer to go into critical period management, the pumping is abruptly reduced to about 86,000 acre-feet per year. This reduction can cause a quick rebound in water levels and springflows thus bringing the aquifer out of critical period management and suddenly increasing pumping to 572,000 acre-feet per year, which then lowers water levels and springflows.

Managing the aquifer in this fluctuating manner may not be good for the species (rapid swings in springflows) or for associated infrastructure (turning wells on and off). Furthermore, these pumping reductions result in long-term flow averages much higher than historical values which may also be detrimental to the species. It is also probably not realistic to bring permit holders in and out of critical period management on a monthly basis. Although less of a cutback at a relatively continuous rate might stabilize springflows, it is not possible to simulate such a scenario with the current management module.

Although the critical period management that results from the flow recommendations may not appear realistic, our study shows that pumping reductions will need to exceed 80 percent to achieve springflow goals during a repeat of the drought of record. Any decisions on a final critical period management plan that includes large reductions in

pumping will need to include an assessment of how fluctuations in springflows and much higher long-term average springflows may affect the species.

Further studies

We believe further study is needed to (1) improve springflow measurement, (2) conduct sensitivity analyses, (3) run optimization models, (4) estimate the probability of recurrence of the 1950s drought, (5) evaluate the potential effects of climate variability on recharge, (6) conduct additional runs to refine withdrawal reductions, (7) update the model, (8) refine the calibration of the model, (9) enhance the management module, and (10) refine model calibration between San Marcos and Barton springs.

Improve springflow measurement

Additional field studies could be done to improve the accuracy of current springflow measurements and evaluate alternative instrumentation. These studies include:

- Measuring flows to test the accuracy of the stage-discharge relationships whenever springflows approach drought triggers. The accuracy of measurements could also be increased by additional measurements in the upper portions of the rating curves. Periodic discharge measurements could be made at a cross section located about 150 feet downstream of the Comal Springs control structure and compared to the discharge measured at the upstream cross section to assess the accuracy of the measurements.

- Coordinating with the U.S. Fish and Wildlife Service and other resource agencies to select an appropriate location for a low-flow control section in the San Marcos River that minimizes the disturbance of endangered species and maximizes accuracy of continuous measurements.

- Continuing studies to evaluate various types of instruments to directly measure spring orifice discharge and stream velocities to determine whether more accurate instrumentation and methodologies might improve the overall accuracy and timeliness of springflow measurements.

- Establishing a water-level monitoring network in the San Marcos Springs area and conducting field studies to correlate groundwater levels to flow at San Marcos Springs.

Conduct sensitivity analyses

We made several assumptions to complete our analysis, including those affecting the timing of reductions in irrigation pumping and the effects of increasing and shifting demands for groundwater over time. As the effects of these assumptions on model results are not fully understood, it is impossible to know the extent to which assumptions of a different type or direction may have altered model results and, ultimately, our results.

Therefore, to obtain a better understanding of how the Edwards Aquifer might respond to these and other assumptions, we recommend that a systematic sensitivity analysis be conducted to determine the specific effects on our various model assumptions.

Run optimization models

Since the early 1960s, hydrologists and water managers have increasingly depended upon the results of numerical simulations to evaluate groundwater flow systems and preferred strategies of groundwater development. For some time, groundwater models have been used to test the merits of different water-management scenarios using trial-and-error approaches to isolate the seemingly most-plausible plan from sets of alternative strategies. Typically, management decisions are made in consideration of the alternatives that simulated results indicate as best satisfying specific water-management goals and hydrologic constraints. However, due to the complex nature of groundwater systems and the variety of competing interests often stemming from different political, legal, and economic factors, the process of selecting the "best" operating procedure or policy can be extremely difficult or impossible. To address this dilemma, groundwater simulation models can be coupled with optimization techniques (Ahlfeld and Mulligan 2000) to determine optimal management strategies from competing alternatives.

Because hydrologic optimization models are designed to account for the combined effects of the most relevant water-management objectives and hydrogeologic constraints, such an approach can greatly increase the efficiency and effectiveness of groundwater studies as well as the legitimacy of their overall conclusions. Using a simulation-optimization approach, the modeler specifies the desired end products of specific water-management needs and (or) hydrologic conditions (such as minimum required springflows or maximum allowable groundwater declines). The model then provides the solution—from a set of potential management scenarios—for a management strategy that is numerically determined to most-effectively satisfy the specified desired conditions.

Since 1985, several computer codes have been developed to facilitate the application of groundwater simulation-optimization modeling (Lefkoff and Gorelick 1987, Greenwald 1998, Zheng and Wang 2002, Ahlfeld and Riefler 2003, and Peralta 2004). These codes differ, for the most part, in terms of what numerical model is believed most appropriate for representing the particular aquifer and solving the management problems of interest.

Given the proven utility and cost-effectiveness of simulation-optimization models used in studies of aquifers with hydrogeologic characteristics and problems similar to those of the Edwards Aquifer, it is recommended that efforts be undertaken to develop an optimization model of the Edwards Aquifer and apply it toward obtaining a better understanding of (and more-effective management strategies for) the Edwards Aquifer. For example, rather than relying on the laborious, drawn-out process (using minimum springflow constraints) to evaluate the effects of different critical-period trigger levels and percent pumping reductions, a properly designed and calibrated optimization model might have saved the subcommittee significant time and effort toward arriving at the optimum balance among the choices for triggers and cutbacks while maximizing pumping.

Estimate the probability of recurrence of the 1950s drought

The hydrologic modeling analyses done in support of these results for critical period management are based on the climate history from 1947 to 2000. This period of time includes the drought of the 1950s. It would be valuable to know the chance that any one year will experience rainfall deficits at least as severe as the worst part of the 1950s drought. Reconstructed climate history based on tree-ring data (Cleaveland 2006) might be used to estimate the frequency of annual rainfall deficits as severe as or worse than those that occurred during the worst part of the drought of the 1950s.

Evaluate the potential effects of climate variability on recharge

Global climate models used by the International Panel on Climate Change suggest that Texas will be warmer and most suggest that Texas will be drier (Kundzewicz and others 2007). Warmer temperatures increase evapotranspiration which decreases runoff (all other factors remaining the same), an important factor for recharge to the Edwards Aquifer. A recent study commissioned by the Lower Colorado River Authority and the San Antonio Water System showed that even with increased rainfall, runoff was expected to decrease in the contributing basins to the Highland Lakes (CH2M Hill 2008).

Several authors have investigated climate change and the Edwards Aquifer (Loáiciga and others 1996, Loáiciga and others 2000, Chen and others 2001, Mace and Wade 2008), but a regional study that includes an assessment of runoff in the Hill Country with the updated climate models is needed. The assumption that climate and drought in the future will look like climate and drought in the past needs to be examined. The study should evaluate the currently available literature and studies that have been produced related to the predicted effects of climate change and global warming, to aid in forming recommendations related to withdrawal reduction levels and states for critical period management. The study should analyze the range of potential effects on the Edwards Aquifer and the spring ecosystems due to climate change, including the effects of warmer temperatures and increased evapotranspiration with resulting decreases runoff (all other factors remaining the same), an important factor for recharge to the Edwards Aquifer. Additional climatic modeling, analysis of risk factors of climate change, and predictive atmospheric modeling of precipitation and temperature patterns in the Edwards region will assist in the planning efforts to deal with the uncertainties of future climatic conditions.

Conduct additional runs to refine withdrawal reductions

Although we are delivering withdrawal reductions in this report that meet the flow requirements, we did not have time to request and consider model runs to potentially refine those reductions. For example, given additional time, we would have requested model runs to investigate different trigger levels and withdrawal reductions.

Refine the calibration of the model

The current version of the model was released in 2004; however, no aquifer characterization data after 2002 was incorporated into the model, and most data and

information used in the model assembly are from much earlier times. In terms of calibration, the transient calibration period for the Edwards Aquifer model was 1947 through 1990. Transient simulation included a model testing period of 1991 through 2000 to establish greater confidence in the ability of the model to reproduce measured hydraulic heads and springflows.

The period of 2001 through 2009 has exhibited several extreme hydrologic events including periods of excessive precipitation and recharge interspersed with at least one period of severe drought (2007 through 2009). Hydrologic data collection during this time has been significantly more extensive and comprehensive compared with prior time periods. Near historic groundwater highs in the Edwards Aquifer in 2002 and 2007 were followed by different periods of reduced precipitation. High resolution precipitation data for the periods following the 2002 and 2007 periods of groundwater high levels can be correlated with groundwater highs and spring discharges to gain insight on ability of the aquifer to store water. Performing this analysis will help ascertain the ability of the model to predict aquifer response to periods of prolonged drought. We recommend that a post-audit be performed on the model for 2001 through 2009 and, if appropriate, adjustments be made to the calibration. We also recommend that more robust calibration technologies, such as PEST or Bayesian inversion, be employed to provide the best possible outcome.

Study the response of the aquifer during the drought of 2007 through 2009

From September 2007 through January 2009, San Antonio experienced the driest 17-month period since 1885, according to records kept by the National Weather Service (2009). Because of abundant rainfall in the first eight months of 2007, aquifer levels and springflows did not reach critically low levels during 2008. J-17 began 2008 at 689 feet above mean sea level and was below 660 feet for two weeks in late June 2008, reaching a low of 657 feet. On January 1, 2009, J-17's water level was approximately at 670 feet. On April 24, 2009, when J-17 reached the Stage I trigger level of 660 feet, pumping in the San Antonio Pool east of Uvalde County was reduced by 20 percent, in accordance with the critical period management plan in Senate Bill 3. The Edwards Aquifer Authority Act exempts agricultural pumping from mandatory reduction if crops have been planted prior to the triggers being met. Thus, agricultural irrigators pumped until approximately July 1, 2009, when they traditionally begin to harvest their corn crop. As a result of agricultural pumping and increased summer pumping in the municipal sector, J-17 levels as well as springflow levels continued to drop through the first six months of 2009. J-17 water levels reached the Stage II trigger level (650 feet) on June 14, 2009, resulting in a 30 percent reduction in municipal and industrial pumping in the area east of Uvalde County.

On approximately July 1, 2009, as irrigation pumping ended, water levels in J-17, as well as flow at Comal Springs, appeared to stabilize. J-17 water levels varied from 640 to 645 feet for the period from July 1 until mid-September, when the region began to receive rain events. This came at the end of the hottest year-to-date on record for the San Antonio area, where the National Weather Service recorded 67 days of temperatures reaching or exceeding 100 degrees. Cumulative rainfall for 2009 in Bexar County prior to September 1 was officially 8.43 inches, approximately 44 percent of normal rainfall to that date.

Historical data for J-17 and Comal and San Marcos springs have traditionally shown a rapid decline from March through July with a continuing but less rapid decline from July through October. The aquifer's behavior during the summer and early fall of 2009 has therefore raised questions as to what caused the observed response. J-17 water levels, as well as springflow measured at Comal Springs, when analyzed on a daily basis, appear to have reacted to watering restrictions imposed by the San Antonio Water System, the Bexar Metropolitan Water District, and other surrounding municipalities. Levels dropped from Monday through Thursday each week, leveled off on Friday, and rose on Saturday and Sunday. This occurred even though the area received no rainfall and dealt with extended periods of temperatures exceeding 100 degrees.

This response during the summer and early fall of 2009—the leveling of water levels in J-17 and springflows—needs to be further analyzed to determine what factors caused it to occur and what the implications are for maintaining aquifer and springflow levels in the future. One proposed method of analysis would be to look at the aquifer response with the model after it has been recalibrated with additional data collected through 2009. An analysis of pumping levels and pumping distribution on a monthly basis, compared with aquifer response, may also provide useful information.

Update the model

The model should be updated to incorporate (1) additional aquifer characterization data and information collected since the development of the model and (2) new modeling software, such as MODFLOW-2005 (CFP) and MODFLOW-DCM, that accommodate both diffuse and conduit flow.

Considerable new data and interpretations of groundwater flow in the Edwards Aquifer have come forth since the development of the current model. These data and interpretations provide reconceptualizations of boundary conditions, geologic structure, hydraulic architecture, recharge, and water budget. Although not all aspects of characterizing the Edwards Aquifer are known, there has been sufficient advance in the characterization of the aquifer to justify consideration of updating the current model at this time.

Enhance the management module

The critical period management module does not accurately model the Edwards Aquifer Authority's rules for reduction of pumping by water rights holders. There are two issues.

- The model for the Edwards Aquifer with the Critical Period Management Module instantaneously reduces pumping by all pumpers when triggers are reached for springflow or water levels in the monitoring wells. The Authority's regulations, however, do not require that these reductions in pumping be made "instantaneously". Instead, a water right holder cannot exceed his reduced permitted water right by the end of the year. The water right holder does not have to start reducing when the trigger level is hit. The reduced permitted amount is calculated at the end of the year and based on a percentage for the number of days that the aquifer is in a declared critical management stage. Additionally, an irrigator is not required to reduce his pumping by any amount once the crop is in

the ground. The Critical Period Management Module needs to be revised to account for how pumping reductions are actually implemented. Alternatively, the Edwards Aquifer Authority might consider modification of its rules to provide for more immediate responses to critical period management triggers.

- Hydrogeologically, the Uvalde Pool is considered to be west of the Knippa Gap. Administratively, the Uvalde Pool is considered to be west of the Medina-Uvalde county line. This means that many pumpers in eastern Uvalde County are in the San Antonio Pool from a hydrogeologic perspective, but in the Uvalde Pool from an administrative basis. These eastern Uvalde County wells, however, are subject to the critical period management cutbacks of the Uvalde Pool and not the San Antonio Pool. It is important that the model and the administration of the critical period management rules are in synch.

Evaluate the hydraulic relationship between the Trinity and Edwards aquifers

The connection between the Edwards Aquifer and the Trinity Aquifer should be refined, especially with respect to cross-formational flow from the Trinity Aquifer to the Edwards Aquifer in the San Marcos Springs area. As reflected in the model, there are two primary sources of flow from the Trinity Aquifer to the Edwards Aquifer: (1) that sourced from recharge to the Trinity Aquifer from Cibolo Creek and (2) that sourced from elsewhere in the Trinity Aquifer. Flow into the Edwards Aquifer sourced from Cibolo Creek is allowed to vary over time in the model whereas flow sourced from the rest of the Trinity Aquifer remains the same over time. Along the northern boundary in the steady-state model of the Edwards Aquifer, the general-head boundary package of MODFLOW was used to simulate a head-dependant flux boundary condition in order to estimate the equilibrium inflow from the Trinity Aquifer to the Edwards Aquifer. The boundary heads for the simulation were based on published historical water levels for the Edwards-Trinity Aquifer system. For the transient simulation, the MODFLOW well package was used to simulate a constant flux, equal to the model-calculated head-dependant flux from the steady-state simulation (Lindgren and others, 2004). In reality, this flow probably varies over time. Given the probable importance of this flow to maintaining springflows in San Marcos Springs, additional study is warranted to better understand—and better model—this flow.

Refine model calibration between San Marcos and Barton springs

The model of the Edwards Aquifer presently includes the portion of the aquifer located between San Marcos and the Colorado River (Barton Springs) as one continuous system and provides estimates of Barton Springs discharge and leakage to the Colorado River. It is understood and demonstrated by model results that calibration of the model within this segment of the aquifer was perceived to be less critical than for other segments, in part because of the historical recognition of a transient groundwater divide generally coincident with Onion Creek, north of the Blanco River watershed boundary. A number of studies have referenced the occurrence of this groundwater divide or mounding during wet and average periods; however, recent studies and field measurements during 2009 have demonstrated that this mounding dissipates or disappears during drought. Hence, a groundwater level gradient from San Marcos Springs to Barton Springs has been shown

to exist during drought, indicating that recharge in the San Antonio Segment of the aquifer is migrating to the Barton Springs Segment and that pumping in the San Antonio Segment affects discharge from Barton Springs. Recalibration and refinement of the model would facilitate more accurate simulation of flows between the San Antonio and Barton Springs segments of the Edwards Aquifer, thereby allowing more rigorous consideration of withdrawal reduction levels and stages for critical period management.

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Appendix A: The formation and operation of the Edwards Aquifer Area Expert Science Subcommittee

The Texas Legislature required the Steering Committee for the Edwards Aquifer Recovery Implementation Program to establish an Edwards Aquifer Area Expert Science Subcommittee of individuals "with technical expertise regarding the Edwards Aquifer system, the threatened and endangered species that inhabit that system, springflows, or the development of withdrawal limitations." The legislature required the subcommittee to prepare "initial recommendations by December 31, 2008", regarding:

- The option of designating a separate San Marcos pool, how such a designation would affect existing pools, and the need for an additional well to measure the San Marcos pool if designated;
- The necessity to maintain minimum springflows, including a specific review of the necessity to maintain a flow to protect federally threatened and endangered species; and
- Whether adjustments in the trigger levels for the San Marcos Springs flow for the San Antonio pool should be made.

The Steering Committee refers to these recommendations as the "k" charges. In making their recommendations, the Science Subcommittee was tasked to "consider all reasonably available science" and "base its recommendations solely on the best science available." In addition, the legislature tasked the subcommittee to "operate on a consensus basis to the maximum extent possible."

The Steering Committee appointed 15 scientists to serve on the Expert Science Subcommittee and one non-voting member. A list of the members and their affiliations is included at the beginning of this report (page iii).

Members were seated using a formal nomination and selection process:

- The Steering Committee established an Expert Science Subcommittee nominations workgroup to handle the application process.
- The workgroup accepted nominations from members of the Edwards Aquifer Recovery Implementation Program (an individual could also nominate themselves).
- Nominated individuals were asked to complete and submit an application summarizing their applicable areas of expertise and any possible conflicts of interest.
- The workgroup reviewed and compiled all applications by area of expertise.
- The compiled applications information was made available to all members of the Edwards Aquifer Recovery Implementation Program.
- Members of the Edwards Aquifer Recovery Implementation Program were invited to endorse nominees without limitation on the number of endorsements.
- The workgroup presented the endorsement results to the Steering Committee.
- At the January 2008 general Edwards Aquifer Recovery Implementation Program meeting, the Steering Committee held open discussions regarding the selection of

the Expert Science Subcommittee members. Consensus was reached to seat seven members, and these seven members were tasked to make recommendations to the Steering Committee regarding filling the remaining eight vacancies from the original pool of nominees/applicants.

- The newly-formed Expert Science Subcommittee met in late January 2008 and reached consensus regarding recommendations to fill the remaining eight vacancies.
- At the February 2008 general Edwards Aquifer Recovery Implementation Program meeting, the Steering Committee reached consensus on the eight nominees recommended by the Expert Science Subcommittee. At this same meeting, the Steering Committee reached consensus on the addition of one non-voting member to the subcommittee.
- Subsequent filling of available Expert Science Subcommittee slots (due to resignations) was accomplished by the Expert Science Subcommittee reaching consensus on a nominee/applicant from the original pool and making a recommendation to the Steering Committee. In each case, the subcommittee's recommendation was accepted by the Steering Committee.

Additional information about the establishment and the work of the Expert Science Subcommittee can be found at http://earip.tamu.edu/SciComm.cfm.

Appendix B: Excerpts from the Edwards Aquifer Authority Act, as amended by Senate Bill 3, Regular Session, 80th Legislature, that concern the Edwards Aquifer Area Expert Science Subcommittee

Section 1.14 WITHDRAWALS

(a) Authorizations to withdraw water from the aquifer and all authorizations and rights to make a withdrawal under this Act shall be limited in accordance with this section to:
  (1) protect the water quality of the aquifer;
  (2) protect the water quality of the surface streams to which the aquifer provides springflow;
  (3) achieve water conservation;
  (4) maximize the beneficial use of water available for withdrawal from the aquifer;
  (5) recognize the extent of the hydro-geologic connection and interaction between surface water and groundwater;
  (6) protect aquatic and wildlife habitat;
  (7) protect species that are designated as threatened or endangered under applicable federal or state law; and
  (8) provide for instream uses, bays, and estuaries.

(b) *Repealed by Act of May 28, 2007, 80th Leg., R.S., ch. 1351, § 2.09, 2007 Tex. Gen. Laws 4612, 4634; Act of May 28, 2007, 80th Leg., R.S., ch. 1430, § 12.09, 2007 Tex. Gen. Laws 5848, 5908.*

(c) Except as provided by Subsections (f) and (h) of this section and Section 1.26 of this article, for the period beginning January 1, 2008, the amount of permitted withdrawals from the aquifer may not exceed or be less than 572,000 acre-feet of water for each calendar year, which is the sum of all regular permits issued or for which an application was filed and issuance was pending action by the authority as of January 1, 2005.

(d) *Repealed by Act of May 28, 2007, 80th Leg., R.S., ch. 1351, § 2.09, 2007 Tex. Gen. Laws 4612, 4634; Act of May 28, 2007, 80th Leg., R.S., ch. 1430, § 12.09, 2007 Tex. Gen. Laws 5848, 5908.*

(e) The authority may not allow withdrawals from the aquifer through wells drilled after June 1, 1993, except for replacement, test, or exempt wells or to the extent that the authority approves an amendment to an initial regular permit to authorize a change in the point of withdrawal under that permit.

(f) If the level of the aquifer is equal to or greater than 660 feet above mean sea level as measured at Well J-17, the authority may authorize withdrawal from the San Antonio pool, on an uninterruptible basis, of permitted amounts. If the level of the aquifer is equal to or greater than 845 feet at Well J-27, the

authority may authorize withdrawal from the Uvalde pool, on an uninterruptible basis, of permitted amounts.

(h) To accomplish the purposes of this article, the authority, through a program, shall implement and enforce water management practices, procedures, and methods to ensure that, not later than December 31, 2012, the continuous minimum springflows of the Comal Springs and the San Marcos Springs are maintained to protect endangered and threatened species to the extent required by federal law and to achieve other purposes provided by Subsection (a) of this section and Section 1.26 of this article. The authority from time to time as appropriate may revise the practices, procedures, and methods. To meet this requirement, the authority shall require:

(1) phased adjustments to the amount of water that may be used or withdrawn by existing users or categories of other users, including adjustments in accordance with the authority's critical period management plan established under Section 1.26 of this article; or

(2) implementation of alternative management practices, procedures, and methods.

Act of May 30, 1993, 73rd Leg., R.S., ch. 626, § 1.14, 1993 Tex. Gen. Laws 2350, 2360; as amended by Act of May 28, 2007, 80th Leg., R.S., ch. 1351, § 2.02, 2007 Tex. Gen. Laws 4612, 4627; Act of May 28, 2007, 80th Leg., R.S., ch. 1430, § 12.02, 2007 Tex. Gen. Laws 5848, 5901.

Section 1.26A DEVELOPMENT OF WITHDRAWAL REDUCTION LEVELS AND STAGES FOR CRITICAL PERIOD MANAGEMENT THROUGH RECOVERY IMPLEMENTATION PROGRAM.

(h) Where reasonably practicable or as required by law, any meeting of the steering committee, the Edwards Aquifer area expert science subcommittee, or another subcommittee established by the steering committee must be open to the public.

(i) The steering committee appointed under this section shall appoint an Edwards Aquifer area expert science subcommittee not later than December 31, 2007. The expert science subcommittee must be composed of an odd number of not fewer than seven or more than 15 members who have technical expertise regarding the Edwards Aquifer system, the threatened and endangered species that inhabit that system, springflows, or the development of withdrawal limitations. The Bureau of Economic Geology of The University of Texas at Austin and the River Systems Institute at Texas State University shall assist the expert science subcommittee. Chapter 2110, Government Code, does not apply to the size, composition, or duration of the expert science subcommittee.

(j) The Edwards Aquifer area expert science subcommittee shall, among other things, analyze species requirements in relation to spring discharge rates and aquifer levels as a function of recharge and withdrawal levels. Based on that analysis and the elements required to be considered by the authority under Section 1.14 of this article, the expert science subcommittee shall, through a collaborative process designed to achieve consensus, develop recommendations for withdrawal reduction levels and stages for critical

period management including, if appropriate, establishing separate and possibly different withdrawal reduction levels and stages for critical period management for different pools of the aquifer needed to maintain target spring discharge and aquifer levels. The expert science subcommittee shall submit its recommendations to the steering committee and all other stakeholders involved in the recovery implementation program under this section.

(k) The initial recommendations of the Edwards Aquifer area expert science subcommittee must be completed and submitted to the steering committee and other stakeholders not later than December 31, 2008, and should include an evaluation:
    (1) of the option of designating a separate San Marcos pool, of how such a designation would affect existing pools, and of the need for an additional well to measure the San Marcos pool, if designated;
    (2) of the necessity to maintain minimum springflows, including a specific review of the necessity to maintain a flow to protect the federally threatened and endangered species; and
    (3) as to whether adjustments in the trigger levels for the San Marcos Springs flow for the San Antonio pool should be made.

(l) In developing its recommendations, the Edwards Aquifer area expert science subcommittee shall:
    (1) consider all reasonably available science, including any Edwards Aquifer-specific studies, and base its recommendations solely on the best science available; and
    (2) operate on a consensus basis to the maximum extent possible.

(m) After development of the cooperative agreement, the steering committee, with the assistance of the Edwards Aquifer area expert science subcommittee and with input from the other recovery implementation program stakeholders, shall prepare and submit recommendations to the authority. The recommendations must:
    (1) include a review of the critical period management plan, to occur at least once every five years;
    (2) include specific monitoring, studies, and activities that take into account changed conditions and information that more accurately reflects the importance of critical period management; and
    (3) establish a schedule for continuing the validation or refinement of the critical period management plan adopted by the authority and the strategies to achieve the program and cooperative agreement described by this section.

Act of May 28, 2007, 80th Leg., R.S., ch. 1351, § 2.06, 2007 Tex. Gen. Laws 4612, 4630; Act of May 28, 2007, 80th Leg., R.S., ch. 1430, § 12.06, 2007 Tex. Gen. Laws 5848, 5904.

Appendix C: Memorandum of Agreement for the Edwards Aquifer Recovery Implementation Program

MEMORANDUM OF AGREEMENT FOR EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM

This Memorandum of Agreement ("MOA") is intended to serve as the Memorandum of Agreement for the Edwards Aquifer Recovery Implementation Program (the "Program") under the Endangered Species Act and as the Memorandum of Agreement required by Senate Bill 3. It is made and agreed to by the Parties signing below and is effective on the Effective Date. The Parties will work together in good faith and cooperation to achieve the purposes and goals provided in the following provisions of this MOA.

Article 1. Purposes

Section 1.1. The purpose of this MOA is to formally initiate the development and implementation of the Edwards Aquifer Recovery Implementation Program. The Program is a collaborative initiative among stakeholders to participate in efforts to contribute to the recovery of the Edwards Species, develop aquifer management measures, and develop conservation measures for the Edwards Aquifer.

Section 1.2. During the 80th Regular Session, the Texas Legislature enacted Senate Bill 3, establishing, among other things, minimum requirements applicable to the Program. It is the intent of the Parties to comply with those minimum requirements and to build upon them to ensure that the Program is as effective and as inclusive as is reasonably possible, while also maintaining compliance with applicable provisions of the Endangered Species Act.

Section 1.3. The Parties acknowledge that Program efforts will be mindful of minimizing impacts on other protected species when advancing Program initiatives. The Parties also acknowledge the necessity of finding ways to balance the Program's contribution to recovery of Edwards Species with human water needs, while maintaining compliance with applicable provisions of the Endangered Species Act.

Article 2. Goals

Section 2.1. The goals of the Program, which are intended to be broadly interpreted, include, but are not limited to, the following:

(a) review, develop, and implement sound scientific research, analysis and other measures which contribute to understanding and meeting the needs of the Edwards Species;
(b) review, develop, and implement strategies which balance the needs of the Edwards Species with overall water use and supply in the Edwards Aquifer region;
(c) develop and complete an implementing agreement by December 31, 2009;
(d) develop and complete a program document by September 1, 2012, that shall take effect December 31, 2012, and may be in the form of a habitat conservation plan for the Edwards Species;
(e) implement the program document; and

(f) secure federal, state, and other available funding to assist with the development and implementation of the Program.

Section 2.2. The Parties to this MOA will participate in good faith in a cooperative, consensus-based process consistent with the purposes of the Program, and the requirements and deadlines imposed by Senate Bill 3. The Parties acknowledge that reasonable flexibility to adapt Program activities, particularly in response to new information and changed circumstances, is necessary to effectively meet the purposes of the Program.

Article 3. Definitions and Construction.

Section 3.1. Definitions. In this MOA, the following terms shall have the meanings assigned in this section unless the context clearly specifies a different meaning:

"Edwards Aquifer" means the same as the definition for "Aquifer" used in The Edwards Aquifer Authority Act.

"Edwards Species" means aquatic species that (1) are listed as threatened or endangered pursuant to the Endangered Species Act, and (2) are found in the Edwards Aquifer or found in or around the springs associated with the Edwards Aquifer. The Edwards Species, as of the Effective Date, are as follows: fountain darter, San Marcos gambusia, San Marcos salamander, Texas blind salamander, Comal Springs riffle beetle, Comal Springs dryopid beetle, Peck's cave amphipod, and Texas wild rice. This definition may be expanded by decision of the Steering Committee, without amending the MOA, to include additional species that are proposed for listing as threatened or endangered and that otherwise meet the definition of Edwards Species.

"Effective Date" means the date this MOA is effective, which shall be that date on which the MOA has been executed by duly authorized representatives of (1) the Edwards Aquifer Authority, United States Fish and Wildlife Service, Texas Commission on Environmental Quality, Texas Parks and Wildlife Department, Texas Department of Agriculture, Texas Water Development Board and (2) of other interests designated in Senate Bill 3 as initial members of the Steering Committee such that, collectively, at least 75% of the initial members of the Steering Committee have signed the document.

"Endangered Species Act" means the federal Endangered Species Act of 1973, as amended, 16 U.S.C. §§ 1531, et seq.

"Habitat Conservation Plan" means a conservation plan as referred to in Section 10 (a)(2), 16 U.S.C. § 1539 (a)(2), of the Endangered Species Act.

"Recovery" means the process by which the decline of an endangered or threatened species is arrested or reversed, and threats removed or reduced so that the species' long term survival in the wild can be ensured.

"Senate Bill 3" means Article 12 of Senate Bill 3, 80th Regular Session, 2007, of the Texas Legislature and Article 2 of House Bill 3, 80th Regular Session, 2007, of the Texas Legislature.

The Articles amend the Edwards Aquifer Authority Act ("Act"), Chapter 626, Acts of the 73rd Legislature, Regular Session, 1993, Section 1.26(A) of the Act provides for the development of a recovery implementation program. Identical provisions are included in Article 2 of House Bill 3, 80th Regular Session of the Texas Legislature.

Section 3.2. Construction. The Parties intend this MOA to be construed to comply with Senate Bill 3 establishing, among other things, minimum requirements applicable to the Program and with applicable requirements of the Endangered Species Act.

Article 4. Participation

Section 4.1. The Parties pledge to participate in good faith in an open, voluntary, and cooperative process that will strive to reach consensus on issues that further the purposes and goals of the Program. To achieve these purposes and goals, the Program will be overseen by a Steering Committee designed to ensure opportunities for participation and adequate representation of stakeholders. The Steering Committee will adopt procedures consistent with the MOA to ensure the Program includes, but is not limited to, the following procedural elements: an open process, advance public notice of meetings and proposed actions, opportunity for stakeholder participation, open communication, and consensus-based decision-making.

Section 4.2. Senate Bill 3 established the composition of an initial Steering Committee. Senate Bill 3 also allows, upon execution of this MOA, the initial Steering Committee to vote to add Members and to change the composition of the Steering Committee. In order to ensure adequate stakeholder representation on the Steering Committee, the signatories of this MOA recommend that the Steering Committee, at its earliest opportunity, add to the Steering Committee five other persons in the following categories:

(a) A representative of a holder of an Edwards Aquifer Authority initial regular permit issued to a small municipality (population under 50,000) located east of San Antonio,
(b) A representative of Edwards Aquifer region municipal ratepayers/general public,
(c) A representative of Guadalupe River Basin municipal ratepayers/general public,
(d) A representative of a conservation organization, and
(e) A representative of the Nueces River Authority.

Section 4.3. The Steering Committee will adopt procedures for the designation of primary, alternate, and replacement members of the Steering Committee. When changing or adding members, including members in addition to those listed in Section 4.2, the Steering Committee shall seek to maintain the balance of interests represented in the initial Steering Committee as set out in Senate Bill 3.

Section 4.4. In accordance with Senate Bill 3, the Steering Committee shall appoint an Edwards Aquifer area expert science subcommittee no later than December 31, 2007. As soon as reasonably possible, the Steering Committee shall establish a recharge facility feasibility subcommittee; other subcommittees shall be established as the Steering Committee determines appropriate. The Steering Committee shall ensure procedural elements are adopted to ensure an open process, advance public notice of meetings and proposed actions, opportunity for

stakeholder participation, open communication, and consensus-based decision-making are followed in subcommittees.

Article 5. Governance

Section 5.1. In addition to the responsibilities expressed in Senate Bill 3, the Steering Committee will adopt procedures to: address employment of a Program Manager and determine the Program Manager's role in the Program; establish appropriate Program subcommittee processes, to include membership, responsibilities, and decision-making recommendations; obtain funding for the Program ; adopt or amend Program Operational Rules; and other matters for which the Steering Committee determines procedures are necessary.

Section 5.2. The goal of the Steering Committee is to achieve consensus-based decision-making. Consensus is reached when no Member of the Steering Committee is opposed to a proposal. It is understood and accepted that in order to achieve a consensus on the Steering Committee, each Member will be open to pursuing "win-win" alternatives and to considering variations on the proposal that he or she might initially prefer. In its deliberations, the Steering Committee shall seek to exhaust every reasonable and practicable effort to reach consensus.

Section 5.3. In furtherance of consensus-based decision-making, when a proposal to the Steering Committee involving a Tier 1 decision (as set out in Section 5.5) does not achieve consensus, the Steering Committee will adopt a process which requires further deliberation and development of the proposal by an Issue Team. The Issue Team will be a smaller team of stakeholders as appointed by the Steering Committee and will include, to the extent practicable, participants representing all different viewpoints on the proposal, which may include participants who are not members of the Steering Committee. The Issue Team process will provide an opportunity for input from other stakeholders. The goal of the Issue Team is to achieve consensus on the proposal, or to develop a restatement of the proposal that may better achieve consensus of the Steering Committee. If after resubmission to the Steering Committee, or restatement of the proposal and resubmission to the Steering Committee, consensus has not been achieved, the Steering Committee will then vote on the proposal. A resubmitted or restated proposal will be deemed to have been approved by the Steering Committee when at least 75 percent of the entire Steering Committee has voted in favor of the proposal in accordance with voting procedures to be adopted by the Steering Committee.

Section 5.4. The Steering Committee will adopt procedures for appointment of Issue Teams, time requirements for resubmission and restatement of proposals, flexibility to continue to pursue consensus, an allowance for a minority report to be included with Tier 1 decisions, and voting procedures. These procedures to be adopted by the Steering Committee will apply to all Tier 1 decisions.

Section 5.5. The following types of decisions are considered to be Tier 1 decisions:

(a) Hiring or terminating of Program Manager;
(b) Approval of annual budget;
(c) Formal Recommendations to the EAA;

(d) Recommendations or Reports to the Legislature;
(e) Membership, responsibilities, and procedures of subcommittees;
(f) Changes to the membership of the Steering Committee beyond initial changes set out in Section 4.2 above;
(g) Adoption and amendment of the decision process of the Steering Committee;
(h) Decisions related to adoption or amendment of any Program agreements including, but not limited to the Memorandum of Agreement, the Implementing Agreement, the Cooperative Agreement, and the Program Document;
(i) Adoption or amendment of Program Operational Rules; and
(j) Any significant action determined by the Steering Committee to require Tier 1 decision-making in accordance with procedures to be developed.

Section 5.6. The Steering Committee will adopt simplified procedures for all other decisions of the Steering Committee. For those decisions other than Tier 1 decisions, a decision will be deemed to have been approved by the Steering Committee when a majority of the entire Steering Committee has voted in favor of the proposal in accordance with voting procedures adopted by the Steering Committee. Non-Tier 1 decisions are not subject to the Issue Team process described in Section 5.3.

Article 6. General Provisions

Section 6.1. This MOA shall remain in effect until the earlier of September 1, 2012 or the execution of a program document in compliance with the requirements of Senate Bill 3 and the Endangered Species Act. However, any signatory retains the ability to withdraw from the Program at any time by providing written notice of withdrawal to the Steering Committee. This MOA, including the term of the MOA, may be amended by action of the Parties in accordance with Senate Bill 3 and the decision processes established by the Steering Committee.

Section 6.2. Nothing herein shall constitute, nor be deemed to constitute, an obligation of future appropriations by the signatories to this MOA where creating such an obligation would be inconsistent with applicable federal, state, or local laws. Funding commitments made under this MOA by the signatories are understood to be contingent on obtaining approval and appropriations by the applicable local, state, or federal regulatory or legislative bodies. This MOA does not create an exclusive arrangement between the United States Fish and Wildlife Service (Service) or the Department of the Interior and the Parties to this agreement or commit the Service or the Department of the Interior to enter into any contract or other binding obligation. By entering into this MOA, no Party is obligated to enter into any contract or other binding obligation. This MOA is subject to and is intended to be consistent with all applicable federal, state, and local laws.

Section 6.3. All signatories to this MOA recognize that various parties have statutory responsibilities that cannot be delegated. Nothing in this MOA shall be construed to abrogate any of the statutory responsibilities of any signatory of the MOA**,** including:

(1) responsibilities that relate to implementing specific strategies included in the Program Document;

(2) authority to decide whether to approve any document, or amendment thereto, specifically required to be entered into by the parties under Senate Bill 3; or

(3) the Service's statutory authority under the Endangered Species Act.

Section 6.4. This MOA is effective on the date fully signed as described in the Definition of Effective Date. The MOA may be signed by additional stakeholders, including other appropriate federal agencies, following the Effective Date of the MOA.

Appendix D. Presentations made to the Edwards Aquifer Area Expert Science Subcommittee

Steve Clouse (Chief Operating Officer, San Antonio Water Supply) and Pablo Martinez (Planner III, San Antonio Water Supply)
TOPIC: Recycled water

Phillip Cook, P.E. (Director of Production, San Antonio Water Supply) and Jeff Haby, P.E. (Manager of Production, San Antonio Water Supply)
TOPIC: Aquifer storage and recovery/conservation efforts and successes

Brock Curry (Assistant General Manager–Administration and Operation, Edwards Aquifer Authority)
TOPIC: Critical period—Evolution of drought management (1989–Present)

John Hoyt, P.G., (Assistant General Manager–Aquifer Management, Edwards Aquifer Authority)
TOPIC: Edwards Aquifer Authority water quantity management

Karen Guz (Director of Conservation, San Antonio Water Supply)
TOPIC: Conservation efforts and successes

Rick Illgner (Governmental Affairs Officer, Edwards Aquifer Authority)
TOPIC: Critical period management: Quarterly versus annual allocations

Charles Jackson, Ph.D. (Institute for Geophysics, University of Texas at Austin)
TOPIC: Climate changes in Texas

Barbara Mahler (U.S. Geological Survey)
TOPIC: Work on Barton Springs Segment of the Edwards Aquifer

Darwin Ockerman (U.S. Geological Survey)
TOPIC: Streamflow gains and losses in the Guadalupe relative to the major springs

George Ozuna (U.S. Geological Survey)
TOPIC: Basic Hydrology and San Marcos Springs

Geary Schindel, P.G. (Chief Technical Officer, Edwards Aquifer Authority)
TOPIC: Edwards Aquifer MODFLOW model—Development, benefits, limitations, current and future applications

Geary Schindel, P.G. (Chief Technical Officer, Edwards Aquifer Authority)
TOPIC: EAA San Marcos report (Evaluation of the option to designate a separate San Marcos pool for critical period management)

Sam Vaugh, P.E. (Vice President, HDR Engineering, Inc.)
TOPIC: Environmental flows in the Guadalupe River Basin

Adam Zerrenner (U.S. Fish and Wildlife Service)
TOPIC: Reviewing influence diagrams and how they can provide flexibility

Appendix E. Position papers submitted by the stakeholders of the Edwards Aquifer Recovery Implementation Program

The Edwards Aquifer Area Expert Science Subcommittee solicited position papers from any interested stakeholder involved with the Edwards Aquifer Recovery Implementation Program. Instructions were to identify, per task/charge, three references that the stakeholder felt the subcommittee needed to consider and a position paper limited to one page. The positions are given according to Senate Bill 3's charges to the subcommittee (see Appendix B). We have not edited these submissions. This appendix includes these submissions, listed in alphabetical (citation style) order.

J Charge Position

Submitted by Guadalupe Basin Coalition:
Contact: **Tom Taggart**
Date: **August 12, 2009**
Email Address: **ttaggart@sanmarcostx.gov**
Contact Phone Number: **512-393-8004**

Top Three Position Supporting References:

(1) Johnson, S.B., and Schindel, G.M., 2008, Evaluation of the Option to Designate a Separate San Marcos Pool for Critical Period Management, 151 p.
(2) Most Current versions of ModFlow andGWSIM models as appropriate
(3) HDR Technical Memo Re: Hydrologic Connection of the Edwards Aquifer between San Marcos Springs and Barton Springs, October 18, 2008
(4) HDR Technical Memo Re: Impact of Pumping LCRA Well on Flow from Comal and San Marcos Springs during 1950s Drought, July 2, 2008

Your Position (limited to two pages):

1. Science Subcommittee recommendations on the items listed in the J charge, including any proposed withdrawal reduction stages and critical period management reduction amounts, should be based solely on the best available science.

2. A separate pool for San Marcos Springs or Hays County should not be designated.

3. While the impacts to springflow from additional recharge merit further study, additional recharge should not be an assumption built into the Science Subcommittee's recommendations at this time.

4. Refugia should not be considered an acceptable adaptive management strategy for maintenance of the endangered and threatened species in lieu of adequate springflow.

5. Recirculation initiatives have not included scientific studies to demonstrate that the quality of aquifer water will be protected (**EAA Act, Section 1.14(a)(2)**) and that adequate flows for instream uses, bays and estuaries will be ensured (**EAA Act, Section 1.14(a)(8))**. In fact, water quality effects have been largely ignored in the multiple studies to date. These initiatives should not be advanced related to the J charges.

6. Supposition of effects or impacts related to springflows based on anecdotal, incomplete data, and speculative studies (e.g. LCRA well influence suppositions) should be avoided in completing this task.

J Charge Position

Submitted By: **Guadalupe Blanco River Authority**
Contact: **Todd Votteler**
Date: **August 12, 2009**
Email Address: **tvotteler@gbra.org**
Contact Phone Number: **830-379-5822**

Top Three Position Supporting References:

(1) Land, Larry, and Paula Jo Lemonds, HDR Technical Memo Re: Hydrologic Connection of the Edwards Aquifer between San Marcos Springs and Barton Springs, October 18, 2008

(2) Land, Larry, HDR Technical Memo Re: Impact of Pumping LCRA Well on Flow from Comal and San Marcos Springs during 1950s Drought, July 2, 2008

(3) Votteler, Todd H., *1996 Emergency Withdrawal Reduction Plan for the Edwards Aquifer*. Prepared for the U.S. District Court, Western District of Texas, The Honorable Lucius Bunton, Presiding, August 23, 1996, pp. 37.

Your Position (limited to two pages):

1. Science Subcommittee recommendations on the items listed in the J charge, including any proposed withdrawal reduction stages and critical period management reduction amounts, should be based solely on the best available science.

2. Any management plan for groundwater withdrawals should include a requirement for weekly pumping reporting by permit holders during critical periods.

3. Any proposed withdrawal reduction stages and critical period management reduction amounts should consider reductions to base usage, and below if required. Base usage is indexed to the monthly winter usage, i.e., average of the three lowest months of November, December, January, and February.

4. Supposition of effects or impacts related to springflows based on anecdotal, incomplete data, and speculative studies (e.g. LCRA well influence suppositions) should be avoided in completing this task.

5. The potential impacts of Edwards Aquifer groundwater withdrawals upon discharge rates at Barton Springs should be considered in any proposed withdrawal reduction stages and critical period management reduction amounts by the Science Subcommittee once data from the current U.S. Geological Survey-Barton Springs Edwards Aquifer Conservation District-HDR-Guadalupe Blanco River Authority monitoring program is available in September.

6. A separate pool for San Marcos Springs or Hays County should not be designated.

7. While the impacts to springflow from additional recharge merit further study, additional recharge should not be an assumption built into the Science Subcommittee's recommendations at this time.

8. Refugia should not be considered an acceptable adaptive management strategy for maintenance of the endangered and threatened species in lieu of adequate springflow.

9. Recirculation initiatives have not included scientific studies to demonstrate that the quality of aquifer water will be protected (**EAA Act, Section 1.14(a)(2)**) and that adequate flows for instream uses, bays and estuaries will be ensured (**EAA Act, Section 1.14(a)(8))**. In fact, water quality effects have been largely ignored in the multiple studies to date. These initiatives should not be advanced related to the J charges.

J Charge Position

Submitted By: Regional Clean Air & Water Association
Date: August 12, 2009
Email Address: cgpatterson@grandecom.net
Contact Phone Number: 210 824-3407

Top Three Position Supporting References:

(1) "Recharge and Recirculation Edwards Aquifer Optimization Program," prepared by Todd Engineers for the EAA in Phase I, II, III and IV Reports

(2) Evaluation of Augmentation Methodologies in Support of In Situ Refugia at Comal and San Marcos Springs," prepared by LBG-Guyton Associates for the EAA in 2004.

(3) Edwards Aquifer Authority Enabling Act, Sec. 1.14

Your Position (limited to four pages):

The "RCAWA Position Statement" on the 'j' Charge" was passed unanimously at the July 28th 2009 meeting of Regional Clean Air and Water Association.

Regional Clean Air and Water Association believes that the information described in the RCAWA Position Statement that follows (which includes the options of Recharge and Recirculation and Augmentation/In Situ) should be described and developed by some part of the EARIP process (not necessarily the Science Subcommittee) before a final recommendation can be made as to reductions in the pumping cap or floor or critical period reductions.

While we recognize that it is appropriate to provide "baseline" computer simulations, we do not think believe that the "j" charge will be complete without full consideration of the items referred to in Sec. 1.14 of the EAA Act, which includes "alternative management practices, procedures and methods" as described in Sec. 1.14 (h). We also believe that in the "j" charge, the analysis of species requirements in relation to spring discharge is made a "function of recharge and withdrawal levels."

For those reasons and for the reason that we need to be inclusive of options that have been proposed, we believe that before a final recommendation can be made by the EARIP processes with regard to withdrawal reduction levels or critical period stages, an analysis that includes these alternative management practices, procedures and methods should be provided.

/s/ Carol Patterson, President, Regional Clean Air & Water Association

RCAWA POSITION STATEMENT ON THE "j" CHARGE:

In reference to the "j" charge to the EARIP Science Subcommittee found in the EAA Act as amended by S.B. 3, Sec. 1.26A, subsection (j), Regional Clean Air and Water Association (RCAWA) respectfully requests that model runs and other information be provided on the options of (1) enhanced recharge & recirculation, and (2) in situ refugia / augmentation, in coordination with present pumping limits and critical period reductions found in S.B. 3.

These model runs and information would relate to:

(1) The beneficial effect that enhanced recharge and recirculation might have on providing a minimum springflow regime at Comal Springs and San Marcos Springs in a repeat of the drought of record, with the present pumping limits and critical period rules of S.B. 3 in place, including providing enhanced recharge from the sources identified in the Recharge & Recirculation Study and other studies of recharge enhancement possible for the Edwards Aquifer, to meet the goal of providing a minimum springflow regime in an efficient manner;

(2) The beneficial effect that in situ refugia / augmentation of springflows might have on providing waters for maintaining the habitat of the endangered species in the Comal River and the San Marcos River in a repeat of the drought of record, with the present pumping limits and critical period rules of S.B. 3 in place, including providing waters for maintaining the habitat by such means as were identified in the study entitled "Evaluation of Augmentation Methodologies in Support of In Situ Refugia at Comal and San Marcos Springs" done by LBG-Guyton Associates for the EAA in 2004.

It is the position of RCAWA that the "j" charge asks the Science Subcommittee to consider meeting species water requirements as a function of both "recharge" and "withdrawals", *and that the Science Subcommittee should base its recommendations on that analysis as well as "the elements required to be considered by the authority under Section 1.14 of this article"* which include the implementation of "alternative management practices, procedures and methods" referred to in Sec. 1.14(h) of the EAA Act.

RCAWA therefore asks that that the Science Subcommittee provide modeling and other information describing and evaluating these "alternative management practices, procedures and methods" as alternatives to further pumping reductions or to increased critical period reductions from those presently found in S.B. 3, and do this as a part of its work in providing recommendations and useful information to the Steering Committee.

Position Statement was adopted by RCAWA on July 28, 2009.
/s/ Carol Patterson, President of Regional Clean Air & Water Association

San Antonio Water System

San Antonio Water System
J-Charges Position Paper
Submitted by: Calvin Finch, SAWS
Date: July 31, 2009

The San Antonio Water System (SAWS) appreciates the opportunity to provide written comment on Senate Bill 3 "J" charges as requested by the Area Expert Science Subcommittee. SAWS commends the volunteers for taking on this important and difficult task.

In General:

- Decline in critical habitat is influenced by a variety of factors. Pumping is currently the most defined and tightly controlled variable. However, climate, impacts from recreational activities, floods, storm water runoff, and non-native species are some of the equally important variables that are inadequately quantified and defined. Other important factors include unregulated water withdrawals from the Edwards aquifer (domestic wells and unregistered wells) and other more localized contributing sources, such as the Trinity aquifer. SAWS urges that the task of the Science Subcommittee will be incomplete until these other factors are rigorously incorporated into the analysis.

- The spatial distribution of pumping can be just as detrimental to springflow as the amount or timing of the withdrawals. Anecdotal evidence increasingly suggests that pumping in close proximity to the springs has a disproportionately negative impact to the springflow versus pumping elsewhere in the Edwards region. For the first time ever, San Marcos Springs first triggered regional Critical Period cutbacks in spring 2009. In 2006, San Marcos Springs held the region in the Critical Period for several months after J-17 and Comal Springs recovered. We hope that the Science Subcommittee will, as part of developing the J-charge, consider the impact of local, as well as regional, pumping on the springs, and consider variations of critical period management which address appropriate local pumping curtailment. (LBG-Guyton & Associates 2004, LBG-Guyton & Associates 2008)

What are the species requirements?:

- We believe it is undisputed that most of the species of concern have survived past droughts, including the Drought of Record. This fact is supported by observation and acknowledged by the United States Fish & Wildlife Service (USFWS, 2007). The one exception to this observation is the Comal fountain darter, and even the darter might have survived the adverse situation at Comal if not for local activities impacting that ecosystem. Such local activities are known to have included pumping from the power plant well (LBG-Guyton & Associates, 2004), localized flood events, and may also have included rotenone poisoning (BIO-WEST 2003, Linam etal., 1993, Schenck etal., 1976, USFWS, 1996). Observations such as these are *key components* to the scientific process. SAWS has concerns that these valid observations being offered to the Area Expert Science Subcommittee and EARIP are being portrayed as mere "outlier" positions, rather than certain and irrefutable factual observations. <u>We urge that these observations be given substantive recognition and attention by the Subcommittee.</u>

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- What scientific work, judgment or observations linking a given discharge of springflow during a specified duration lead the Subcommittee to conclude the situation is adequate for recovery? We urge the Subcommittee to carefully document the scientific basis for their reasoning.

- Dr. Thom Hardy and his Team have drafted influence diagrams outlining factors that have an impact on the "sentinel" endangered species. Stakeholders were given the opportunity to comment on those influence diagrams. The Science Subcommittee should draw upon the SAWS comments to assist it in addressing the observations above (local activities impacting the ecosystem).

- Accurate measurement of springflow is a key concern for regional water users, and equally important for biological monitoring activities and endangered species relocation and mitigation. The San Marcos springflow volume measurement methodology does not inspire confidence and is currently regarded as less than reliable. This reliability issue results in situations that are problematic for water supply management and for the species. Recalibration of San Marcos spring discharge in early July 2009 resulted in "higher" springflows than initially reported. As a result, critical period biological monitoring was initiated, and Texas Wild-rice was re-planted as called for in the low-flow monitoring and salvaging plan, despite the lack of a "need" to do so after recalibration. As an additional example, imprecise springflow measurements in 2006 were a contributing factor to the decision by SAWS to recover thousands of acre-feet of stored groundwater from the Aquifer Storage and Recovery (ASR) storage facility. This resulted in an unwarranted additional financial cost to the ratepayers of San Antonio above normal operating costs, amounting to millions of dollars.

- The Science Subcommittee should recognize that the Edwards Aquifer receives natural recharge varying between approximately 50,000 acre-feet to more than 2,000,000 acre-feet per year (Edwards Aquifer Authority, 2008). This presents opportunities for optimization and management that can both meet the species requirements and human water supply. To the extent Section 1.14(a) is considered in the formulation of the J-charge recommendation, this optimization component should be considered along with others in Section 1.14(a) (Senate Bill 3, 2007).

- A robust refugium program that pays close attention to genetic integrity of species has been implemented in a number of recovery programs and remains a prudent tool and planning response to protracted drought or other disasters, whether natural or unnatural. The cost to permit-holders to drastically cutback any further is much higher than the cost of a state-of-the-art refugium. Droughts of varying intensity and duration have occurred in the past. While work has been done to evaluate drought during deep historical periods, the Science Subcommittee members should remain focused on the "Drought of Record." A refugium could play a vital role in a reoccurrence of a drought with greater intensity or duration.

- The risk to the endangered species of extinction from springflow cessation is currently low as analyzed in a report by BIO-WEST in 2003. This report included an impact and risk analysis approach to springflow cessation at a variety of pumping levels. This analysis indicated the risk of 0 cfs at Comal was low (0 – 6.2%) with a regional pumping floor of 340,000 acre-feet, and that San Marcos Springs would continue to flow (BIO-WEST, 2003). Garnering any additional "certainty" for springflow utilizing modeling and measurement tools with well-known and acknowledged shortcomings is scientifically unsound.

- The concept of a flow regime for maintenance of endangered species populations has been a topic of discussion among the members of the Science Subcommittee and the 2008 report (Edwards Aquifer Recovery Implementation Program, 2008). The Science Subcommittee seems to be trying to apply the "regime" concept to the lowest biologically-acceptable flow level. From a species perspective, flow regime determinations should focus on the context of the lower end of the scale of flow volumes for endangered species survival. Some of the peer reviewers of the "K-charge" report indicated that a regime approach to species that are adapted for habitat conditions of relative constancy, such as in temperature or water clarity, was unproven (Sustainable Ecosystems Institute, 2009).

- The correlation between the San Antonio segment of the Edwards Aquifer and the San Marcos Springs is deficient with an r^2=0.51 (T. Votteler, presentation to Science Subcommittee April 21, 2008). Water quality data (Johnson and Schindel, 2008; LBG-Guyton & Associates, 2004) has implicated numerous sources for the springs – local unconfined Edwards, regional artesian/confined Edwards, the Blanco River, and the Trinity aquifer all contribute to springflows upon with the species depend. The EAA report (LBG-Guyton & Associates, 2004) states that artesian/confined Edwards accounts for approximately 50 cfs at San Marcos springs during drought periods. If species are dependant on flows greater than this amount, local sources contributing to springflow should be included in the critical period plan.

Development of a Critical Period Management Regimen:

- Before considering alterations to the current critical period management plan, the Science Subcommittee should consider whether or not the current plan is adequate and clearly describe why or why not. One major shortfall in the current policies is they apply disproportionately to different users of the aquifer. SAWS suggests that adjustments should only be recommended if they are to focus on the disproportionate standards applied to various regional water users, who should all contribute to the conservation and recovery of the endangered species.

- Municipal and Industrial permit holders bear the full brunt of early drought cutbacks while controlling less than half of the permitted water uses. Pumping cutbacks on municipal and industrial permit-holders alone will not accomplish springflow protection and do not represent a balanced solution to the regional water challenge.

- In light of the limitations of the tools we have available, a monitoring plan implementing defined elements in an adaptive management framework would be the most prudent approach when considering withdrawal levels. Drought cutback regimes should also be consistently applied and monitored for a minimum of a decade. This would allow for the gathering of data concerning species and ecosystem responses and region-wide water user behavior through various weather patterns. If a robust refugium program is implemented, risks during the adaptive management implementation could be mitigated.

- Recent decisions by the Edwards Aquifer Authority indicate common ground between the EAA Board and SAWS regarding an understanding of the effects of pumping near the springs. Additional or special management considerations for areas near the springs have already been implicitly acknowledged (LBG-Guyton & Associates, 2008). This substantiates our repeated observations that areas east of the Cibolo Creek and down-gradient of Comal Springs deserve special management considerations, especially as the Expert Science Subcommittee develops management recommendations regarding critical period cutbacks.

- EAA provided an extensive report describing how regional flows are important below 100 cfs at San Marcos Springs (Johnson and Schindel, 2008). SAWS believes that flow level is actually below 50 cfs based on work by the USGS (Lindgren etal., 2004 pg. 40 - citing Puente (1976)), Edwards Aquifer Authority (LBG-Guyton & Associates, 2004 pg B-45), and observations from the drought of record, when San Marcos Springs declined to 46 cfs. We urge the Subcommittee to consider in their deliberations special management considerations for Edwards aquifer water use near the springs and that local pumping and locally-sourced springflow be managed before declining to these regional flows.

- The data resource challenges facing the Science Subcommittee in particular, and the EARIP stakeholders more broadly, are significant. Acknowledgement of the limitations of the tools used in developing recommendations, and of the information needed to further refine those recommendations, will assist the EARIP as it develops an Adaptive Management plan.

Thank you for soliciting stakeholder input and for providing your expertise in the formulation of recommendations to assist the EARIP Steering Committee. We hope these comments will contribute to your work.

Sincerely,

Calvin Finch

Calvin Finch
San Antonio Water System

References

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Linam, G.W., K.B. Mayes, and K.S. Saunders, 1993. *Habitat utilization and population size estimate of fountain darters,* Etheostoma fonticola, *in the Comal River, Texas.* Texas Journal of Science 45(4):341-348.

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Sustainable Ecosystems Institute, 2009. *Peer Review of the Edward Aquifer Recovery Implementation Program's Science Subcommittee's "k" Charge Recommendations: Review by Dr. Mark Bain, Cornell University.*

United States Fish & Wildlife Service (USFWS), 1996. *San Marcos/Comal/Edwards Aquifer rare, threatened, and endangered species contingency plan.* Revised version dated May 1996.

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Votteler, T.H., 2008. *Presentation of analysis of J-17 predicting springflow* based on work in "*Water from a stone: The limits of the sustainable development of the Texas Edwards Aquifer*" (January 1, 2000).

Appendix F. Requests for Edwards Aquifer model runs

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Run Request 1

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Run 001: Baseline (current permitted amount+exempt, current distribution of pumping, current critical period management)

San Antonio Pool				
Comal (cfs)	**San Marcos (cfs)**	**J-17 (feet)**	**Stage -**	**Reduction (%)**
<225	<96	<660	I	20
<200	<80	<650	II	30
<150	N/A	<640	III	35
<100	N/A	<630	IV	40

Uvalde Pool		
J-27 (feet)	**Stage -**	**Reduction (%)**
-	I	0
<850	II	**5**
<845	III	20
<842	IV	35

Run 002: No pumpage.

Run 003: 100,000 acre-feet per year of pumpage (+exempt, current distribution, no critical period management)

Run 004: 200,000 acre-feet per year of pumpage (+exempt, current distribution, no critical period management)

Run 005: 300,000 acre-feet per year of pumpage (+exempt, current distribution, no critical period management)

Run 006: 400,000 acre-feet per year of pumpage (+exempt, current distribution, no critical period management)

Run 007: 500,000 acre-feet per year of pumpage (+exempt, current distribution, no critical period management)

Run 008: 572,000 acre-feet per year of pumpage (+exempt, current distribution, no critical period management)

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Run Request 2

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The next two runs relate to using the Senate Bill 3 critical period management scheme with a pumping ceiling based on what would have been pumped in 2008 (a dry year) with no critical period reductions. Actual pumping in 2008 is estimated at 430,000 acre-feet. Pumping in 2008 with no critical period reductions would probably have been 437,000 acre-feet. Run 009 ends with pumping at a rate of 320,000 acre-feet per year in Stage IV, while Run 010 ends with pumping at a rate of 340,000 acre-feet per year in Stage IV. Changes from Senate Bill 3 are indicated in bolded red text.

Stage -	**SB 3 (AFY)**	**Run 009 (AFY)**	**Run 010 (AFY)**
0	572,000	437,000	437,000
I	486,000	401,000	391,000
II	436,000	378,000	365,000
III	393,000	359,000	343,000
IV	350,000	320,000	340,000

Run 009

Pumping is capped at a rate of 437,000 acre-feet per year with reductions in pumping that end with a rate of 320,000 acre-feet per year.

San Antonio Pool

Comal (cfs)	**San Marcos (cfs)**	**J-17 (feet)**	**Stage -**	**Reduction (%)**
<225	<96	<660	I	**14**
<200	<80	<650	II	**21**
<150	N/A	<640	III	**24**
<100	N/A	<630	IV	**28**

Uvalde Pool

J-27 (feet)	**Stage -**	**Reduction (%)**
-	I	0
<850	II	**3**
<845	III	**14**
<842	IV	**24**

Run 010

Pumping is capped at a rate of 437,000 acre-feet per year with reductions in pumping that end with a rate of 340,000 acre-feet per year.

San Antonio Pool

Comal (cfs)	San Marcos (cfs)	J-17 (feet)	Stage -	Reduction (%)
<225	<96	<660	I	**11**
<200	<80	<650	II	**17**
<150	N/A	<640	III	**20**
<100	N/A	<630	IV	**23**

Uvalde Pool

J-27 (feet)	Stage -	Reduction (%)
-	I	0
<850	II	**3**
<845	III	**11**
<842	IV	**20**

==========

The next three runs relate to adjustments to the current critical period management scheme. The trigger levels will remain the same in these runs, but the percent reductions are adjusted. Changes from Senate Bill 3 are indicated in bolded red text. The purpose of these runs is to understand what reductions may be required to maintain springflow.

Stage -	Run 011 (AFY)	Run 012 (AFY)	Run 013 (AFY)
0	572,000	572,000	572,000
I	486,000	486,000	486,000
II	436,000	436,000	436,000
III	350,000	350,000	350,000
IV	286,000	229,000	172,000

Run 011

Pumping is capped at a rate of 572,000 acre-feet per year.

San Antonio Pool

Comal (cfs)	San Marcos (cfs)	J-17 (feet)	Stage -	Reduction (%)
<225	<96	<660	I	20
<200	<80	<650	II	30
<150	N/A	<640	III	**40**
<100	N/A	<630	IV	**50**

Uvalde Pool

J-27 (feet)	Stage -	Reduction (%)
-	I	0
<850	II	5
<845	III	**35**
<842	IV	**50**

Run 012

Pumping is capped at a rate of 572,000 acre-feet per year.

San Antonio Pool

Comal (cfs)	San Marcos (cfs)	J-17 (feet)	Stage -	Reduction (%)
<225	<96	<660	I	20
<200	<80	<650	II	30
<150	N/A	<640	III	**40**
<100	N/A	<630	IV	**60**

Uvalde Pool

J-27 (feet)	Stage -	Reduction (%)
-	I	0
<850	II	5
<845	III	**35**
<842	IV	**60**

Run 013

Pumping is capped at a rate of 572,000 acre-feet per year.

San Antonio Pool				
Comal (cfs)	**San Marcos (cfs)**	**J-17 (feet)**	**Stage -**	**Reduction (%)**
<225	<96	<660	I	20
<200	<80	<650	II	30
<150	N/A	<640	III	**40**
<100	N/A	<630	IV	**70**

Uvalde Pool		
J-27 (feet)	**Stage -**	**Reduction (%)**
-	I	0
<850	II	5
<845	III	**35**
<842	IV	**70**

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Run Request 3

==========

The following two runs are “fill-in” runs similar to the constant pumping runs 002 through 008.

Run 014: 250,000 acre-feet per year of pumpage (+exempt, current distribution, no critical period management)

Run 015: 350,000 acre-feet per year of pumpage (+exempt, current distribution, no critical period management)

It is our understanding that the model runs start with a steady-state initial condition with pumping at about 170,000 acre-feet per year. The following two runs are intended to assess the sensitivity of model results (specifically Run 001) to this “lead in” pumping.

Run 016: Run 001 but with pumping for the steady-state initial condition set at 0.

Run 017: Run 001 but with pumping for the steady-state initial condition set at twice whatever the initial condition pumping is.

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Run Request 4

==========

The following three runs are a variation of runs 11, 12, and 13 but with permitted pumping not allowed to be greater than a rate of 437,000 acre-feet per year. Changes from Senate Bill 3 are indicated in bolded red text.

Stage -	Run 018 (AFY)	Run 019 (AFY)	Run 020 (AFY)
0	437,000	437,000	437,000
I	437,000	437,000	437,000
II	437,000	437,000	437,000
III	350,000	350,000	350,000
IV	284,000	227,000	175,000

Run 018

Permitted pumping is not allowed to be greater than a rate of 437,000 acre-feet per year.

San Antonio Pool

Comal (cfs)	San Marcos (cfs)	J-17 (feet)	Stage -	Reduction (%)
<225	<96	<660	I	**0**
<200	<80	<650	II	**0**
<150	N/A	<640	III	**20**
<100	N/A	<630	IV	**35**

Uvalde Pool

J-27 (feet)	Stage -	Reduction (%)
-	I	0
<850	II	**0**
<845	III	**20**
<842	IV	**35**

Run 019

Permitted pumping is not allowed to be greater than a rate of 437,000 acre-feet per year.

San Antonio Pool

Comal (cfs)	San Marcos (cfs)	J-17 (feet)	Stage -	Reduction (%)
<225	<96	<660	I	**0**
<200	<80	<650	II	**0**
<150	N/A	<640	III	**20**
<100	N/A	<630	IV	**48**

Uvalde Pool

J-27 (feet)	Stage -	Reduction (%)
-	I	**0**
<850	II	**0**
<845	III	**20**
<842	IV	**48**

Run 020

Permitted pumping is not allowed to be greater than a rate of 437,000 acre-feet per year.

San Antonio Pool

Comal (cfs)	San Marcos (cfs)	J-17 (feet)	Stage -	Reduction (%)
<225	<96	<660	I	**0**
<200	<80	<650	II	**0**
<150	N/A	<640	III	**20**
<100	N/A	<630	IV	**60**

Uvalde Pool

J-27 (feet)	Stage -	Reduction (%)
-	I	**0**
<850	II	**0**
<845	III	**20**
<842	IV	**60**

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Run Request 5

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Run 021

The purpose of this run is to test the sensitivity of the aquifer to adjustments in the water-level triggers. This is Run 013 but with the J-17 and J-27 triggers raised by five feet.

San Antonio Pool				
Comal (cfs)	**San Marcos (cfs)**	**J-17 (feet)**	**Stage -**	**Reduction (%)**
<225	<96	<**665**	I	20
<200	<80	<**655**	II	30
<150	N/A	<**645**	III	**40**
<100	N/A	<**635**	IV	**70**

Uvalde Pool		
J-27 (feet)	**Stage -**	**Reduction (%)**
-	I	0
<**855**	II	5
<**850**	III	**35**
<**847**	IV	**70**

Run 022

The purpose of this run is to test the sensitivity of the aquifer to adjustments in the trigger for Comal Springs. This is Run 013 but with the Comal Springs triggers raised by 15 cubic feet per second.

San Antonio Pool				
Comal (cfs)	**San Marcos (cfs)**	**J-17 (feet)**	**Stage -**	**Reduction (%)**
<**240**	<96	<660	I	20
<**215**	<80	<650	II	30
<**165**	N/A	<640	III	**40**
<**115**	N/A	<630	IV	**70**

Uvalde Pool		
J-27 (feet)	**Stage -**	**Reduction (%)**
-	I	0
<850	II	5
<845	III	**35**
<842	IV	**70**

Run 023

The purpose of this run is to test the sensitivity of the aquifer to adjustments in the triggers for the Uvalde Pool. The adjustments to the Uvalde Pool triggers were based on an analysis of how often the San Antonio Pool was in stage I, II, III, and IV for Run 013. We then chose J-27 triggers, again based on Run 013, to achieve similar frequency for the Uvalde Pool.

	J-17 trigger (feet)	%	J-27 "new" (feet)	J-27 "SB3" (feet)
Stage I	660	74.4	870	N/A
Stage II	650	46.0	853.5	850
Stage III	640	18.1	839.4	845
Stage IV	630	0.5	807.6	842

Therefore, this run is Run 013 but with adjustments to the J-27 triggers.

San Antonio Pool

Comal (cfs)	San Marcos (cfs)	J-17 (feet)	Stage -	Reduction (%)
<225	<96	<660	I	20
<200	<80	<650	II	30
<150	N/A	<640	III	**40**
<100	N/A	<630	IV	**70**

Uvalde Pool

J-27 (feet)	Stage -	Reduction (%)
<**870**	I	0
<**854**	II	5
<**839**	III	**35**
<**808**	IV	**70**

Run 024

The purpose of this run is to test the sensitivity of the aquifer to adjustments to reductions in the first two stages. This is Run 013 with adjustments to stages I and II.

San Antonio Pool

Comal (cfs)	San Marcos (cfs)	J-17 (feet)	Stage -	Reduction (%)
<225	<96	<660	I	**25**
<200	<80	<650	II	**35**
<150	N/A	<640	III	**40**
<100	N/A	<630	IV	**70**

Uvalde Pool

J-27 (feet)	Stage -	Reduction (%)
-	I	0
<850	II	5
<845	III	**35**
<842	IV	**70**

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Run Request 6

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Run 025 (Withdrawn)

The purpose of this run is to test the sensitivity of the aquifer to adjustments in the water-level triggers and reductions in the Uvalde Pool. The San Antonio Pool triggers and reductions are the same as for Run 013.

Pumping is capped at a rate of 572,000 acre-feet per year.

San Antonio Pool

Comal (cfs)	San Marcos (cfs)	J-17 (feet)	Stage -	Reduction (%)
<225	<96	<660	I	20
<200	<80	<650	II	30
<150	N/A	<640	III	**40**
<100	N/A	<630	IV	**70**

Uvalde Pool

J-27 (feet)	Stage -	Reduction (%)
< **865**	I	**10**
<**860**	II	**20**
<**855**	III	**35**
<**852**	IV	**70**

Run 026 (Withdrawn)

The purpose of this run is to test the sensitivity of the aquifer to increased reductions at early stages and less reduction at Stage IV for the San Antonio Pool. This is Run 013 with adjustments to reductions for the San Antonio Pool.

Pumping is capped at a rate of 572,000 acre-feet per year.

San Antonio Pool

Comal (cfs)	San Marcos (cfs)	J-17 (feet)	Stage -	Reduction (%)
<225	<96	<660	I	**30**
<200	<80	<650	II	**35**
<150	N/A	<640	III	**45**
<100	N/A	<630	IV	**60**

Uvalde Pool

J-27 (feet)	Stage -	Reduction (%)
-	I	0
<850	II	5
<845	III	**35**
<842	IV	**70**

Run 027 (Withdrawn)

The purpose of this run is to test the sensitivity of the aquifer to increased triggers and increased reductions at early stages and less reduction at Stage IV for the San Antonio Pool. This is Run 013 with adjustments to reductions for the San Antonio Pool.

Pumping is capped at a rate of 572,000 acre-feet per year.

San Antonio Pool

Comal (cfs)	San Marcos (cfs)	J-17 (feet)	Stage -	Reduction (%)
<225	<96	<**665**	I	**30**
<200	<80	<**655**	II	**35**
<150	N/A	<**645**	III	**45**
<100	N/A	<**635**	IV	**60**

Uvalde Pool

J-27 (feet)	Stage -	Reduction (%)
-	I	0
<850	II	5
<845	III	**35**
<842	IV	**70**

Run 028

The purpose of this run is to test the sensitivity of the aquifer to combining increased triggers and increased reductions at early stages for the San Antonio Pool with increases in the water-level triggers and reductions in the Uvalde Pool. This is Run 025 for J-27 and Run 027 for J-17.

Pumping is capped at a rate of 572,000 acre-feet per year.

San Antonio Pool

Comal (cfs)	San Marcos (cfs)	J-17 (feet)	Stage -	Reduction (%)
<225	<96	<**665**	I	**30**
<200	<80	<**655**	II	**35**
<150	N/A	<**645**	III	**45**
<100	N/A	<**635**	IV	**60**

Uvalde Pool

J-27 (feet)	Stage -	Reduction (%)
< **865**	I	**10**
<**860**	II	**20**
<**855**	III	**35**
<**852**	IV	**70**

Run 029

The purpose of this run is to test the sensitivity of the aquifer to increased triggers and reductions for both the San Antonio Pool and the Uvalde Pool.

Pumping is capped at a rate of 572,000 acre-feet per year.

San Antonio Pool

Comal (cfs)	San Marcos (cfs)	J-17 (feet)	Stage -	Reduction (%)
<225	<96	<**665**	I	**20**
<200	<80	<**655**	II	**30**
<150	N/A	<**645**	III	**40**
<100	N/A	<**635**	IV	**70**

Uvalde Pool

J-27 (feet)	Stage -	Reduction (%)
< **865**	I	**20**
<**860**	II	**30**
<**855**	III	**40**
<**852**	IV	**70**

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Run Request 7

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Run 030

This run is the same as Run 029 except with 90 percent reductions at Stage IV.

Pumping is capped at a rate of 572,000 acre-feet per year.

San Antonio Pool

Comal (cfs)	San Marcos (cfs)	J-17 (feet)	Stage -	Reduction (%)
<225	<96	<**665**	I	**20**
<200	<80	<**655**	II	**30**
<150	N/A	<**645**	III	**40**
<100	N/A	<**635**	IV	**90**

Uvalde Pool

J-27 (feet)	Stage -	Reduction (%)
< **865**	I	**20**
<**860**	II	**30**
<**855**	III	**40**
<**852**	IV	**90**

Run 031

This run is the same as Run 030 except with all pumping eliminated in Comal and Hays counties at all stages to test the model's sensitivity to pumping in those counties. Pumping is capped at a rate of 572,000 acre-feet per year (minus Comal and Hays pumping).

San Antonio Pool

Comal (cfs)	San Marcos (cfs)	J-17 (feet)	Stage -	Reduction (%)
<225	<96	<**665**	I	**20**
<200	<80	<**655**	II	**30**
<150	N/A	<**645**	III	**40**
<100	N/A	<**635**	IV	**90**

Uvalde Pool

J-27 (feet)	Stage -	Reduction (%)
< **865**	I	**20**
<**860**	II	**30**
<**855**	III	**40**
<**852**	IV	**90**

Run 032

The purpose of this run is to determine, through trial and error, the maximum amount of annual permitted pumping that will allow the following criteria to be met:

Comal Springs minimum 1-month discharge = 30 cubic feet per second
Comal Springs minimum 6-month average discharge = 75 cubic feet per second
Comal Springs long-term average discharge = 225 cubic feet per second

San Marcos Springs minimum 1-month discharge = 65 cubic feet per second
San Marcos Springs minimum 6-month average discharge = 80 cubic feet per second
San Marcos Springs long-term average discharge = 140 cubic feet per second

The run should not include any critical period management, just fixed annual pumping.

Run 033

The purpose of this run is to combine runs 028 (for J-17) and 029 (for J-27) with increased reductions at Stage IV.

Pumping is capped at a rate of 572,000 acre-feet per year.

San Antonio Pool

Comal (cfs)	San Marcos (cfs)	J-17 (feet)	Stage -	Reduction (%)
<225	<96	<**665**	I	**30**
<200	<80	<**655**	II	**35**
<150	N/A	<**645**	III	**45**
<100	N/A	<**635**	IV	**80**

Uvalde Pool

J-27 (feet)	Stage -	Reduction (%)
< **865**	I	**20**
<**860**	II	**30**
<**855**	III	**40**
<**852**	IV	**80**

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Run Request 8

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Run 034

The purpose of this run is to (a) find a critical period management scenario that meets the springflow requirements and (b) use that critical period management scenario with pumping "capped" at 437,000 acre-feet per year (to reflect the maximum pumping experienced in recent history).

For part (a):

Pumping is capped at a rate of 572,000 acre-feet per year.

San Antonio Pool				
Comal (cfs)	**San Marcos (cfs)**	**J-17 (feet)**	**Stage -**	**Reduction (%)**
<225	<96	<**665**	I	**30**
<200	<80	<**655**	II	**35**
<150	N/A	<**645**	III	**45**
<100	N/A	<**635**	IV	***TBD***

Uvalde Pool		
J-27 (feet)	**Stage -**	**Reduction (%)**
< **865**	I	**30**
<**860**	II	**35**
<**855**	III	**45**
<**852**	IV	***TBD***

TBD means "to be determined" by the modeler through trial and error such that the minimum 6-month average for San Marcos Springs (80 cubic feet per minute) can be met.

Because we are not convinced that the minimum 6-month average for San Marcos Springs can be met with this run, please first run Stage IV with a 100 percent reduction. If the minimum 6-month average for San Marcos Springs is not met with this reduction (in other words, the minimum 6-month average is less than 80 cubic feet per second), then please contact the expert science subcommittee as soon as possible and await further instructions.

If the minimum 6-month average for San Marcos is greater than the springflow requirement (in other words, greater than 80 cubic feet per second), then please refine, through trial and error, the minimum percent reduction (rounded to the whole percentage point) required to meet the minimum 6-month average for San Marcos. If, once you have this reduction number, any of the other flow criteria are not met, then please notify the

expert science subcommittee and await further instruction. Once completed, please write the report and submit it for review to your management as soon as possible. Once you submit the report to your management, you are ready to immediately work on part (b).

To address part (b), we need to "cap" pumping at 437,000 acre-feet per year and calculate reductions for each stage that is equivalent to the amount of pumping allowed in part (a):

Stage -	Part (a) Reduction (%)	Part (a) Pumping (AFY)	Equivalent Part (b) Reduction (%)
I	**30**	**400,400**	**8.38**
II	**35**	**371,800**	**14.92**
III	**45**	**314,600**	**28**
IV	***TBD***	***X***	***Y***

where

$$X = 572{,}000\left(\frac{100 - TBD}{100}\right)$$

and

$$Y = 100\left(\frac{437{,}000 - X}{437{,}000}\right)$$

Therefore, the run for part (b) is:

Pumping is capped at a rate of 437,000 acre-feet per year.

San Antonio Pool

Comal (cfs)	San Marcos (cfs)	J-17 (feet)	Stage -	Reduction (%)
<225	<96	<**665**	I	**8.38**
<200	<80	<**655**	II	**14.92**
<150	N/A	<**645**	III	**28**
<100	N/A	<**635**	IV	***Y***

Uvalde Pool

J-27 (feet)	Stage -	Reduction (%)
< **865**	I	**8.38**
<**860**	II	**14.92**
<**855**	III	**28**
<**852**	IV	***Y***

Once completed, please write the report and submit it for review to your management as soon as possible.

Run 035

Removal of Stage IV and adjustments in pumping reductions for stages I, II, and III for the San Antonio and Uvalde pools and adjustments in J-17 and J-27 triggers for stages I, II, and III (maximum 100 percent reduction in pumping for the San Antonio Pool and maximum 100 percent reduction in pumping for the Uvalde Pool).

Run 036

Removal of stages III and IV and adjustments in pumping reductions for stages I and II for the San Antonio and Uvalde pools and adjustments in J-17 and J-27 triggers for stages I and II (maximum 100 percent reduction in pumping for the San Antonio Pool and maximum 100 percent reduction in pumping for the Uvalde Pool).

Run 037

Removal of stages II, III, and IV and adjustments in pumping reductions for Stage I for the San Antonio and Uvalde pools and adjustments in J-17 and J-27 triggers for Stage I (maximum 100 percent reduction in pumping for the San Antonio Pool and maximum 100 percent reduction in pumping for the Uvalde Pool).

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Run Request 9

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Run 035

The purpose of this run is to identify the pumping reduction required to meet a minimum average 6-month springflow requirement for San Marcos Springs of 75 cubic feet per second.

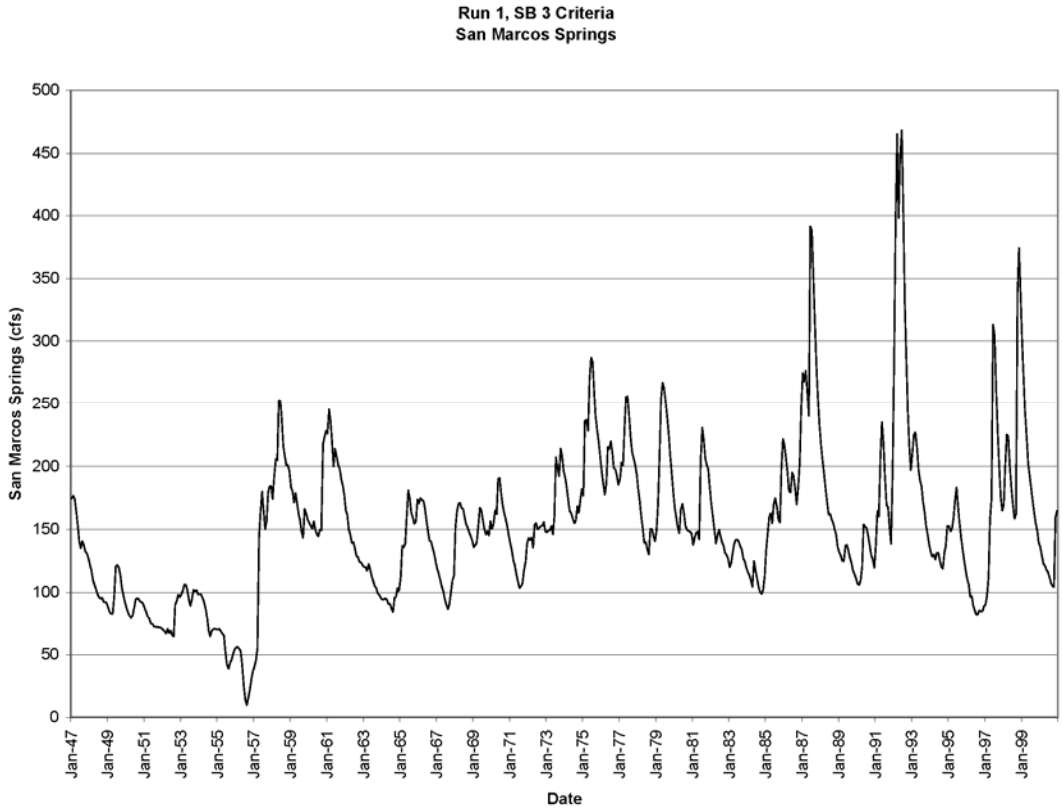
Pumping is capped at a rate of 572,000 acre-feet per year. There is only one stage:

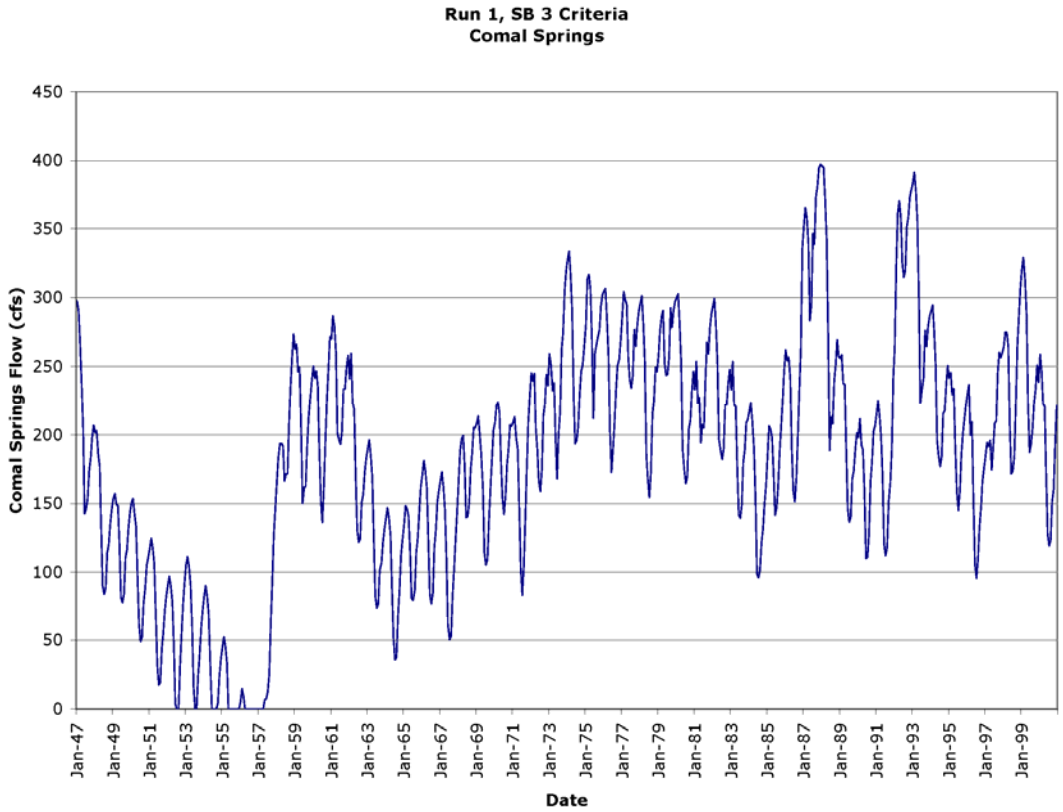
San Antonio Pool				
Comal (cfs)	**San Marcos (cfs)**	**J-17 (feet)**	**Stage -**	**Reduction (%)**
<225	<96	<**665**	I	**X**

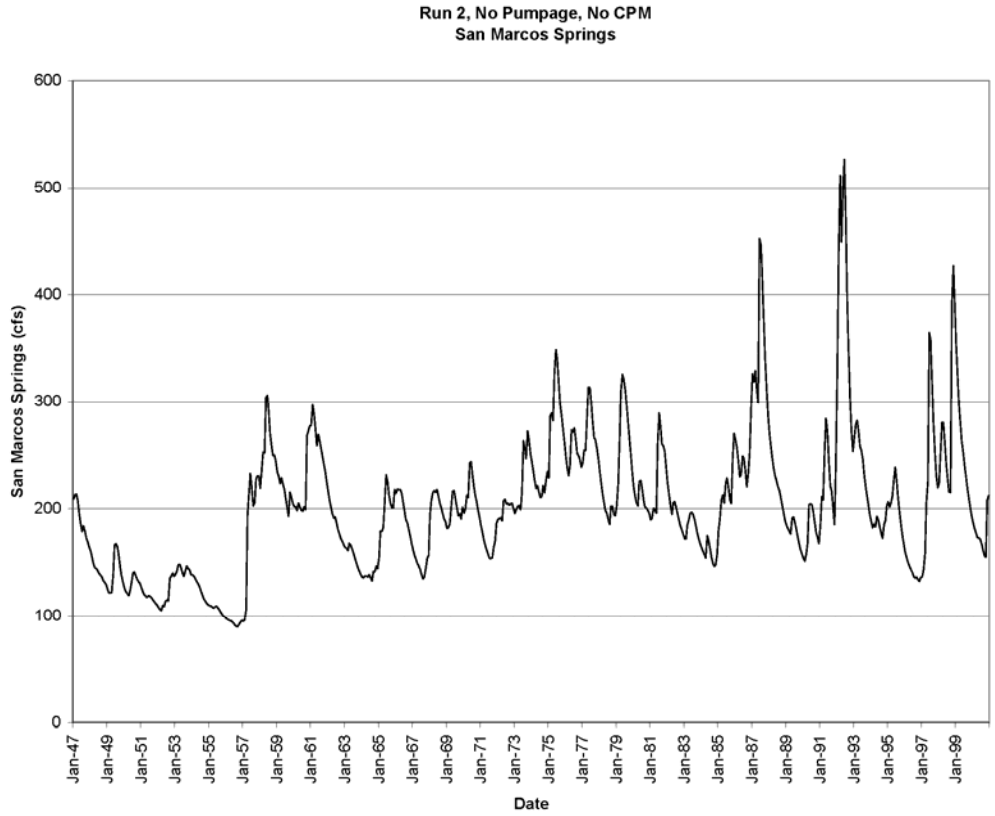
Uvalde Pool		
J-27 (feet)	**Stage -**	**Reduction (%)**
< **865**	I	**X**

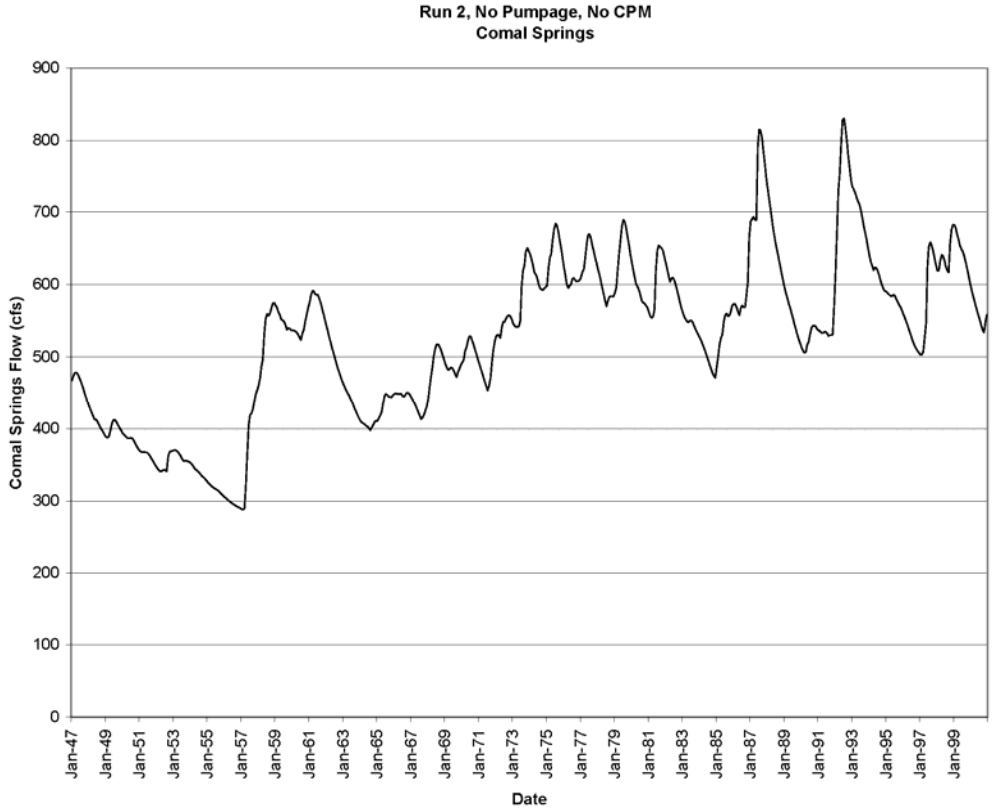
where **X** is the pumping reduction required to meet a minimum average six-month springflow requirement for San Marcos Springs of 75 cubic feet per second. Based on previous runs, we believe **X** is in the vicinity of 86 percent.

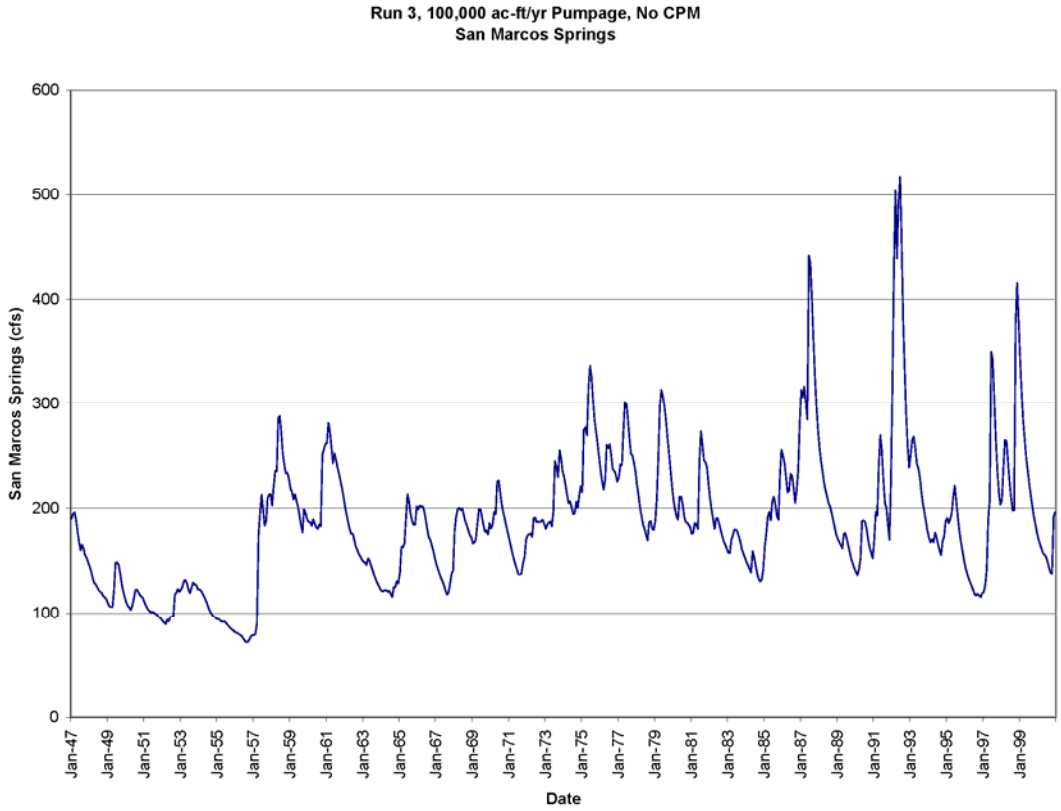
Appendix G. Plots of springflows from the Edwards Aquifer model runs

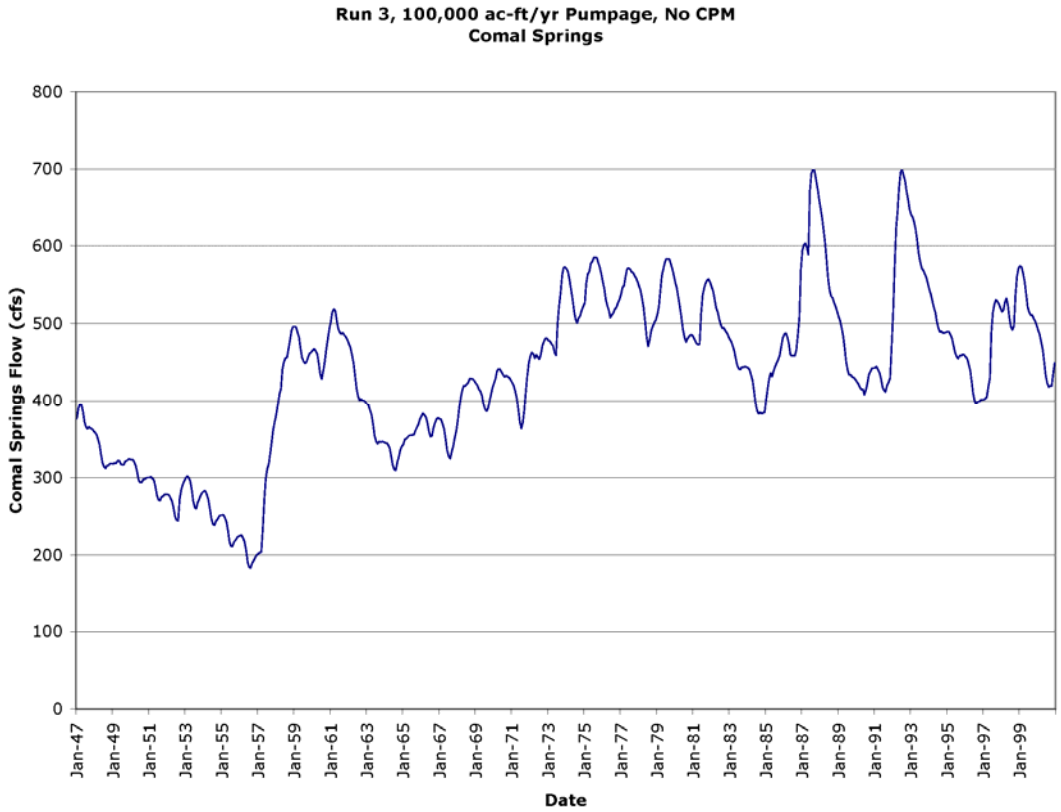

Run 1, SB 3 Criteria
San Marcos Springs
San Marcos Springs (cfs)
Date

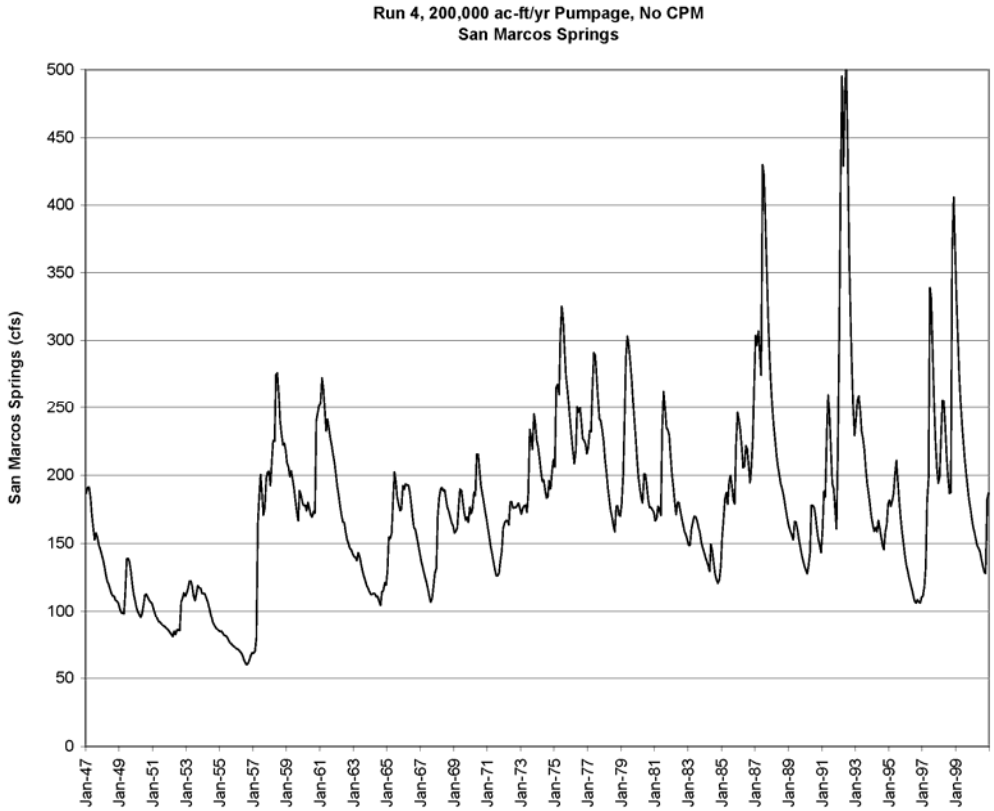

Run 1, SB 3 Criteria
Comal Springs
Comal Springs Flow (cfs)
Date

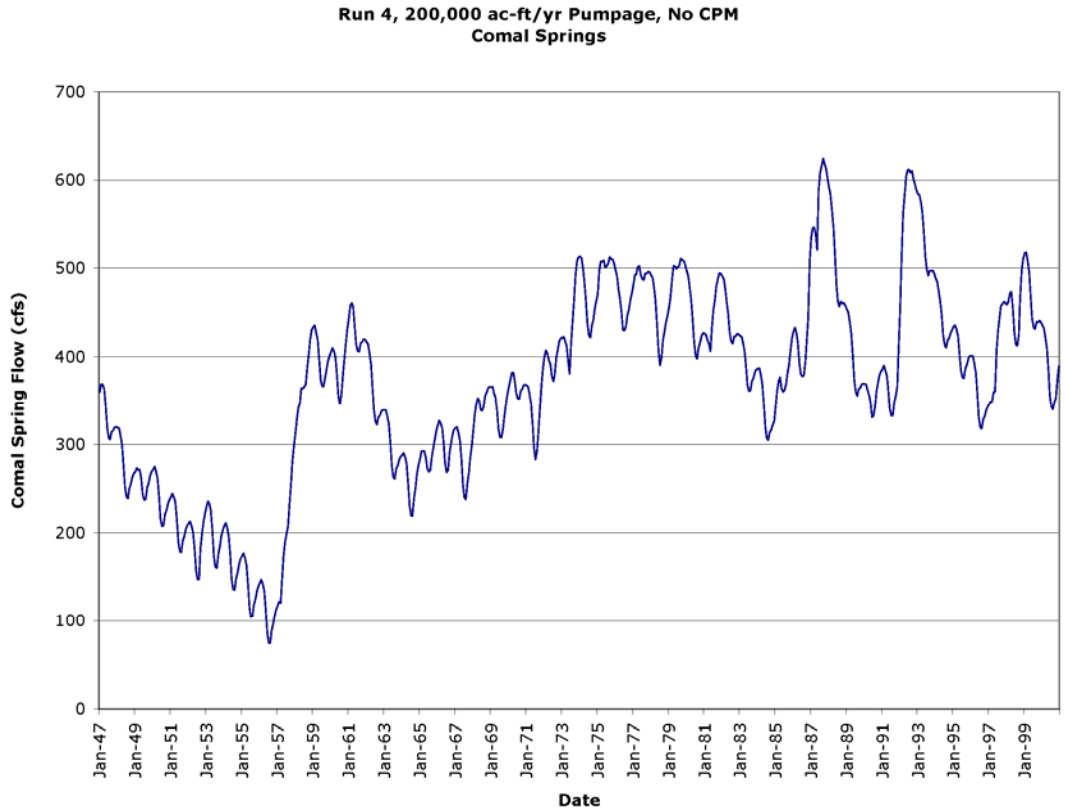

Run 2, No Pumpage, No CPM
San Marcos Springs
San Marcos Springs (cfs)
0
100
200
300
400
500
600
Jan-47
Jan-49
Jan-51
Jan-53
Jan-55
Jan-57
Jan-59
Jan-61
Jan-63
Jan-65
Jan-67
Jan-69
Jan-71
Jan-73
Jan-75
Jan-77
Jan-79
Jan-81
Jan-83
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Date

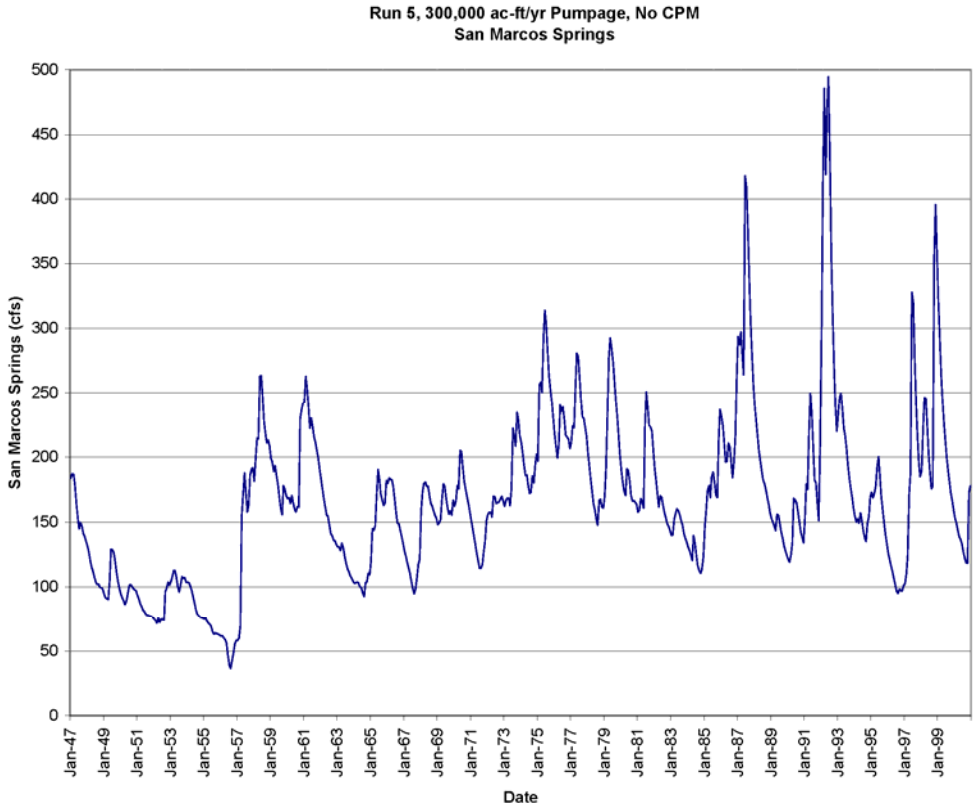

Run 2, No Pumpage, No CPM
Comal Springs
Comal Springs Flow (cfs)
0
100
200
300
400
500
600
700
800
900
Jan-47
Jan-49
Jan-51
Jan-53
Jan-55
Jan-57
Jan-59
Jan-61
Jan-63
Jan-65
Jan-67
Jan-69
Jan-71
Jan-73
Jan-75
Jan-77
Jan-79
Jan-81
Jan-83
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Date

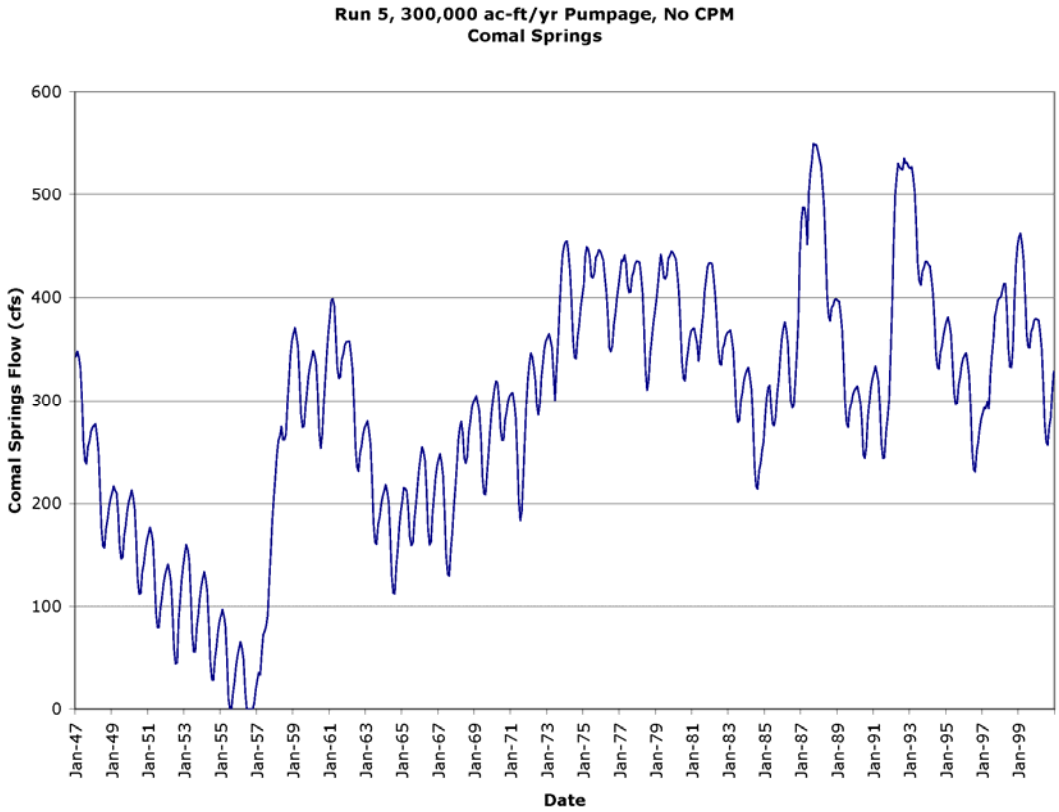

Run 3, 100,000 ac-ft/yr Pumpage, No CPM
San Marcos Springs
San Marcos Springs (cfs)
0
100
200
300
400
500
600
Jan-47
Jan-49
Jan-51
Jan-53
Jan-55
Jan-57
Jan-59
Jan-61
Jan-63
Jan-65
Jan-67
Jan-69
Jan-71
Jan-73
Jan-75
Jan-77
Jan-79
Jan-81
Jan-83
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Date

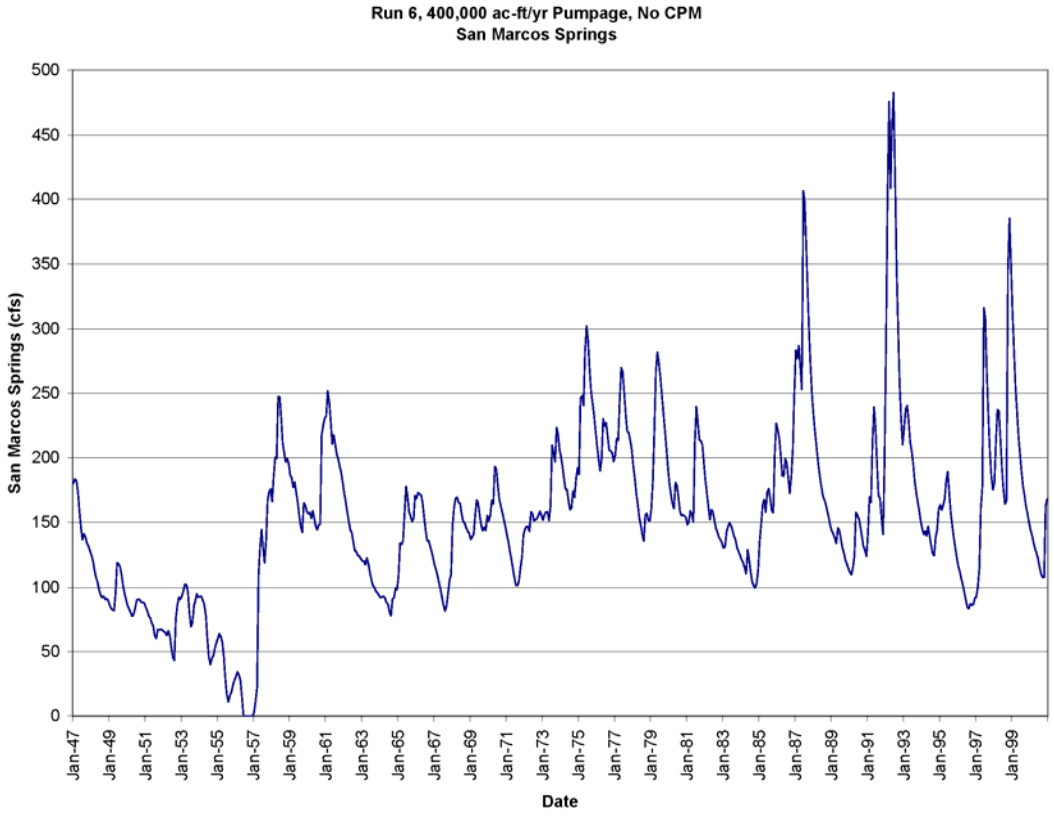

Run 3, 100,000 ac-ft/yr Pumpage, No CPM
Comal Springs
Comal Springs Flow (cfs)
0
100
200
300
400
500
600
700
800
Jan-47
Jan-49
Jan-51
Jan-53
Jan-55
Jan-57
Jan-59
Jan-61
Jan-63
Jan-65
Jan-67
Jan-69
Jan-71
Jan-73
Jan-75
Jan-77
Jan-79
Jan-81
Jan-83
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Date

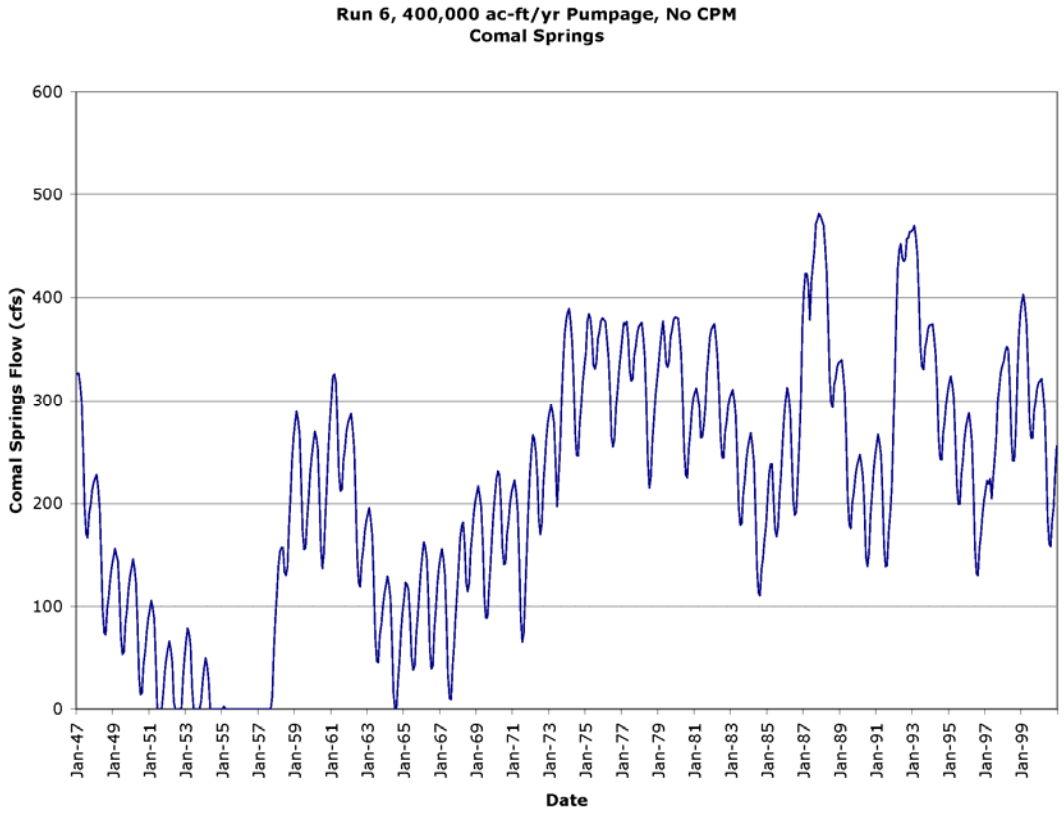

Run 4, 200,000 ac-ft/yr Pumpage, No CPM
San Marcos Springs
San Marcos Springs (cfs)
0
50
100
150
200
250
300
350
400
450
500
Jan-47
Jan-49
Jan-51
Jan-53
Jan-55
Jan-57
Jan-59
Jan-61
Jan-63
Jan-65
Jan-67
Jan-69
Jan-71
Jan-73
Jan-75
Jan-77
Jan-79
Jan-81
Jan-83
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99

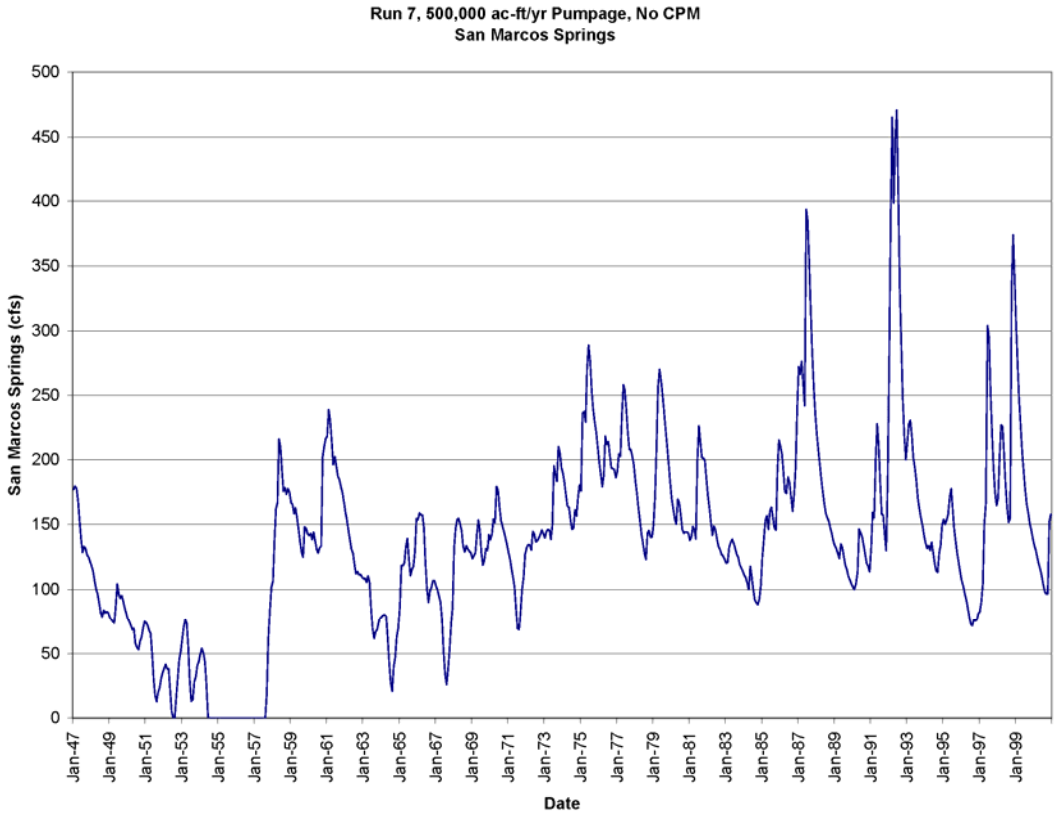

Run 4, 200,000 ac-ft/yr Pumpage, No CPM
Comal Springs
Comal Spring Flow (cfs)
0
100
200
300
400
500
600
700
Jan-47
Jan-49
Jan-51
Jan-53
Jan-55
Jan-57
Jan-59
Jan-61
Jan-63
Jan-65
Jan-67
Jan-69
Jan-71
Jan-73
Jan-75
Jan-77
Jan-79
Jan-81
Jan-83
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Date

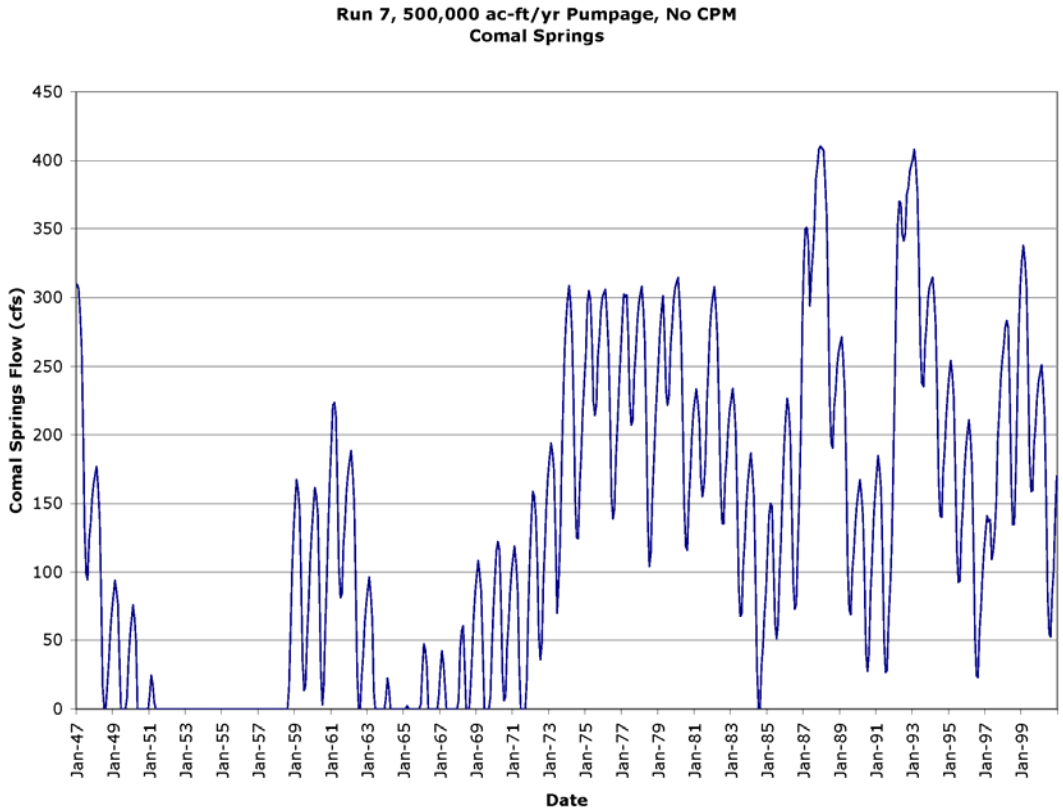

Run 5, 300,000 ac-ft/yr Pumpage, No CPM
San Marcos Springs
San Marcos Springs (cfs)
Date

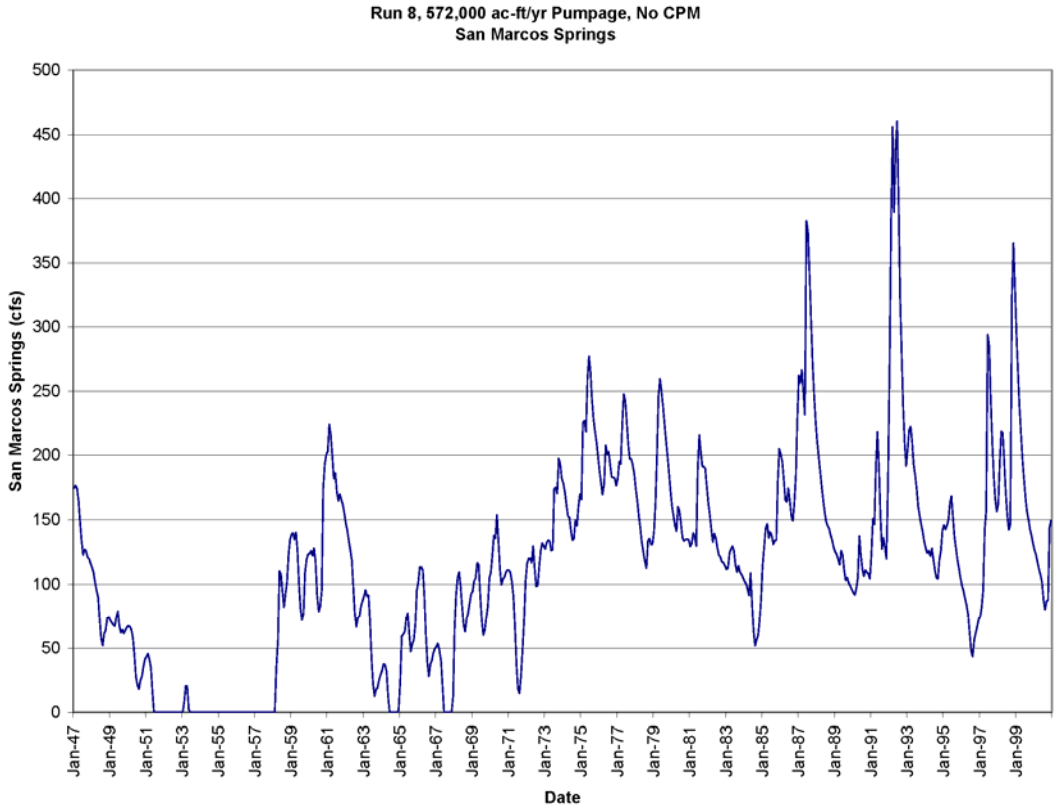

Run 5, 300,000 ac-ft/yr Pumpage, No CPM
Comal Springs
Comal Springs Flow (cfs)
Date

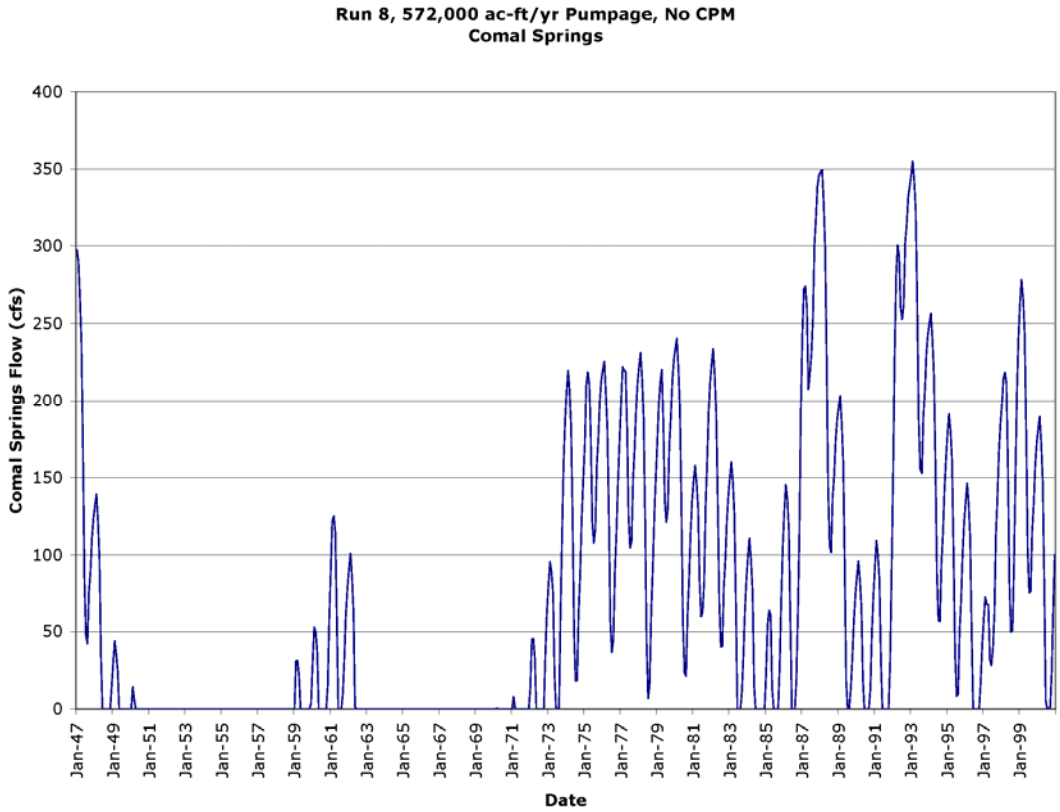

Run 6, 400,000 ac-ft/yr Pumpage, No CPM
San Marcos Springs
San Marcos Springs (cfs)
Date

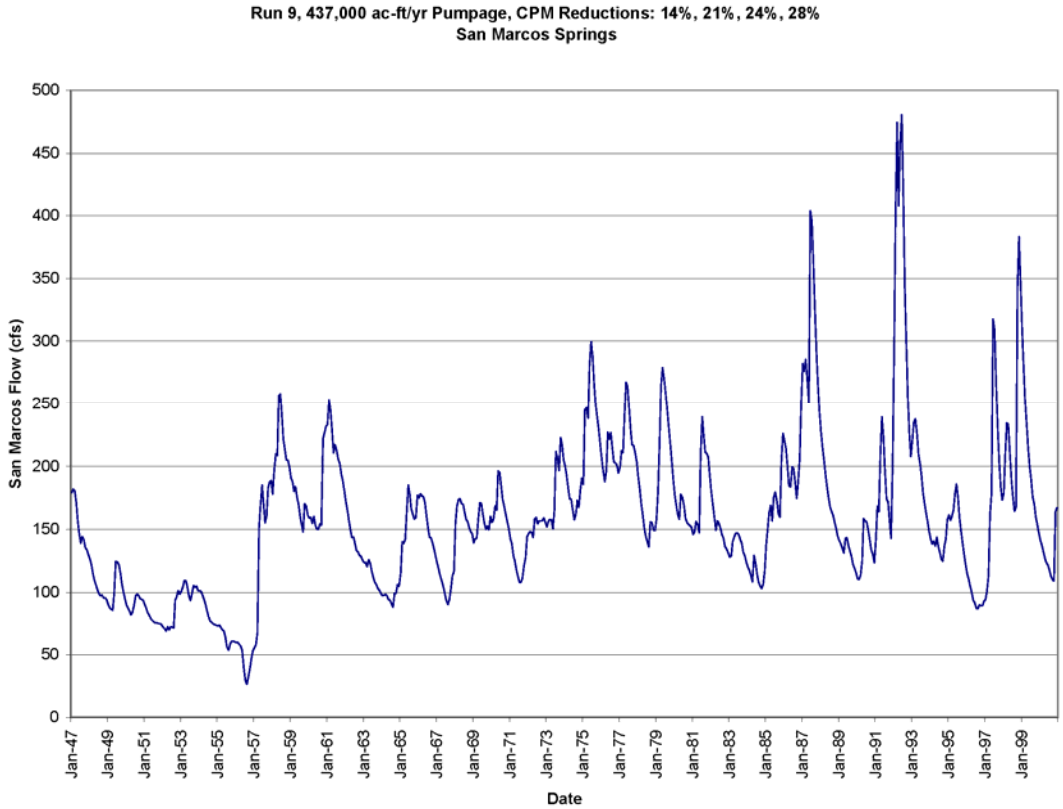

Run 6, 400,000 ac-ft/yr Pumpage, No CPM
Comal Springs
Comal Springs Flow (cfs)
Date

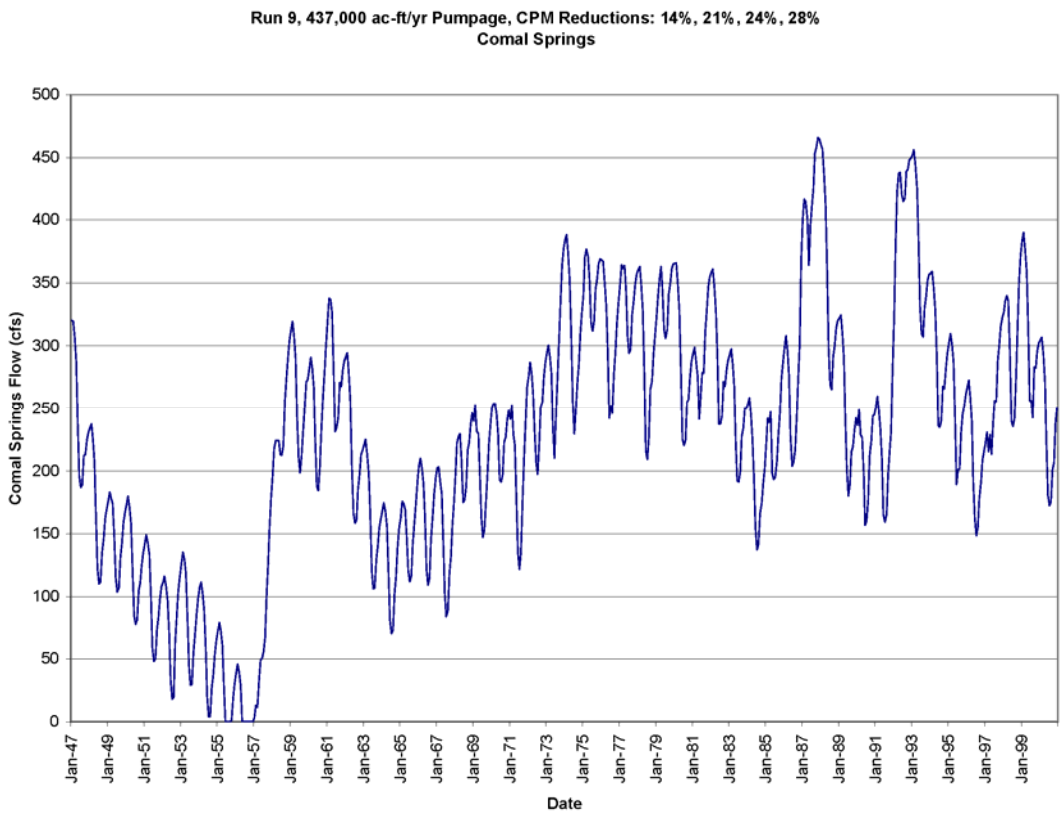

Run 7, 500,000 ac-ft/yr Pumpage, No CPM
San Marcos Springs
San Marcos Springs (cfs)
Date

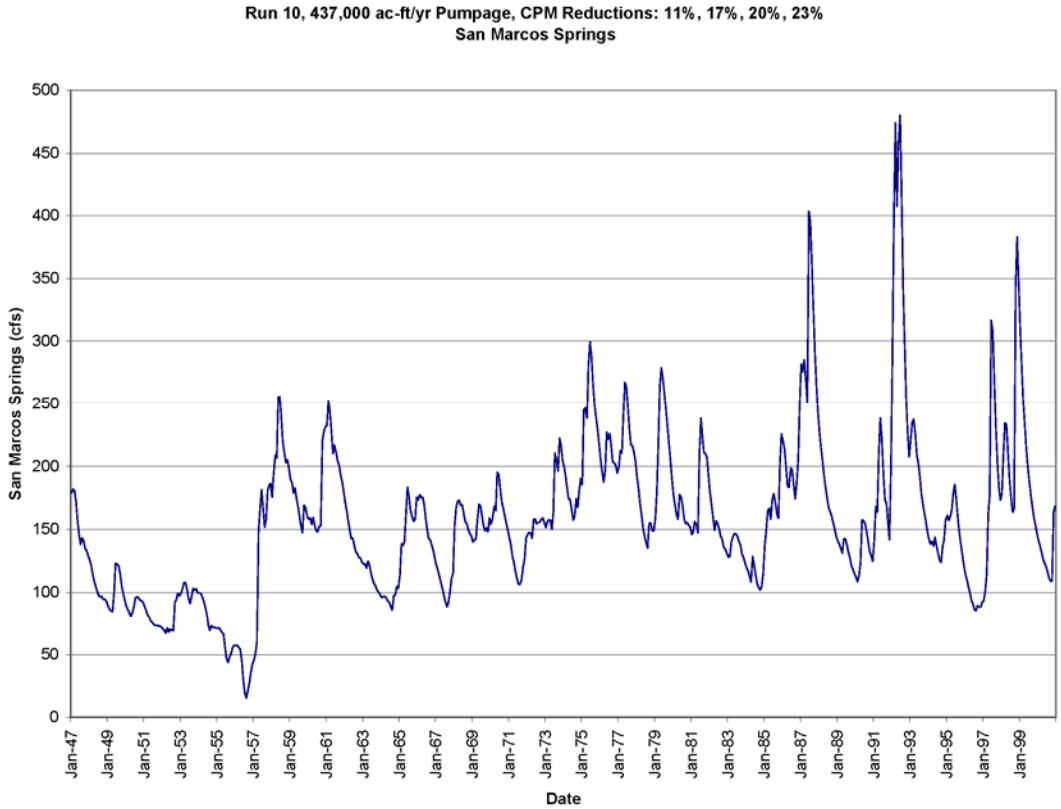

Run 7, 500,000 ac-ft/yr Pumpage, No CPM
Comal Springs
Comal Springs Flow (cfs)
Date

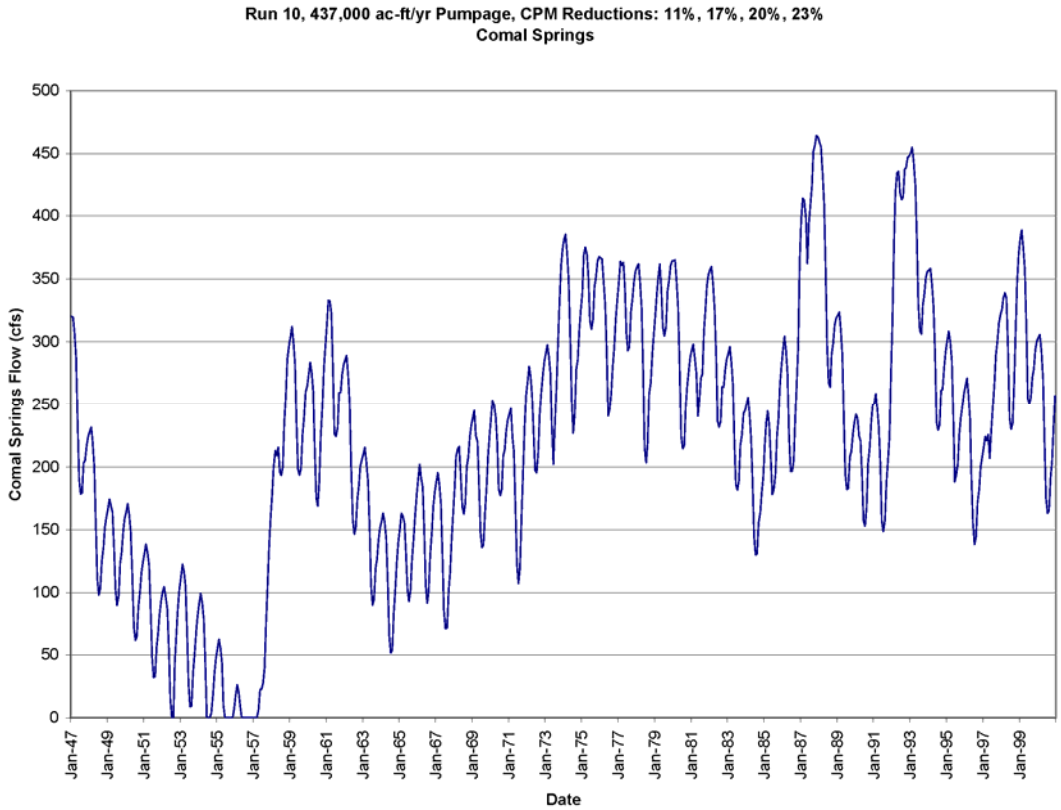

Run 8, 572,000 ac-ft/yr Pumpage, No CPM
San Marcos Springs
San Marcos Springs (cfs)
Date

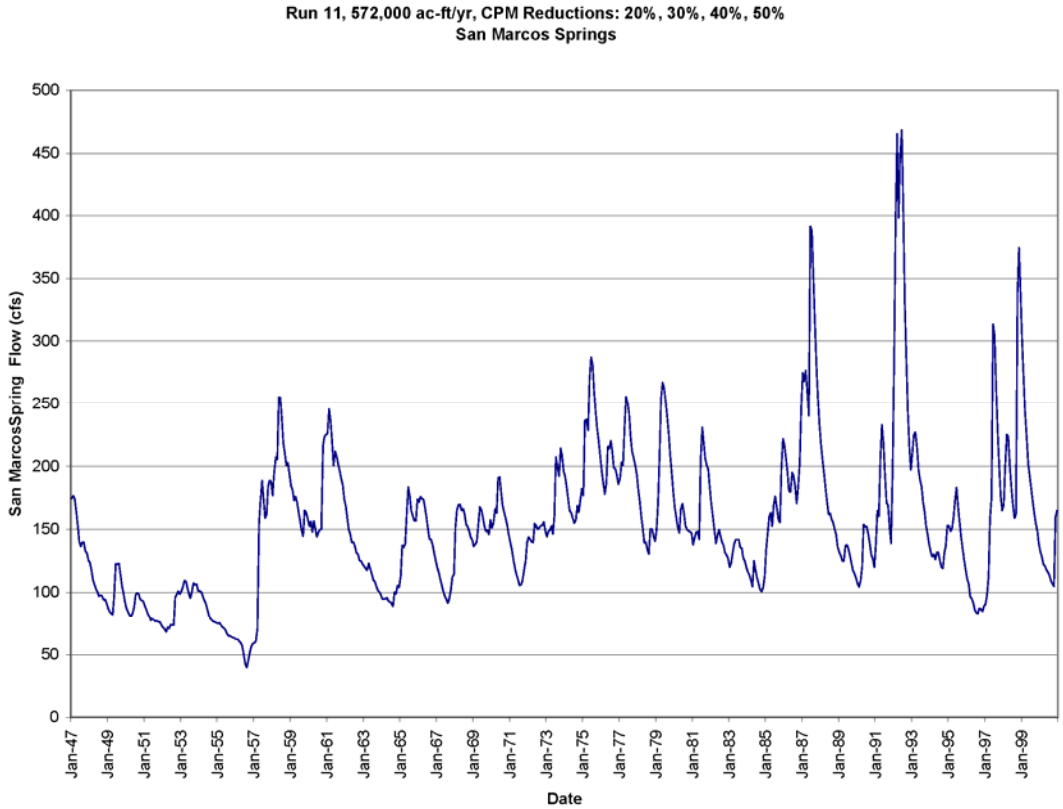

Run 8, 572,000 ac-ft/yr Pumpage, No CPM
Comal Springs
Comal Springs Flow (cfs)
Date

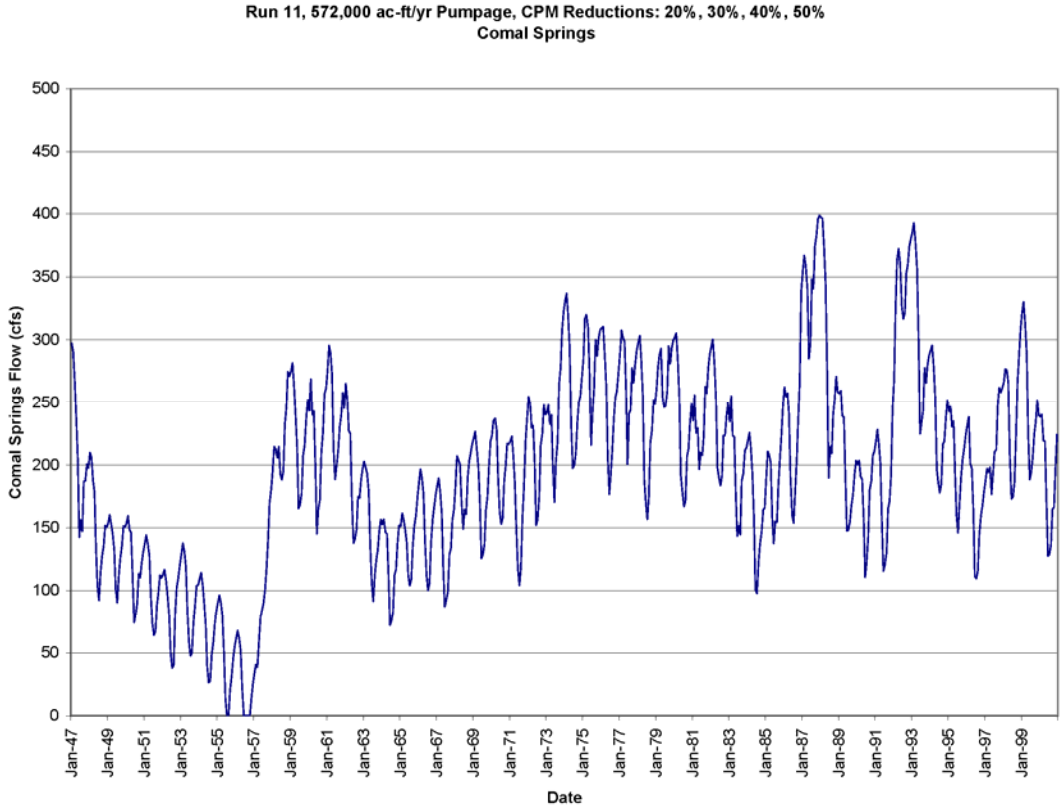

Run 9, 437,000 ac-ft/yr Pumpage, CPM Reductions: 14%, 21%, 24%, 28%
San Marcos Springs
San Marcos Flow (cfs)
Date

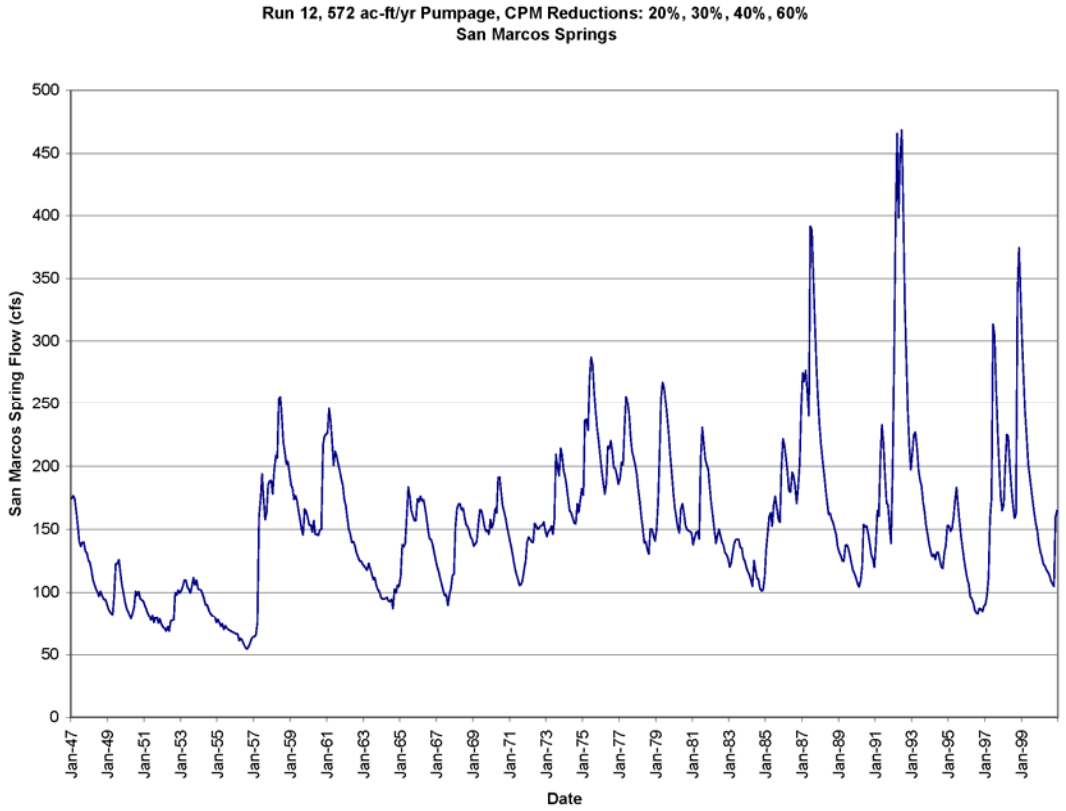

Run 9, 437,000 ac-ft/yr Pumpage, CPM Reductions: 14%, 21%, 24%, 28%
Comal Springs
Comal Springs Flow (cfs)
Date

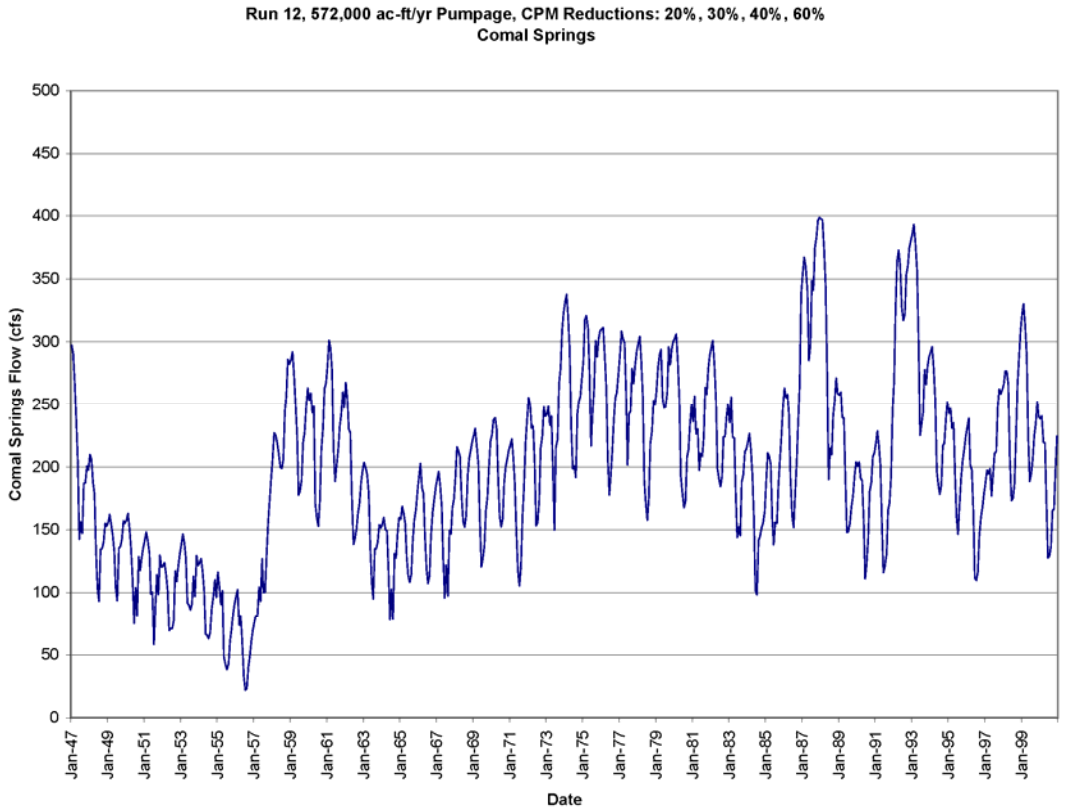

Run 10, 437,000 ac-ft/yr Pumpage, CPM Reductions: 11%, 17%, 20%, 23%
San Marcos Springs
San Marcos Springs (cfs)
Date

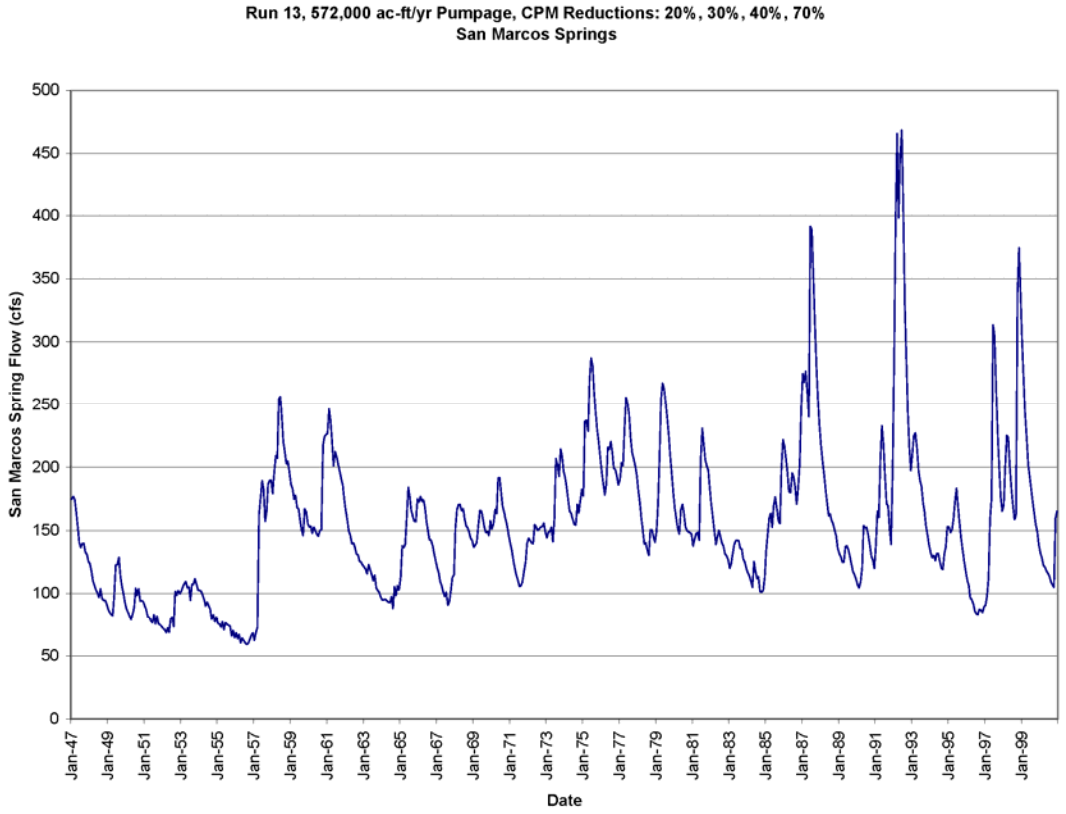

Run 10, 437,000 ac-ft/yr Pumpage, CPM Reductions: 11%, 17%, 20%, 23%
Comal Springs
Comal Springs Flow (cfs)
Date

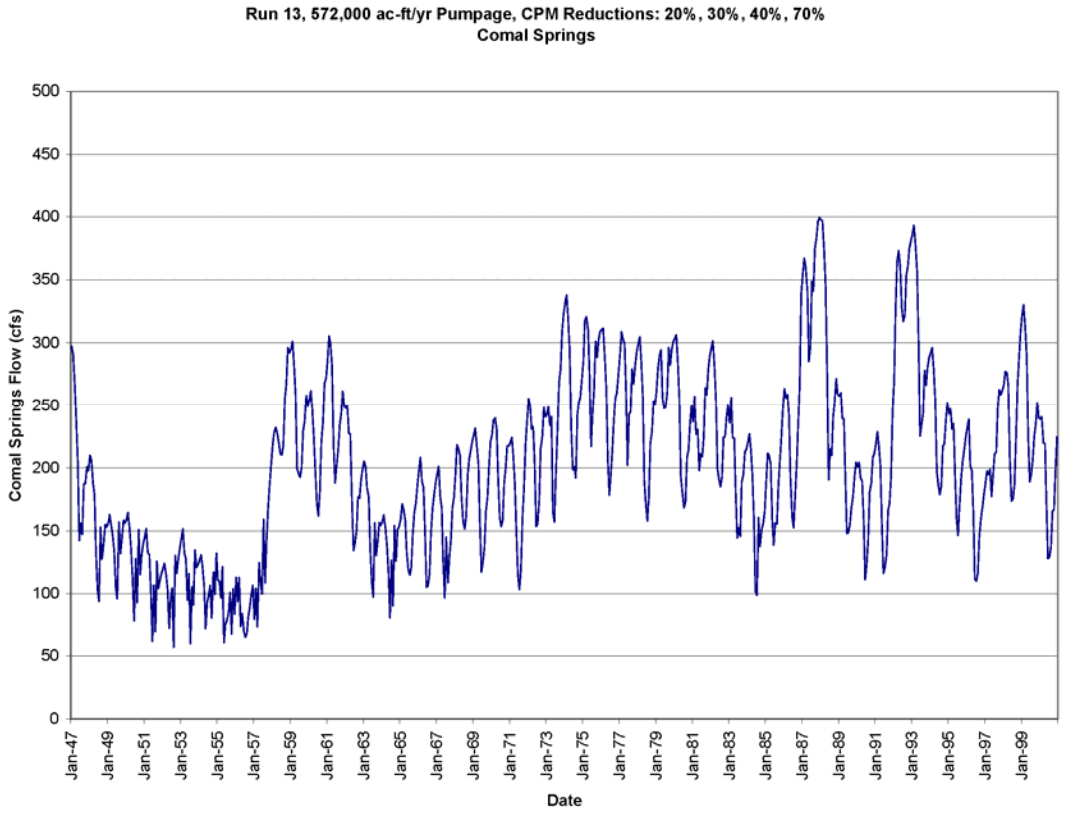

Run 11, 572,000 ac-ft/yr, CPM Reductions: 20%, 30%, 40%, 50%
San Marcos Springs
San MarcosSpring Flow (cfs)
Date

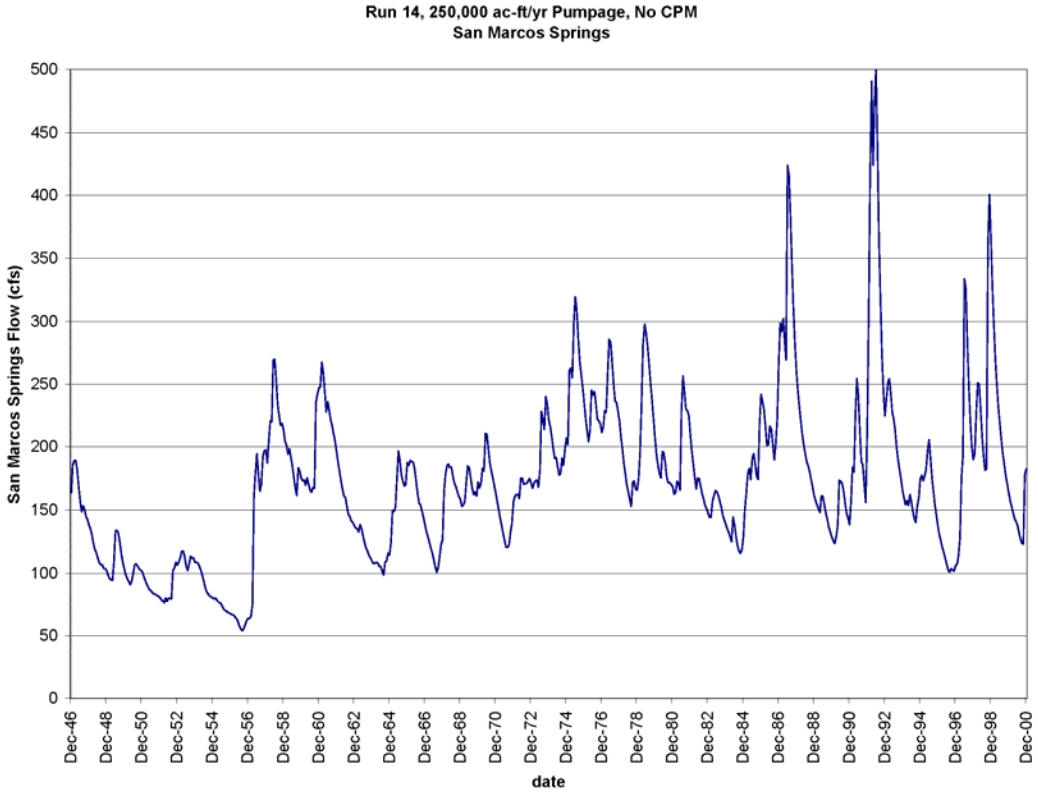

Run 11, 572,000 ac-ft/yr Pumpage, CPM Reductions: 20%, 30%, 40%, 50%
Comal Springs
Comal Springs Flow (cfs)
Date

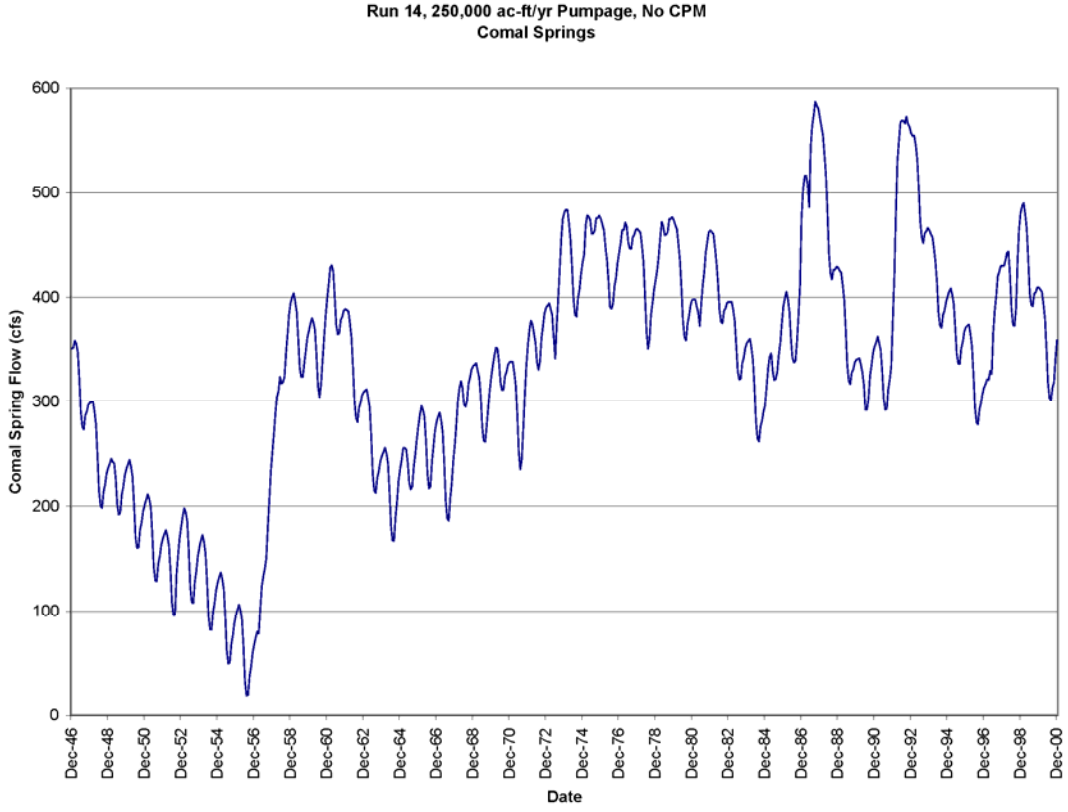

Run 12, 572 ac-ft/yr Pumpage, CPM Reductions: 20%, 30%, 40%, 60%
San Marcos Springs
San Marcos Spring Flow (cfs)
Date

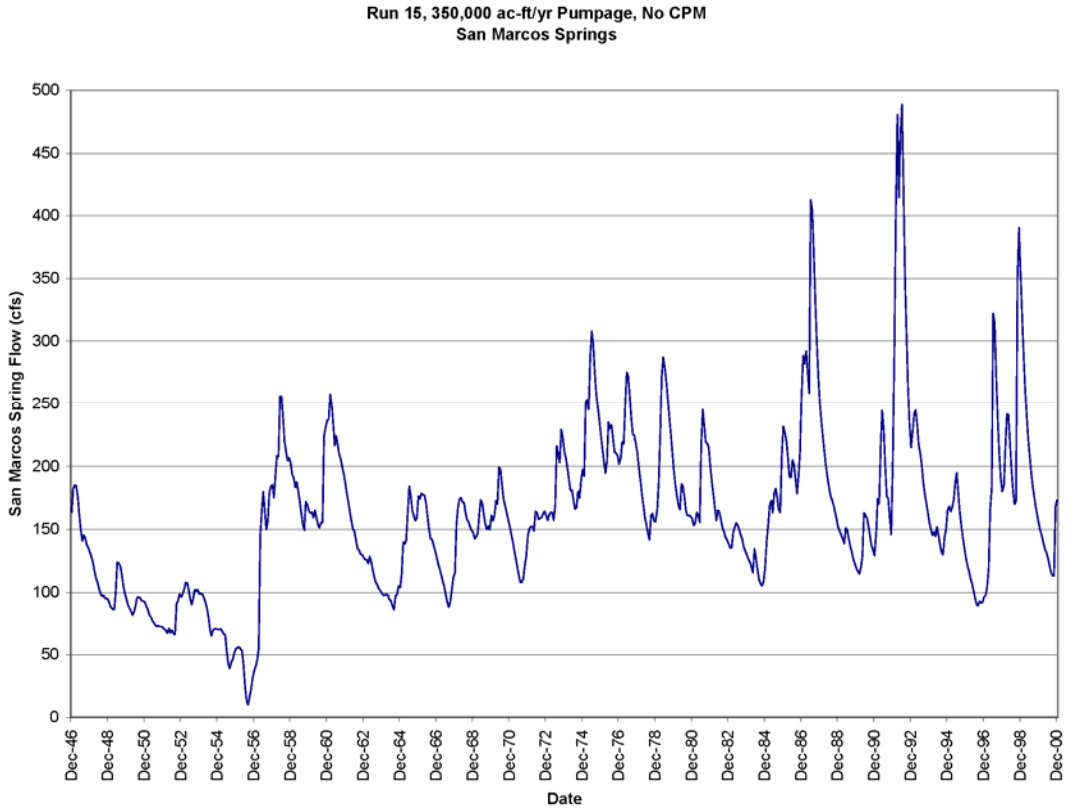

Run 12, 572,000 ac-ft/yr Pumpage, CPM Reductions: 20%, 30%, 40%, 60%
Comal Springs
Comal Springs Flow (cfs)
Date

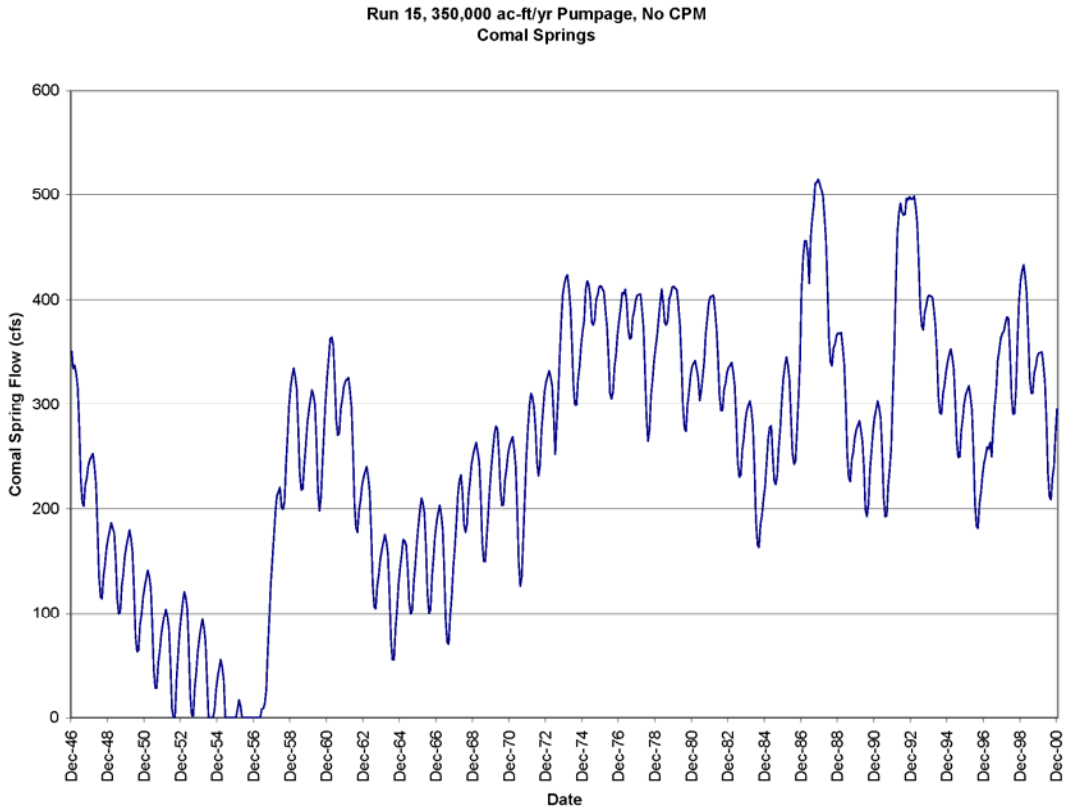

Run 13, 572,000 ac-ft/yr Pumpage, CPM Reductions: 20%, 30%, 40%, 70%
San Marcos Springs
San Marcos Spring Flow (cfs)
0
50
100
150
200
250
300
350
400
450
500
Jan-47
Jan-49
Jan-51
Jan-53
Jan-55
Jan-57
Jan-59
Jan-61
Jan-63
Jan-65
Jan-67
Jan-69
Jan-71
Jan-73
Jan-75
Jan-77
Jan-79
Jan-81
Jan-83
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Date

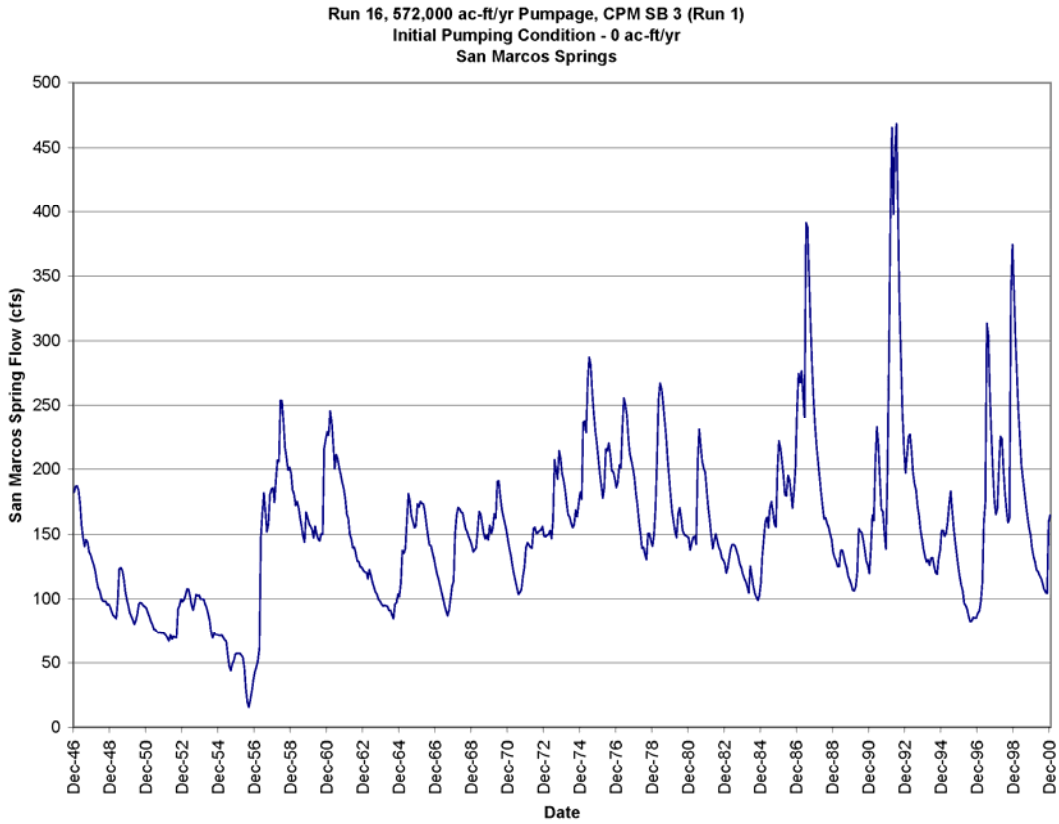

Run 13, 572,000 ac-ft/yr Pumpage, CPM Reductions: 20%, 30%, 40%, 70%
Comal Springs
Comal Springs Flow (cfs)
0
50
100
150
200
250
300
350
400
450
500
Jan-47
Jan-49
Jan-51
Jan-53
Jan-55
Jan-57
Jan-59
Jan-61
Jan-63
Jan-65
Jan-67
Jan-69
Jan-71
Jan-73
Jan-75
Jan-77
Jan-79
Jan-81
Jan-83
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Date

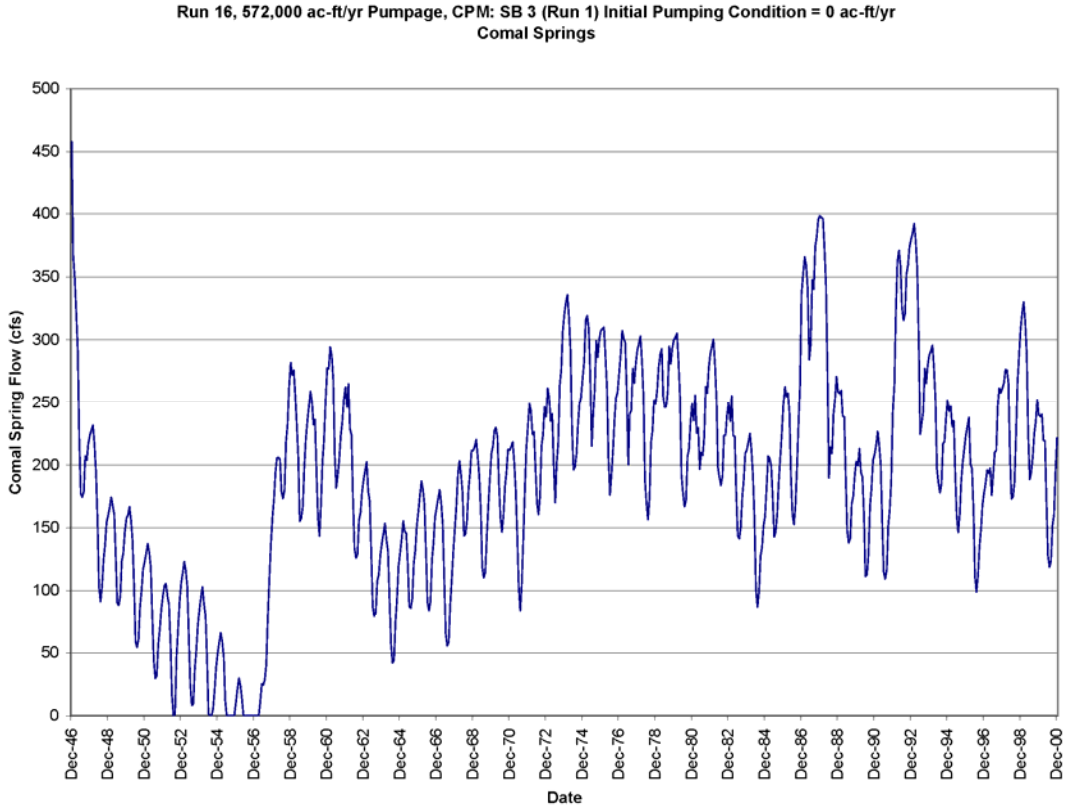

Run 14, 250,000 ac-ft/yr Pumpage, No CPM
San Marcos Springs
San Marcos Springs Flow (cfs)
date

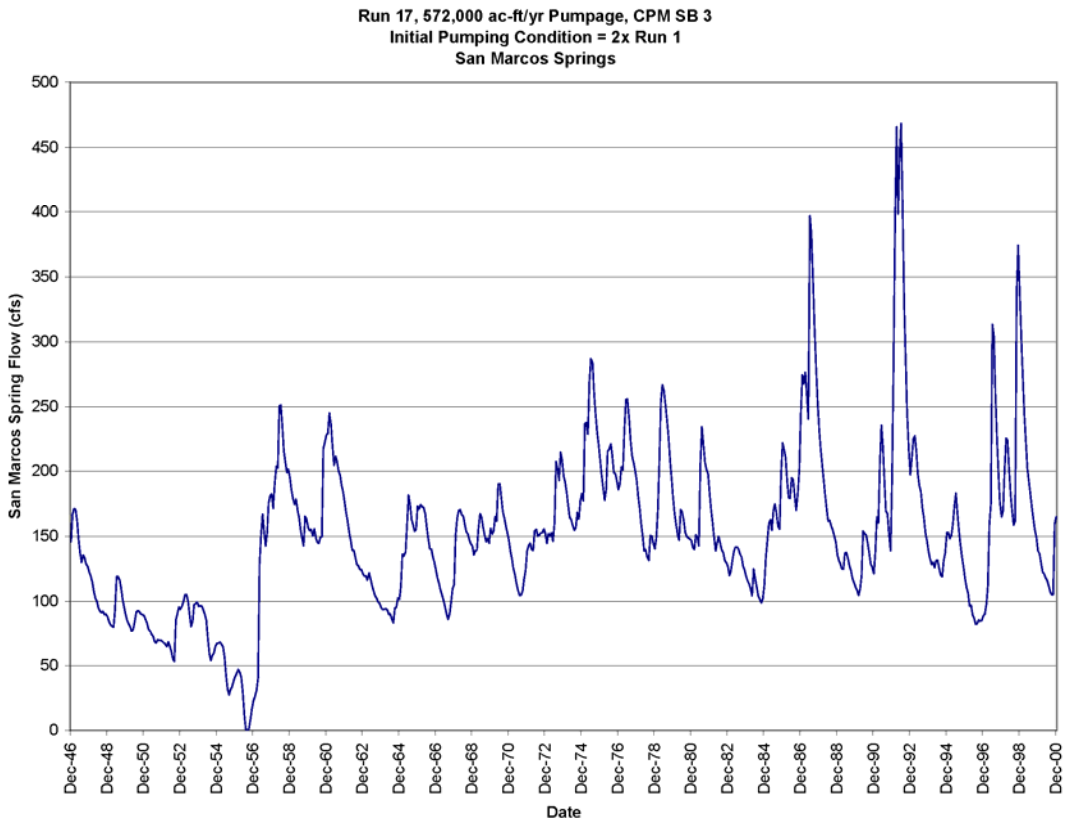

Run 14, 250,000 ac-ft/yr Pumpage, No CPM
Comal Springs
Comal Spring Flow (cfs)
Date

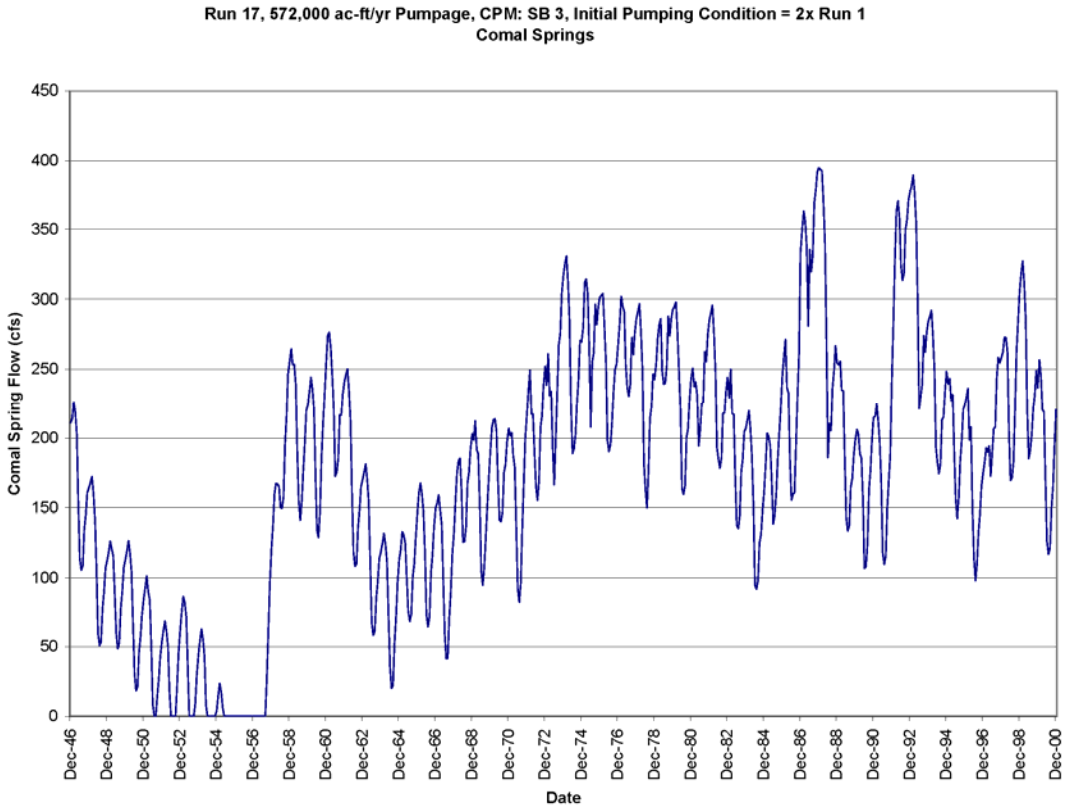

Run 15, 350,000 ac-ft/yr Pumpage, No CPM
San Marcos Springs
San Marcos Spring Flow (cfs)
0
50
100
150
200
250
300
350
400
450
500
Dec-46
Dec-48
Dec-50
Dec-52
Dec-54
Dec-56
Dec-58
Dec-60
Dec-62
Dec-64
Dec-66
Dec-68
Dec-70
Dec-72
Dec-74
Dec-76
Dec-78
Dec-80
Dec-82
Dec-84
Dec-86
Dec-88
Dec-90
Dec-92
Dec-94
Dec-96
Dec-98
Dec-00
Date

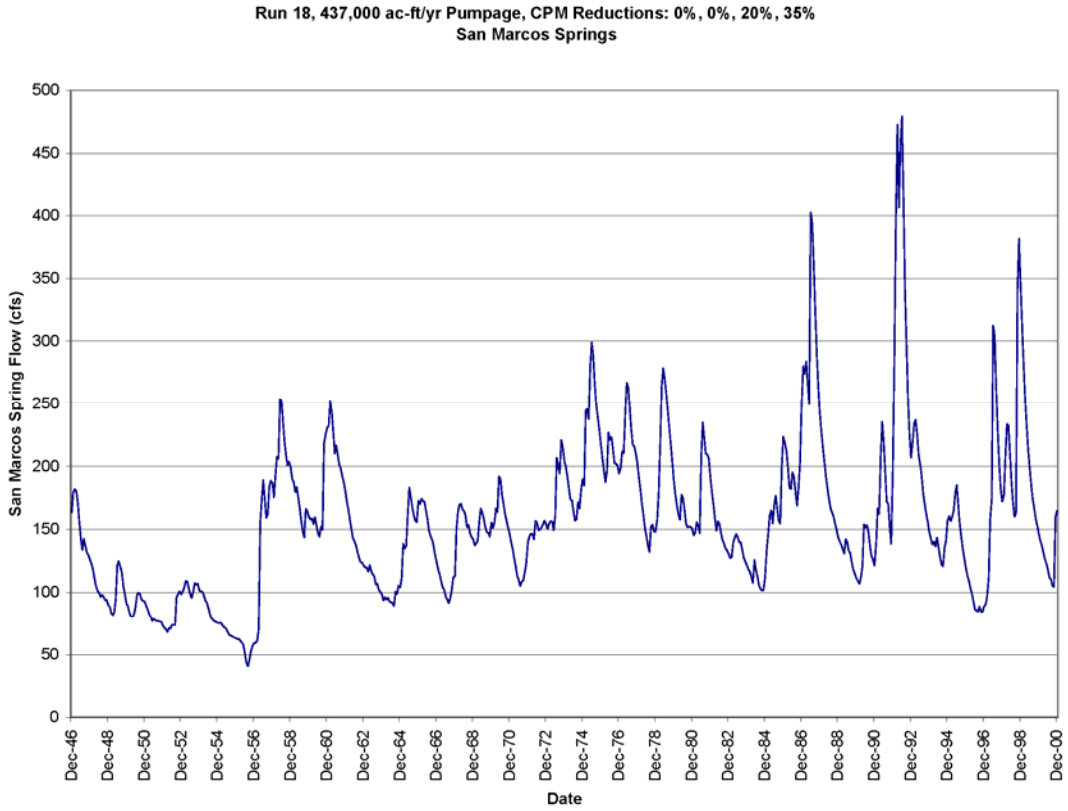

Run 15, 350,000 ac-ft/yr Pumpage, No CPM
Comal Springs
Comal Spring Flow (cfs)
0
100
200
300
400
500
600
Dec-46
Dec-48
Dec-50
Dec-52
Dec-54
Dec-56
Dec-58
Dec-60
Dec-62
Dec-64
Dec-66
Dec-68
Dec-70
Dec-72
Dec-74
Dec-76
Dec-78
Dec-80
Dec-82
Dec-84
Dec-86
Dec-88
Dec-90
Dec-92
Dec-94
Dec-96
Dec-98
Dec-00
Date

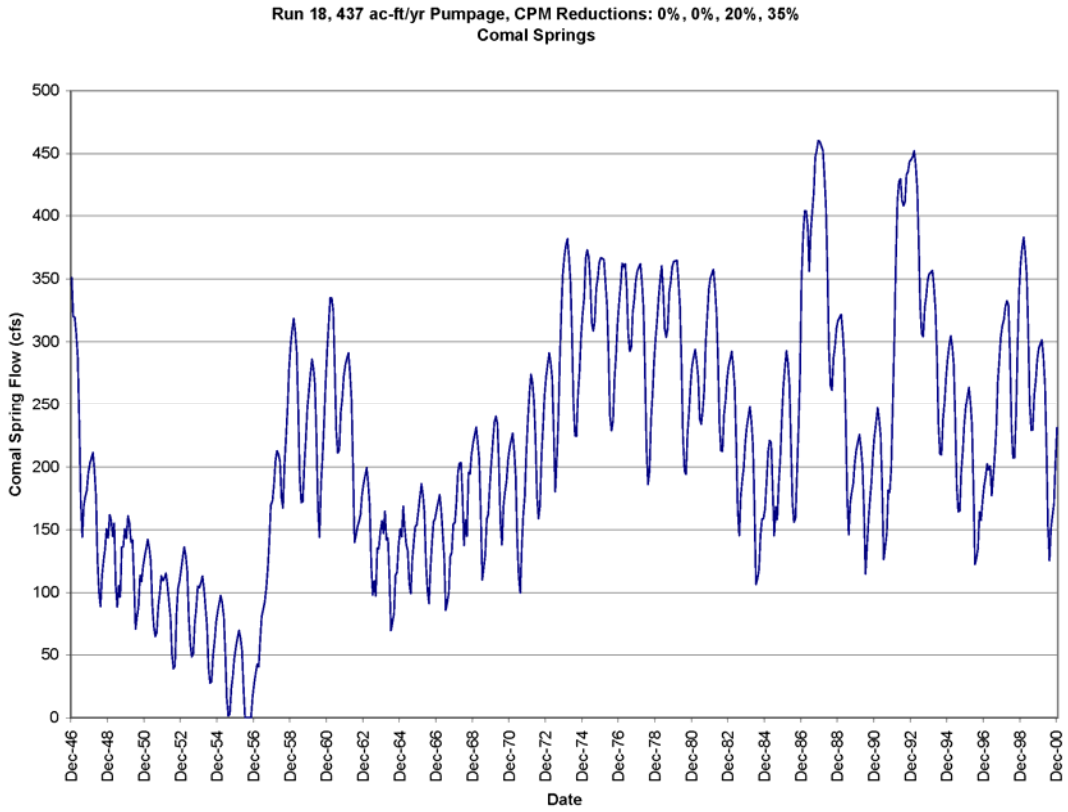

Run 16, 572,000 ac-ft/yr Pumpage, CPM SB 3 (Run 1)
Initial Pumping Condition - 0 ac-ft/yr
San Marcos Springs
San Marcos Spring Flow (cfs)
Date

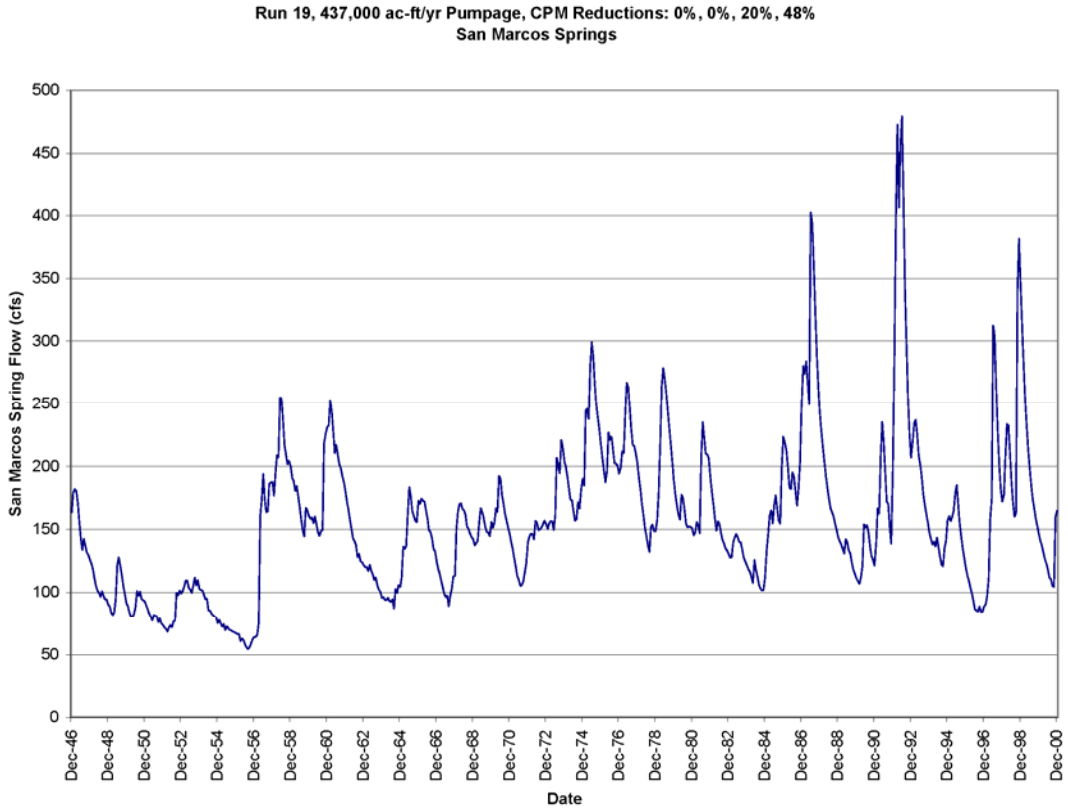

Run 16, 572,000 ac-ft/yr Pumpage, CPM: SB 3 (Run 1) Initial Pumping Condition = 0 ac-ft/yr
Comal Springs
Comal Spring Flow (cfs)
Date

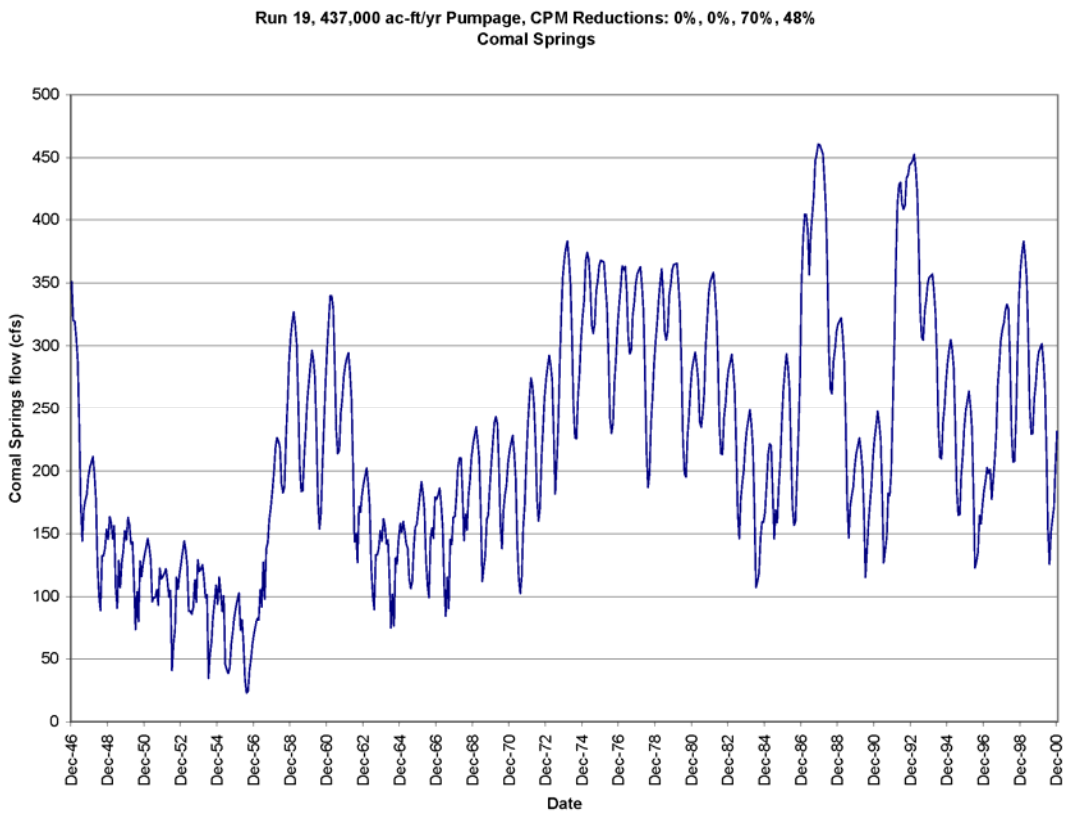

Run 17, 572,000 ac-ft/yr Pumpage, CPM SB 3
Initial Pumping Condition = 2x Run 1
San Marcos Springs
San Marcos Spring Flow (cfs)
Date

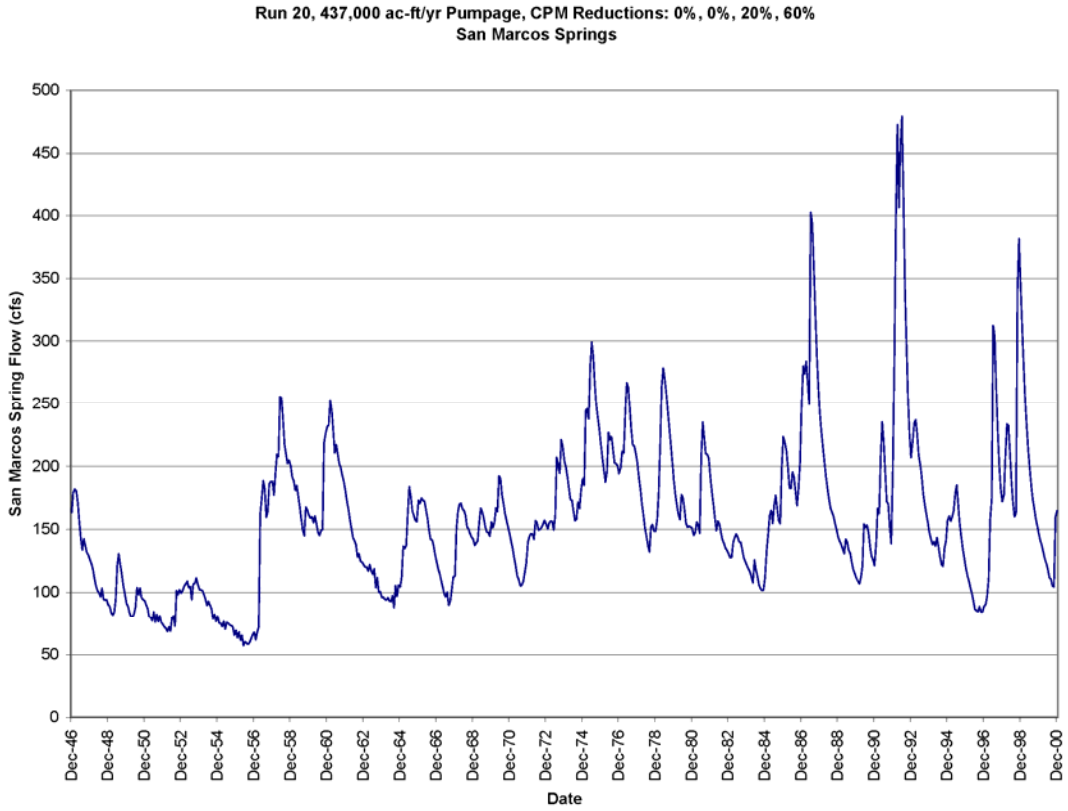

Run 17, 572,000 ac-ft/yr Pumpage, CPM: SB 3, Initial Pumping Condition = 2x Run 1
Comal Springs
Comal Spring Flow (cfs)
Date


Run 18, 437,000 ac-ft/yr Pumpage, CPM Reductions: 0%, 0%, 20%, 35%
San Marcos Springs
San Marcos Spring Flow (cfs)
Date


Run 18, 437 ac-ft/yr Pumpage, CPM Reductions: 0%, 0%, 20%, 35%
Comal Springs
Comal Spring Flow (cfs)
Date


Run 19, 437,000 ac-ft/yr Pumpage, CPM Reductions: 0%, 0%, 20%, 48%
San Marcos Springs
San Marcos Spring Flow (cfs)
Date


Run 19, 437,000 ac-ft/yr Pumpage, CPM Reductions: 0%, 0%, 70%, 48%
Comal Springs
Comal Springs flow (cfs)
Date


Run 20, 437,000 ac-ft/yr Pumpage, CPM Reductions: 0%, 0%, 20%, 60%
San Marcos Springs
San Marcos Spring Flow (cfs)
0
50
100
150
200
250
300
350
400
450
500
Dec-46
Dec-48
Dec-50
Dec-52
Dec-54
Dec-56
Dec-58
Dec-60
Dec-62
Dec-64
Dec-66
Dec-68
Dec-70
Dec-72
Dec-74
Dec-76
Dec-78
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Dec-82
Dec-84
Dec-86
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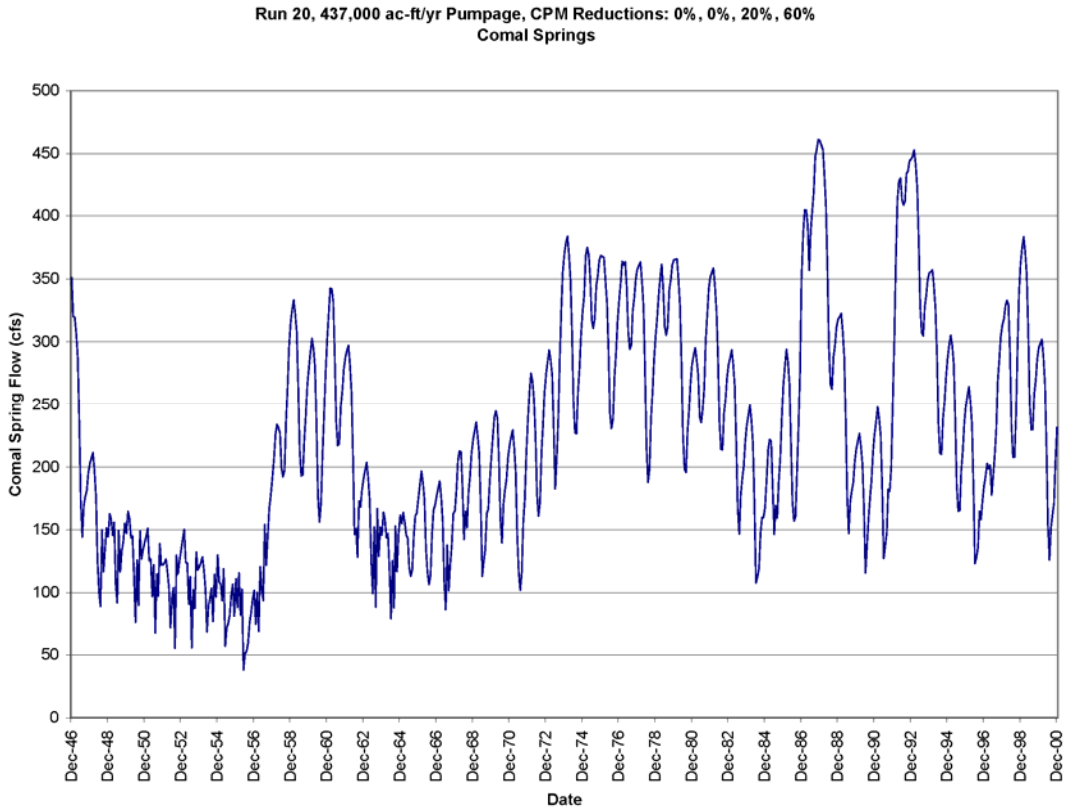
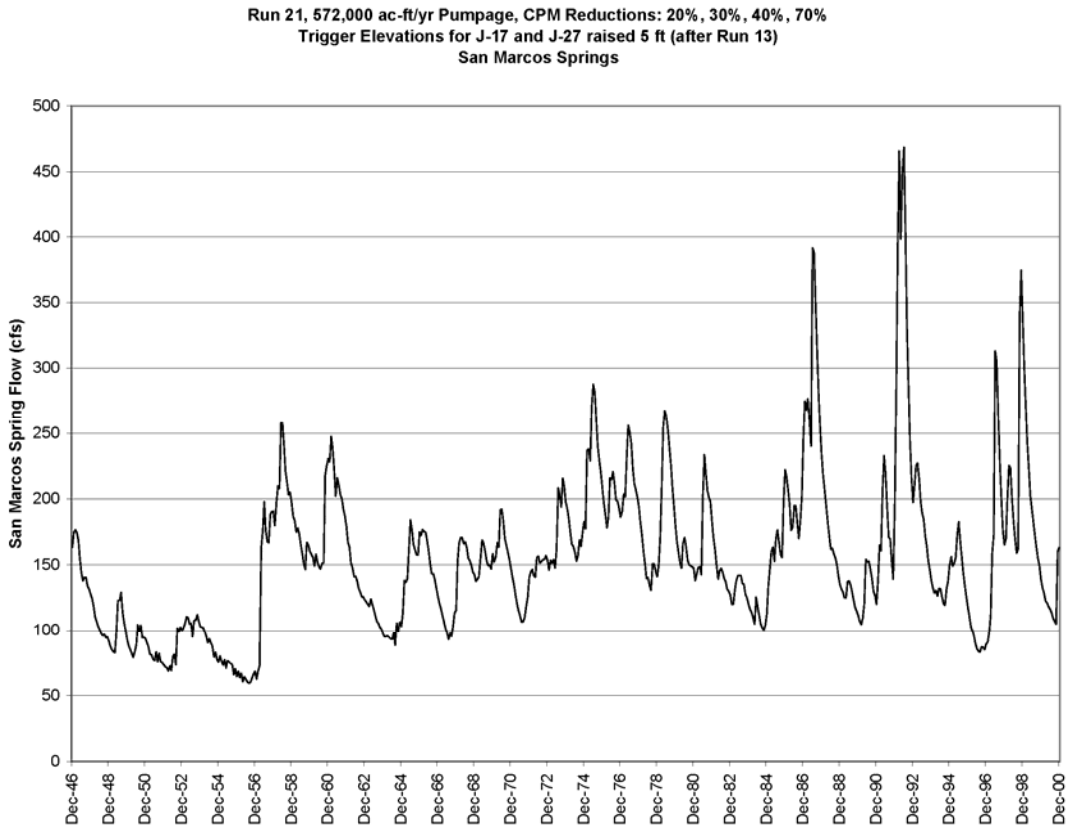
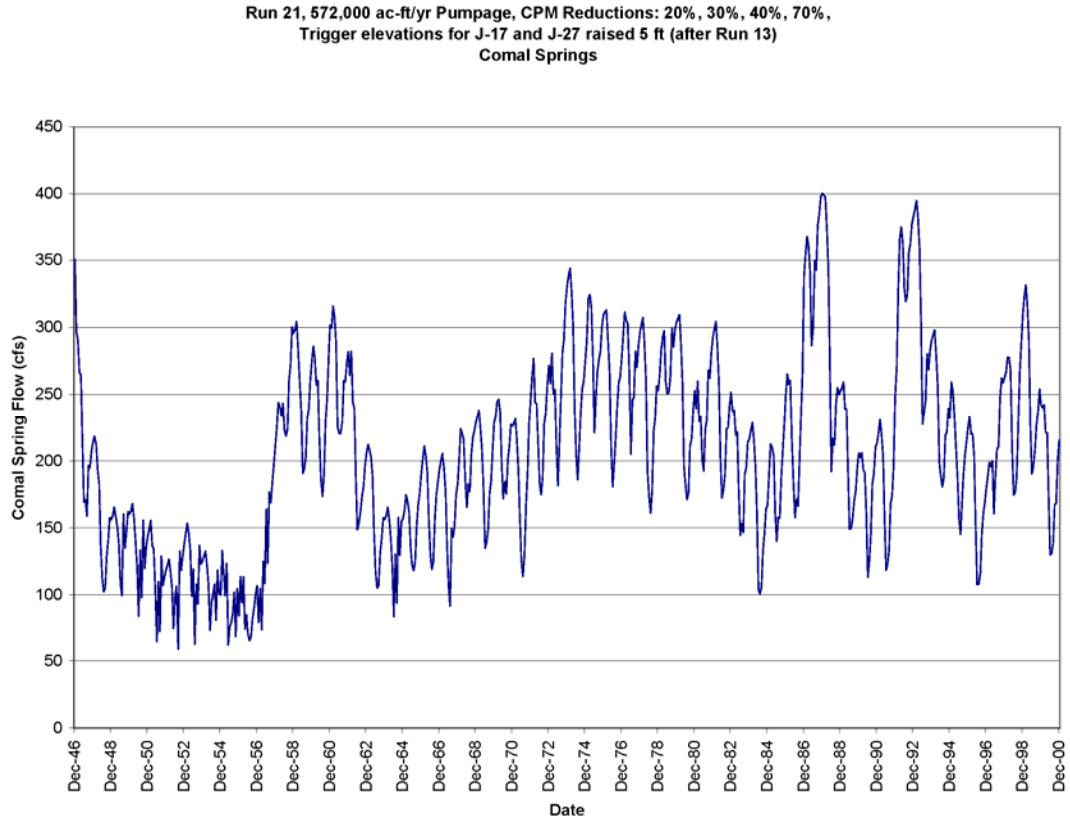
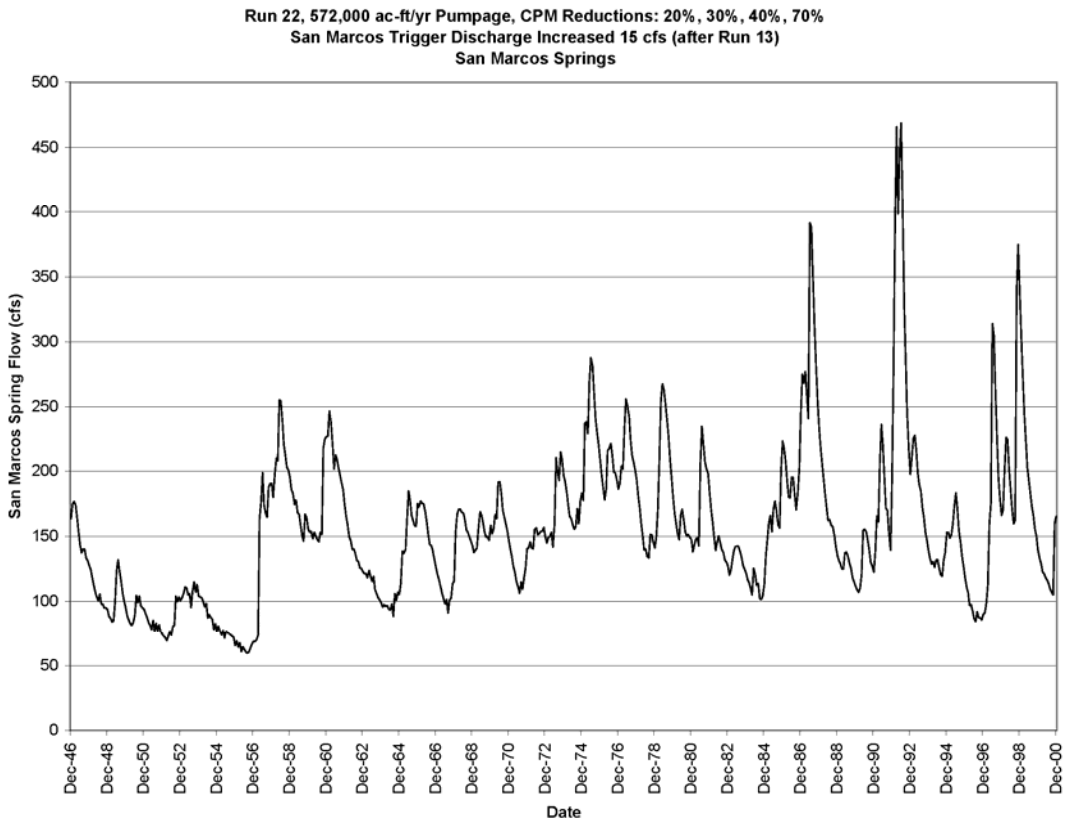
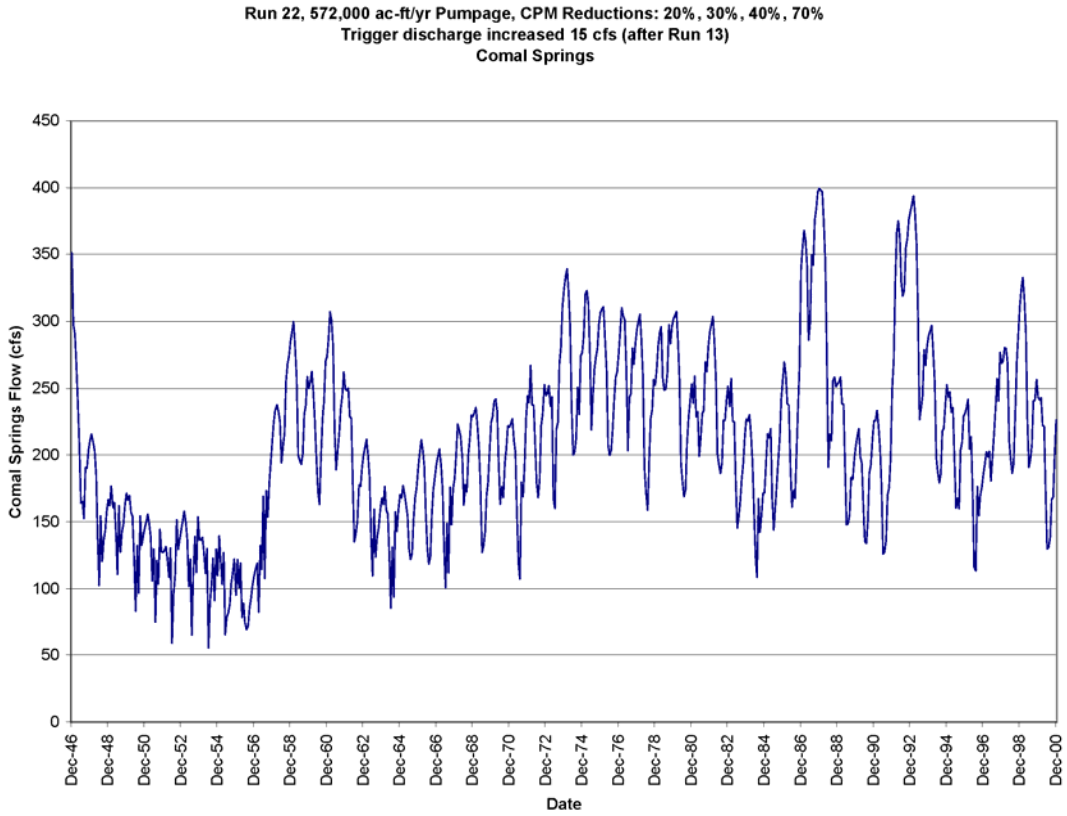
Dec-90
Dec-92
Dec-94
Dec-96
Dec-98
Dec-00
Date

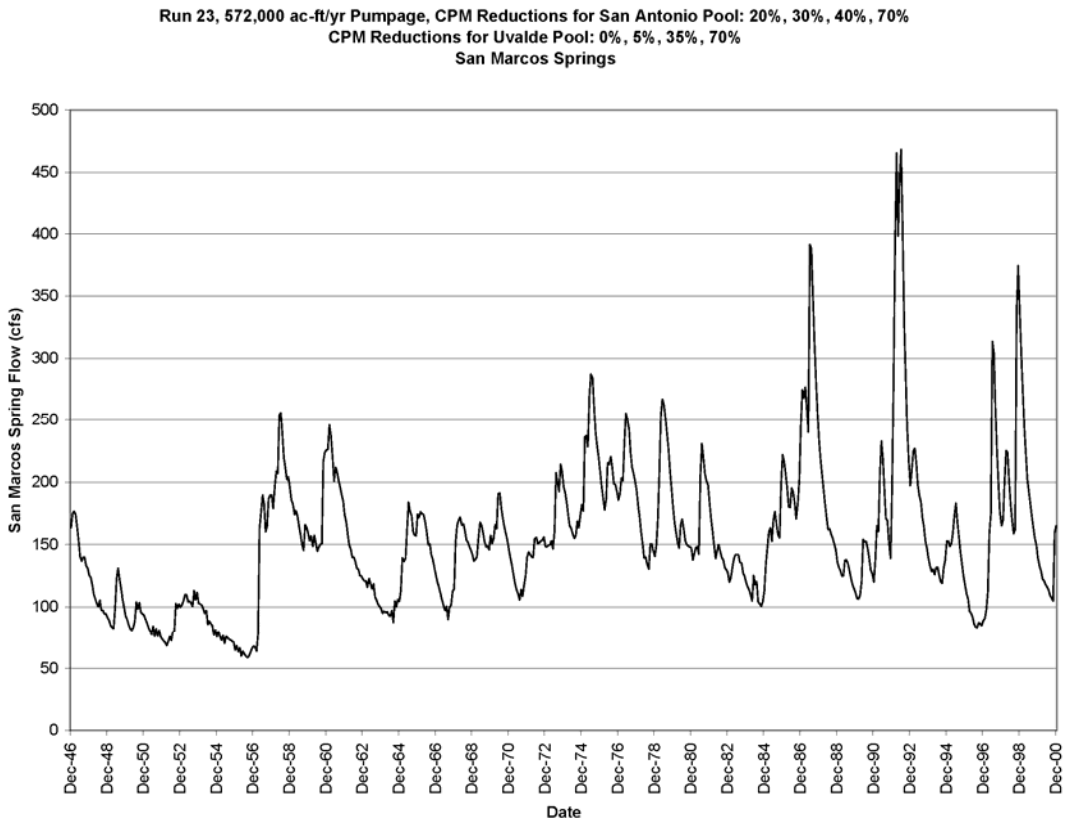

Run 20, 437,000 ac-ft/yr Pumpage, CPM Reductions: 0%, 0%, 20%, 60%
Comal Springs
Comal Spring Flow (cfs)
0
50
100
150
200
250
300
350
400
450
500
Dec-46
Dec-48
Dec-50
Dec-52
Dec-54
Dec-56
Dec-58
Dec-60
Dec-62
Dec-64
Dec-66
Dec-68
Dec-70
Dec-72
Dec-74
Dec-76
Dec-78
Dec-80
Dec-82
Dec-84
Dec-86
Dec-88
Dec-90
Dec-92
Dec-94
Dec-96
Dec-98
Dec-00
Date

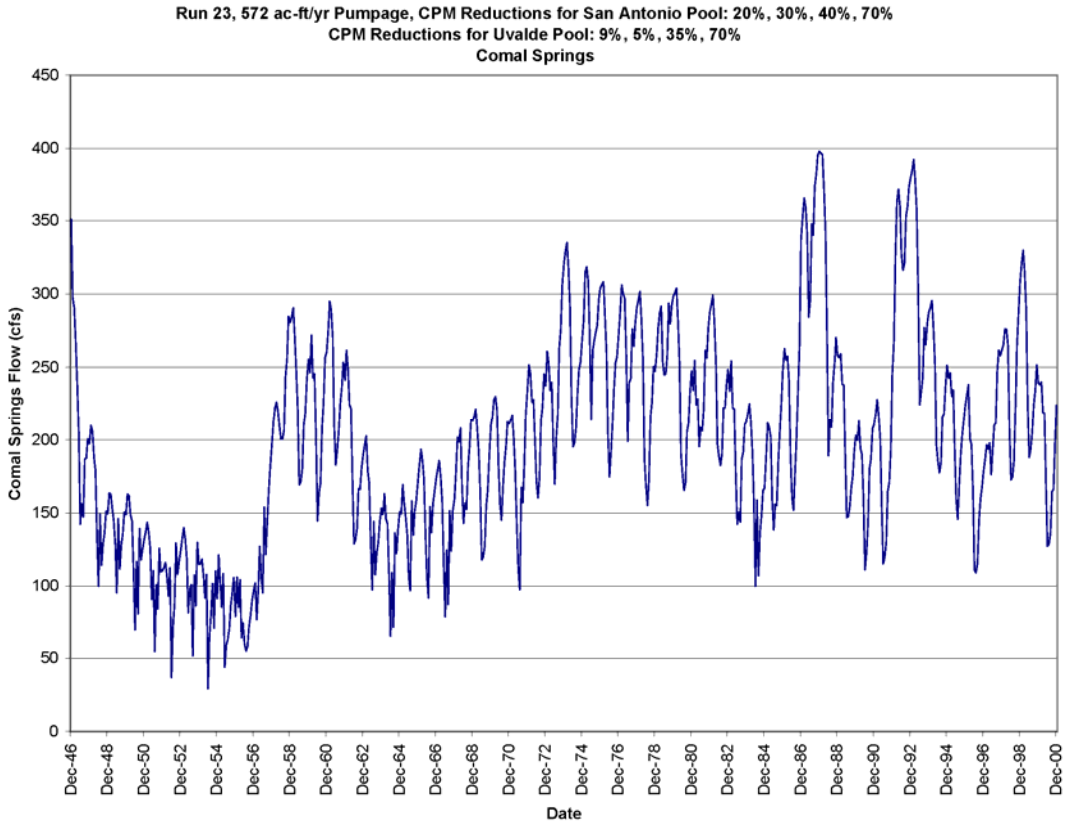

Run 21, 572,000 ac-ft/yr Pumpage, CPM Reductions: 20%, 30%, 40%, 70%
Trigger Elevations for J-17 and J-27 raised 5 ft (after Run 13)
San Marcos Springs
San Marcos Spring Flow (cfs)
0
50
100
150
200
250
300
350
400
450
500
Dec-46
Dec-48
Dec-50
Dec-52
Dec-54
Dec-56
Dec-58
Dec-60
Dec-62
Dec-64
Dec-66
Dec-68
Dec-70
Dec-72
Dec-74
Dec-76
Dec-78
Dec-80
Dec-82
Dec-84
Dec-86
Dec-88
Dec-90
Dec-92
Dec-94
Dec-96
Dec-98
Dec-00

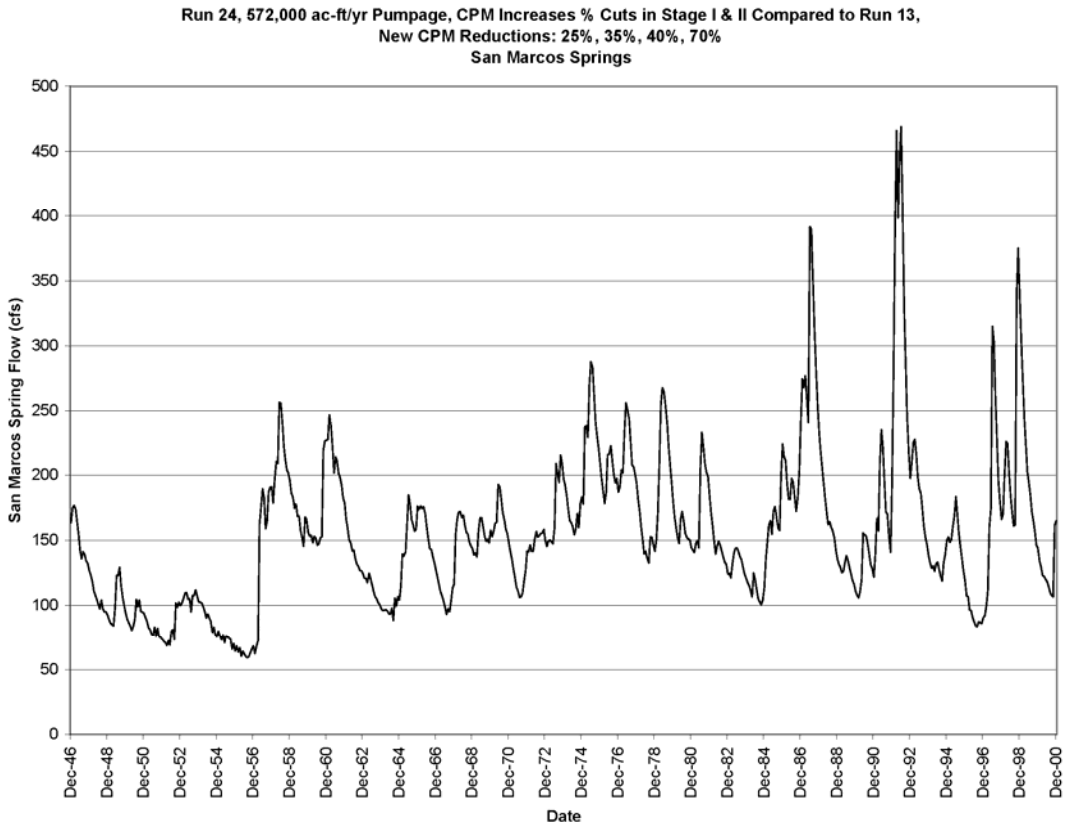

Run 21, 572,000 ac-ft/yr Pumpage, CPM Reductions: 20%, 30%, 40%, 70%,
Trigger elevations for J-17 and J-27 raised 5 ft (after Run 13)
Comal Springs
Comal Spring Flow (cfs)
0
50
100
150
200
250
300
350
400
450
Dec-46
Dec-48
Dec-50
Dec-52
Dec-54
Dec-56
Dec-58
Dec-60
Dec-62
Dec-64
Dec-66
Dec-68
Dec-70
Dec-72
Dec-74
Dec-76
Dec-78
Dec-80
Dec-82
Dec-84
Dec-86
Dec-88
Dec-90
Dec-92
Dec-94
Dec-96
Dec-98
Dec-00
Date

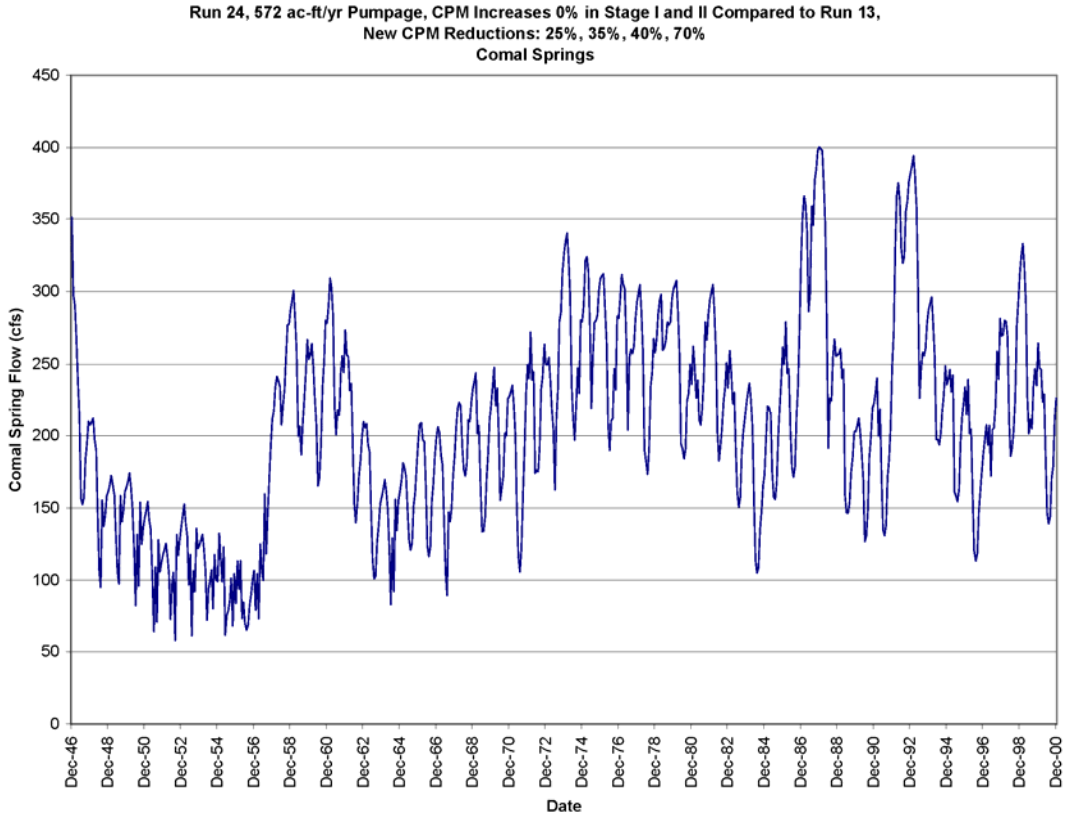

Run 22, 572,000 ac-ft/yr Pumpage, CPM Reductions: 20%, 30%, 40%, 70%
San Marcos Trigger Discharge Increased 15 cfs (after Run 13)
San Marcos Springs
San Marcos Spring Flow (cfs)
Date


Run 22, 572,000 ac-ft/yr Pumpage, CPM Reductions: 20%, 30%, 40%, 70%
Trigger discharge increased 15 cfs (after Run 13)
Comal Springs
Comal Springs Flow (cfs)
Date

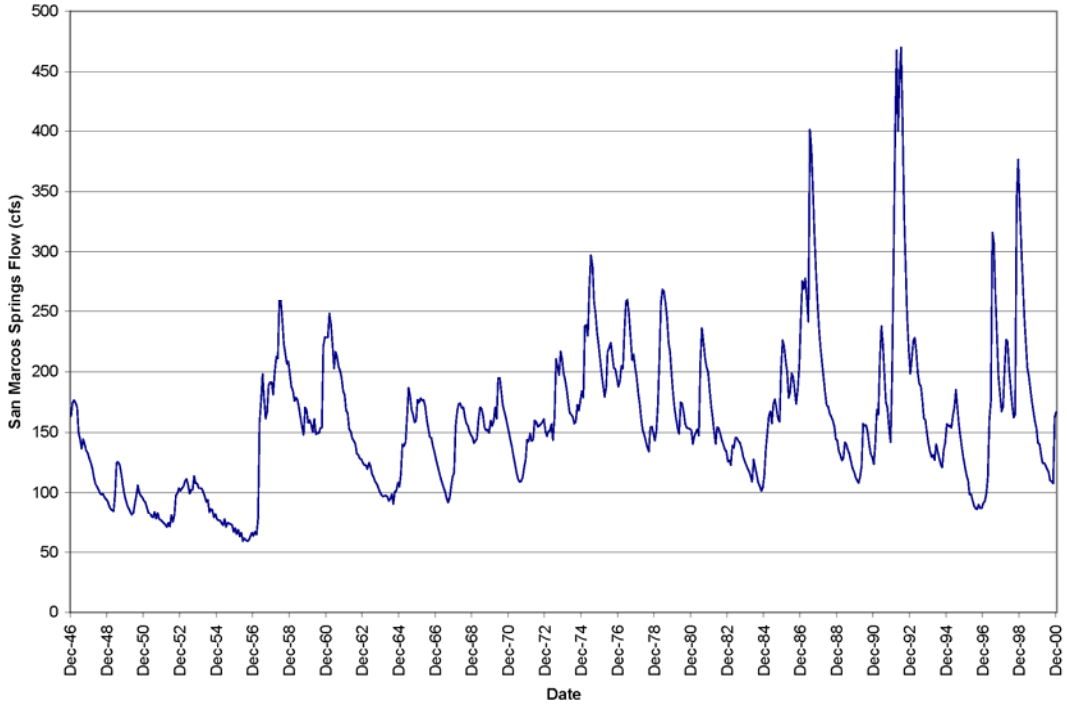

Run 23, 572,000 ac-ft/yr Pumpage, CPM Reductions for San Antonio Pool: 20%, 30%, 40%, 70%
CPM Reductions for Uvalde Pool: 0%, 5%, 35%, 70%
San Marcos Springs
San Marcos Spring Flow (cfs)
Date


Run 23, 572 ac-ft/yr Pumpage, CPM Reductions for San Antonio Pool: 20%, 30%, 40%, 70%
CPM Reductions for Uvalde Pool: 9%, 5%, 35%, 70%
Comal Springs
Comal Springs Flow (cfs)
Date

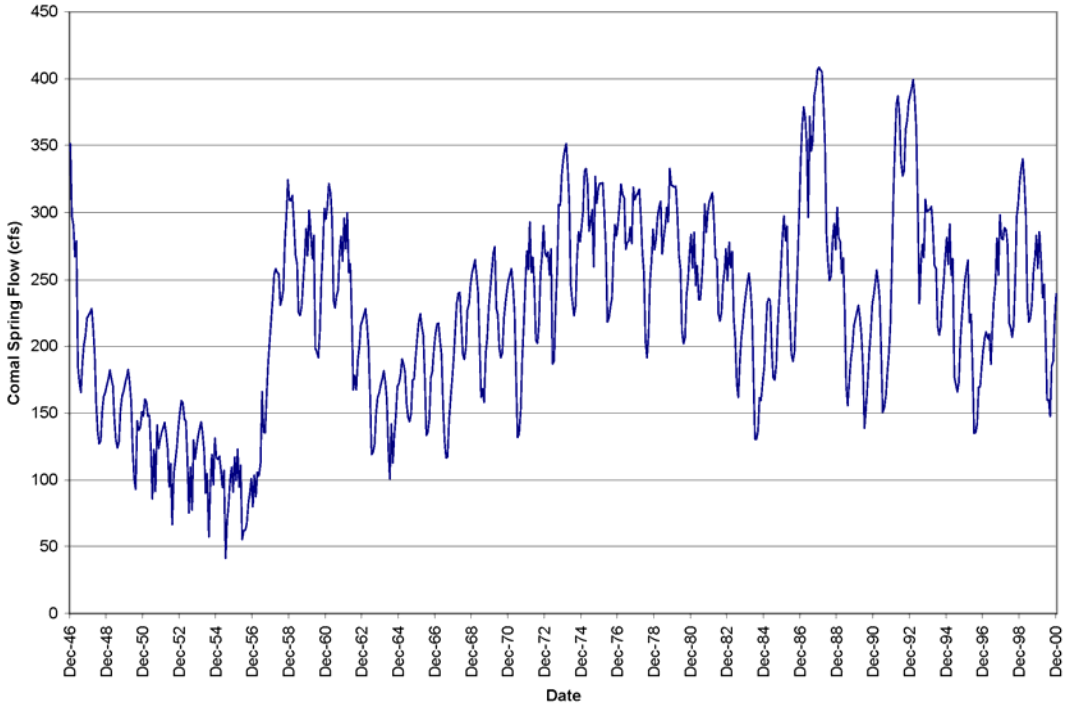

Run 24, 572,000 ac-ft/yr Pumpage, CPM Increases % Cuts in Stage I & II Compared to Run 13,
New CPM Reductions: 25%, 35%, 40%, 70%
San Marcos Springs
San Marcos Spring Flow (cfs)
Date


Run 24, 572 ac-ft/yr Pumpage, CPM Increases 0% in Stage I and II Compared to Run 13,
New CPM Reductions: 25%, 35%, 40%, 70%
Comal Springs
Comal Spring Flow (cfs)
Date

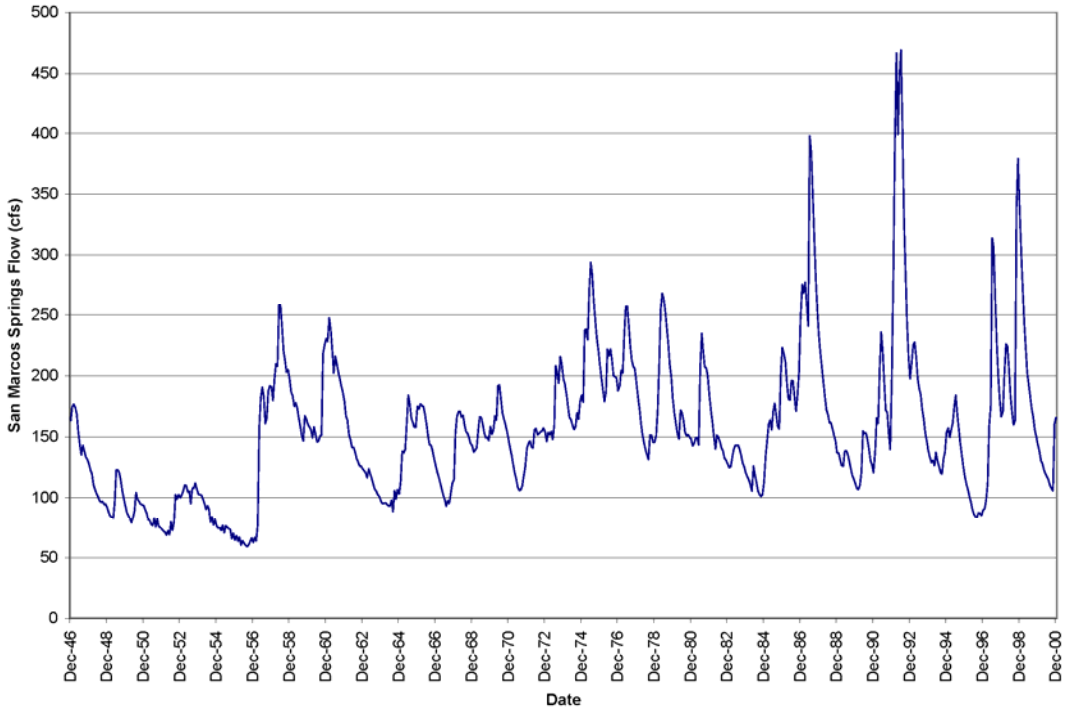
Run 28, 572,000 ac-ft/yr Pumpage, CPM Reductions to test sensitivity of higher percent reductions and higher triggers at earlier stages. (See appendix for description)
San Marcos Springs



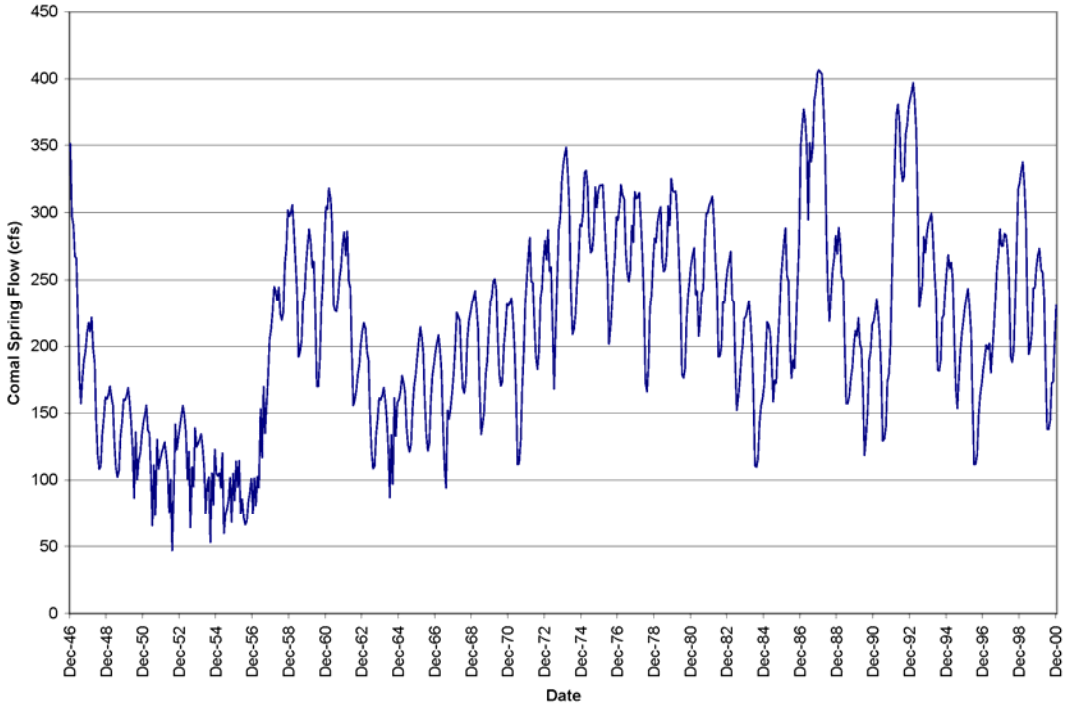
Run 28, 572,000 ac-ft/yr Pumpage, CPM Reductions to test sensitivity of higher percent reductions and higher triggers at earlier stages. (See appendix for description)
Comal Springs

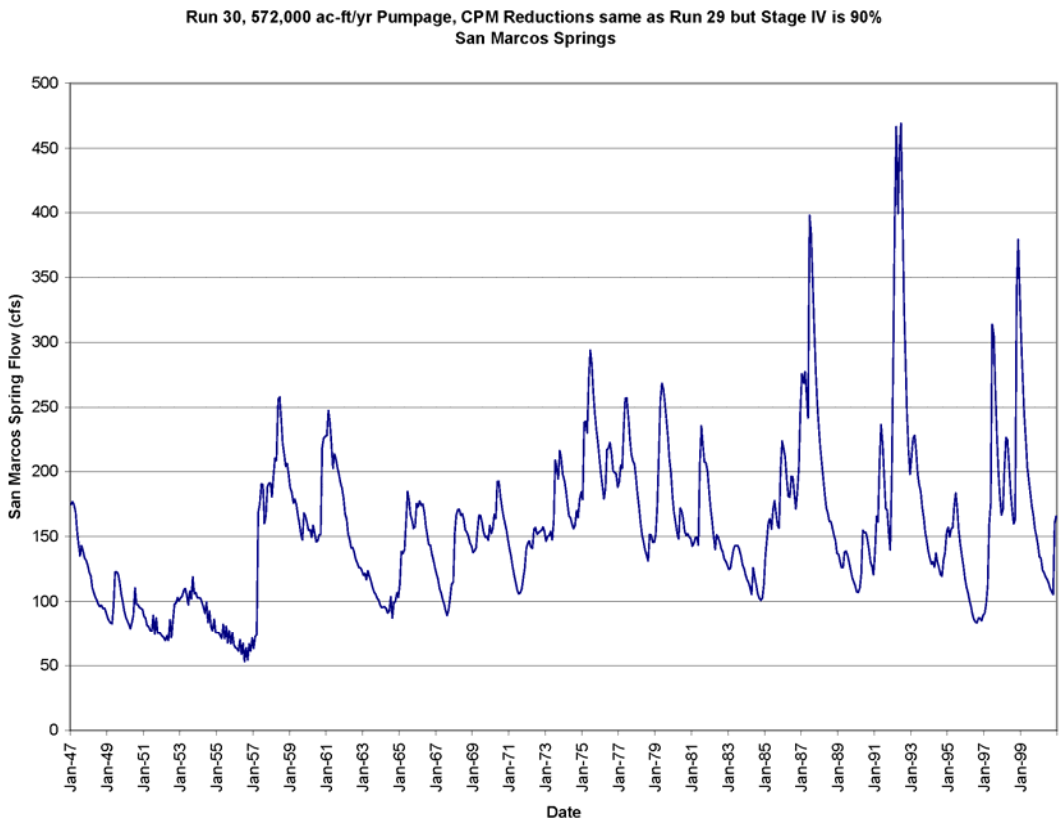


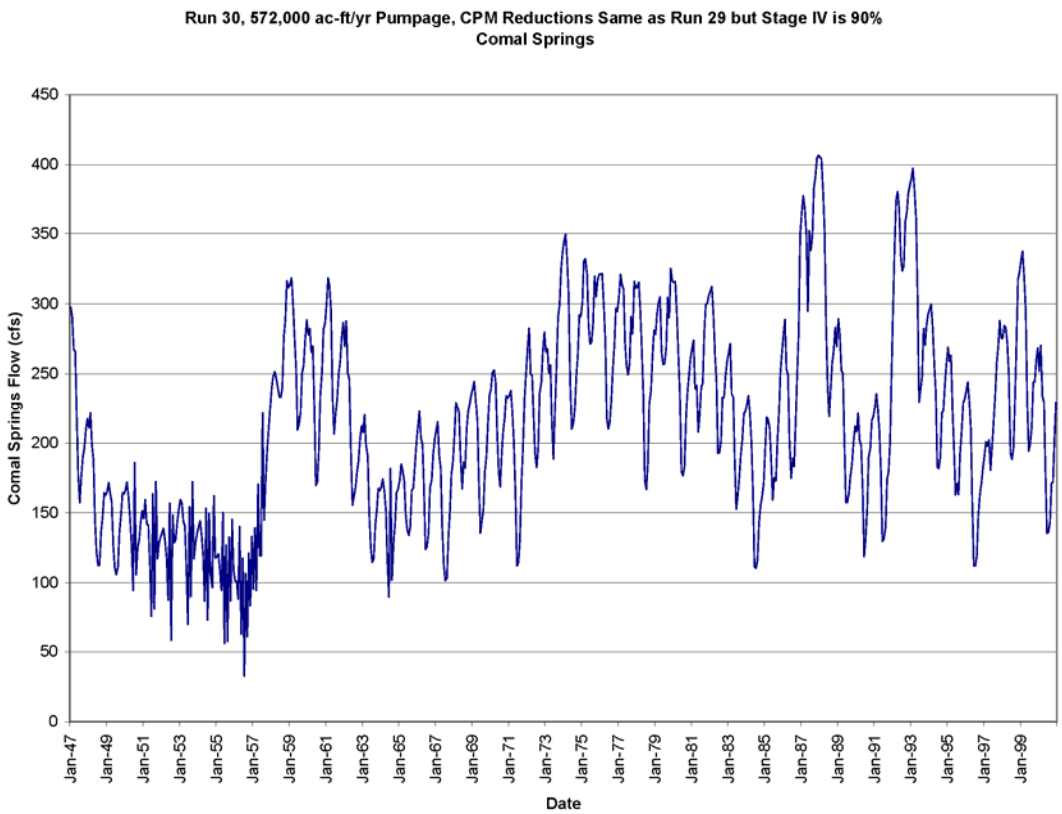
Run 29, 572,000 ac-ft/yr Pumpage, CPM Reduction increases for higher triggers, higher percentages and earlier stages. (See appendix for description)
San Marcos Springs

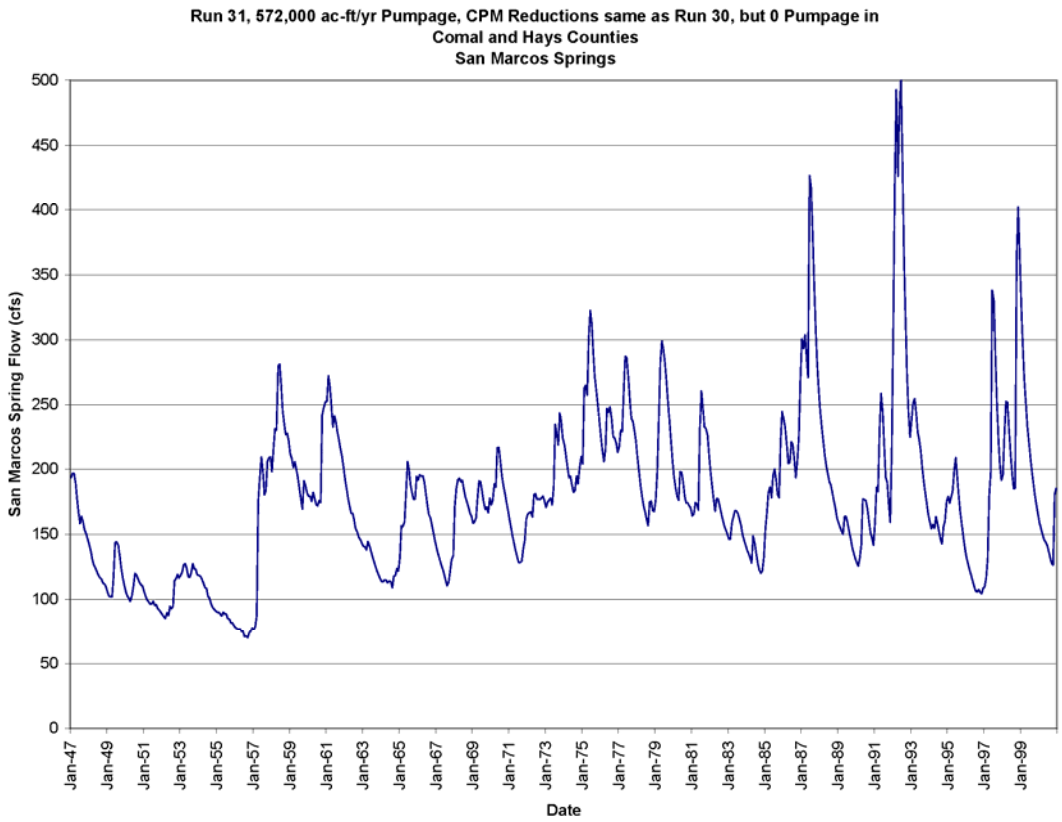


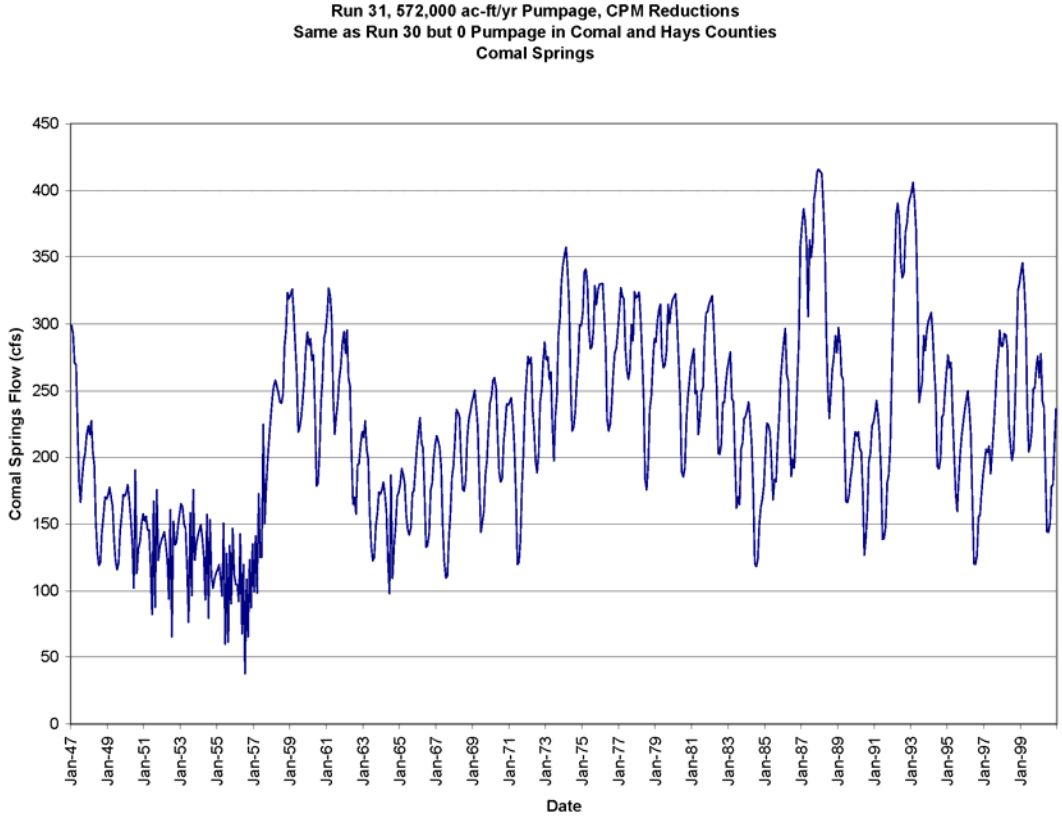
Run 29, 572,000 ac-ft/yr Pumpage, CPM reduction increase for higher triggers, higher percentages and earlier stages. (See appendix for description)
Comal Springs

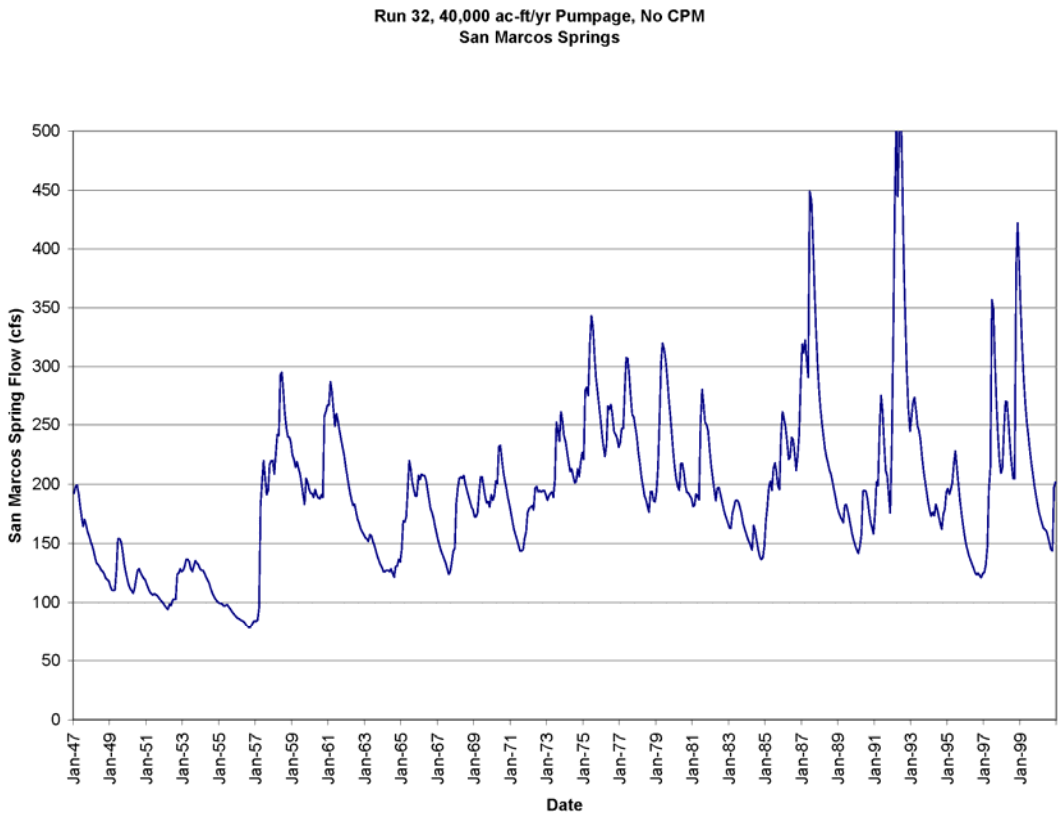


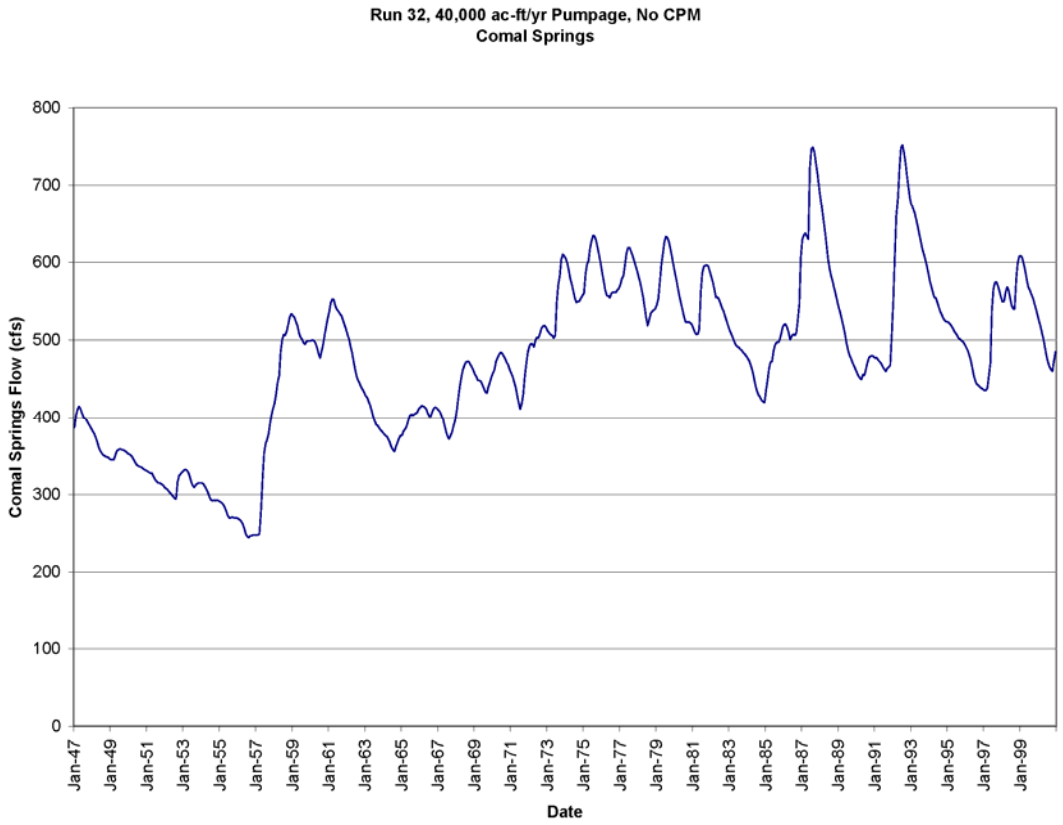

Run 30, 572,000 ac-ft/yr Pumpage, CPM Reductions same as Run 29 but Stage IV is 90%
San Marcos Springs
San Marcos Spring Flow (cfs)
Date

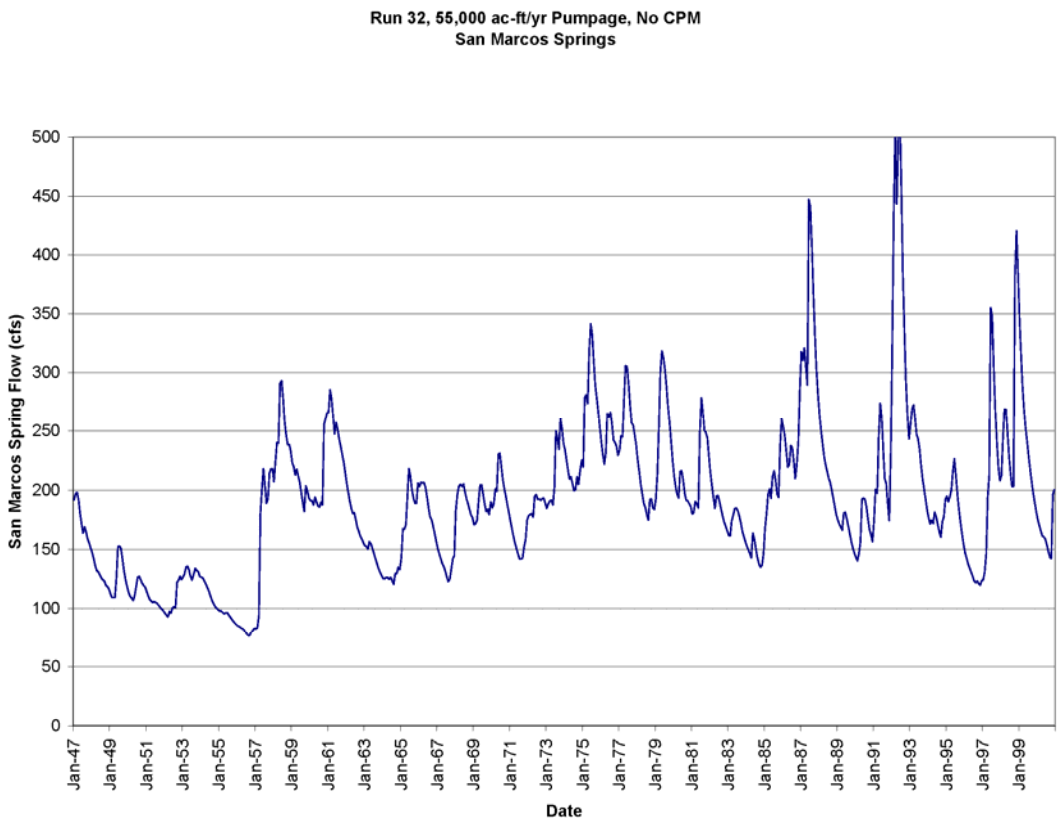

Run 30, 572,000 ac-ft/yr Pumpage, CPM Reductions Same as Run 29 but Stage IV is 90%
Comal Springs
Comal Springs Flow (cfs)
Date

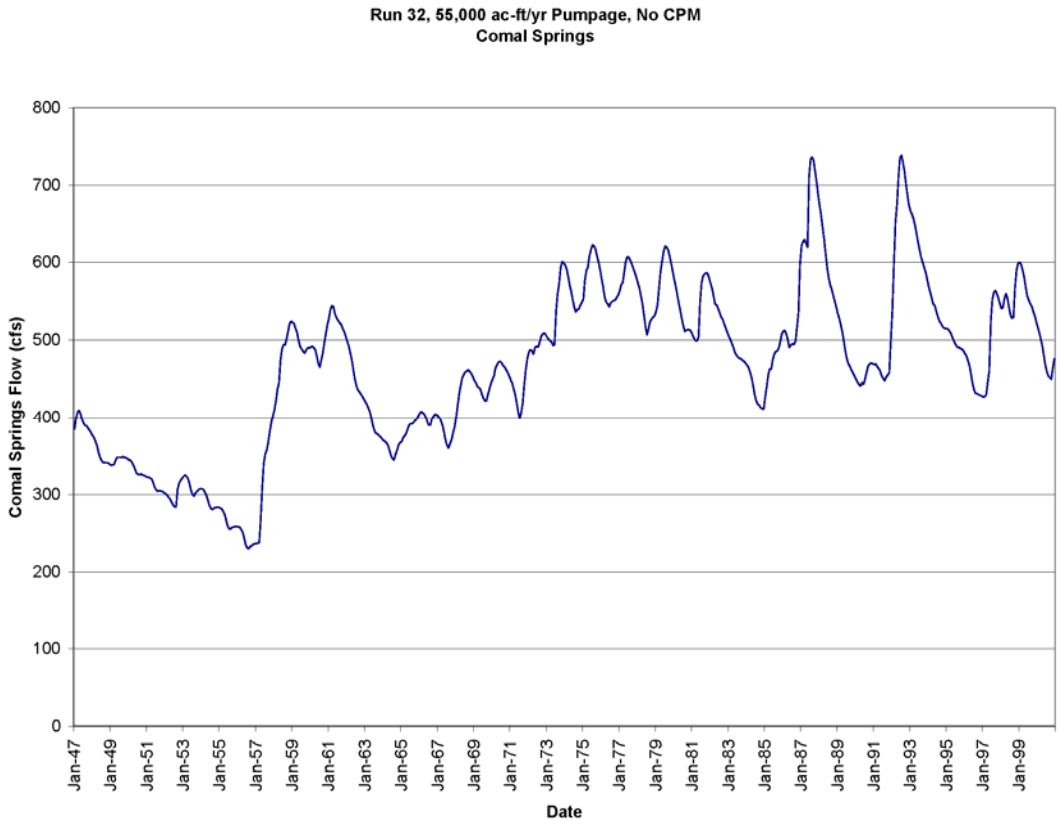

Run 31, 572,000 ac-ft/yr Pumpage, CPM Reductions same as Run 30, but 0 Pumpage in
Comal and Hays Counties
San Marcos Springs
San Marcos Spring Flow (cfs)
Date

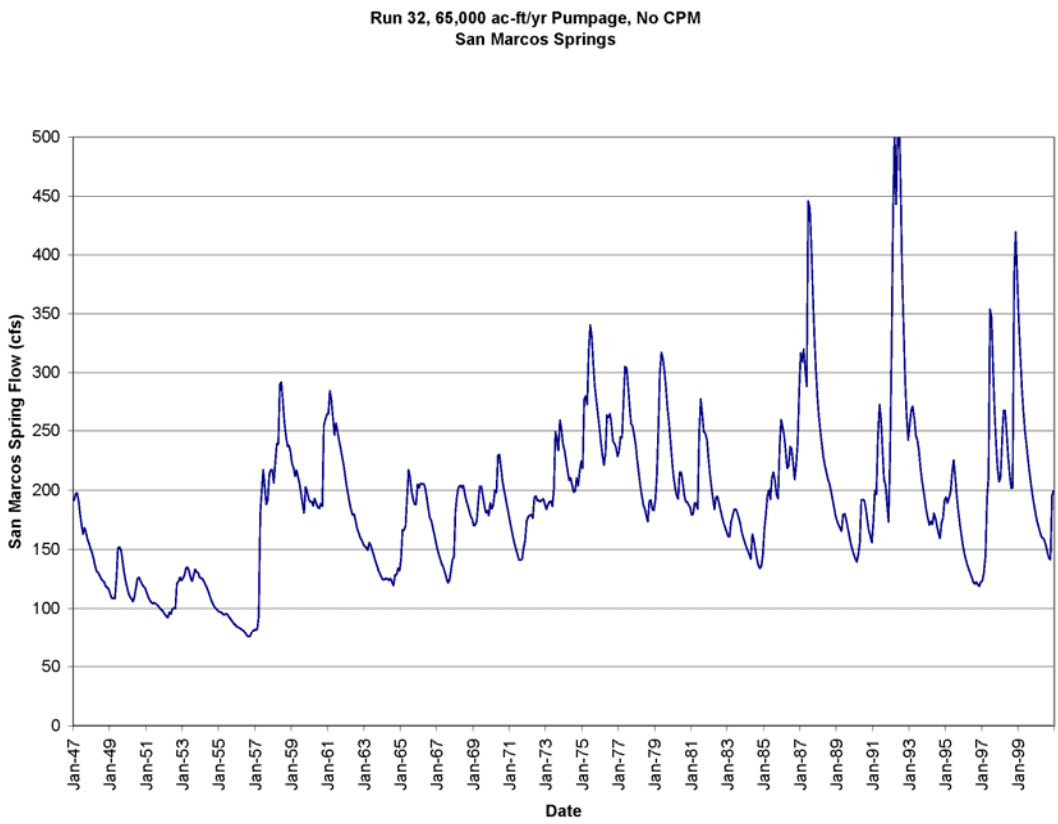

Run 31, 572,000 ac-ft/yr Pumpage, CPM Reductions
Same as Run 30 but 0 Pumpage in Comal and Hays Counties
Comal Springs
Comal Springs Flow (cfs)
Date

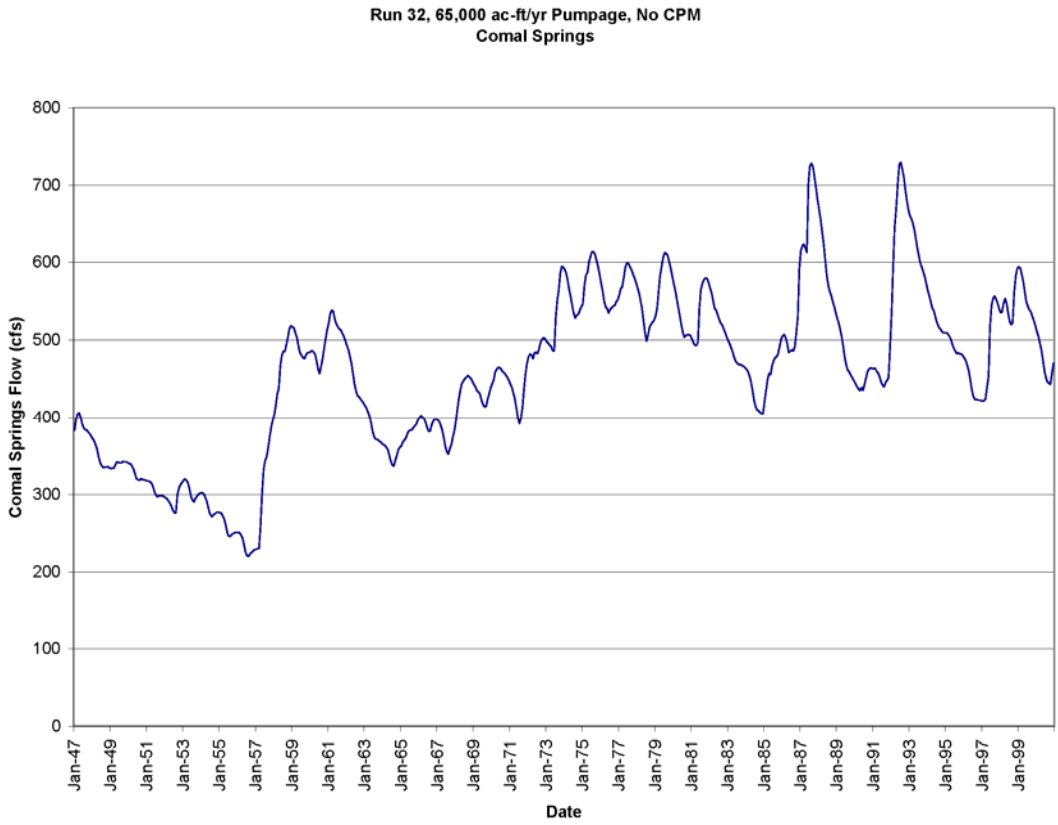

Run 32, 40,000 ac-ft/yr Pumpage, No CPM
San Marcos Springs
San Marcos Spring Flow (cfs)
0
50
100
150
200
250
300
350
400
450
500
Jan-47
Jan-49
Jan-51
Jan-53
Jan-55
Jan-57
Jan-59
Jan-61
Jan-63
Jan-65
Jan-67
Jan-69
Jan-71
Jan-73
Jan-75
Jan-77
Jan-79
Jan-81
Jan-83
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Date

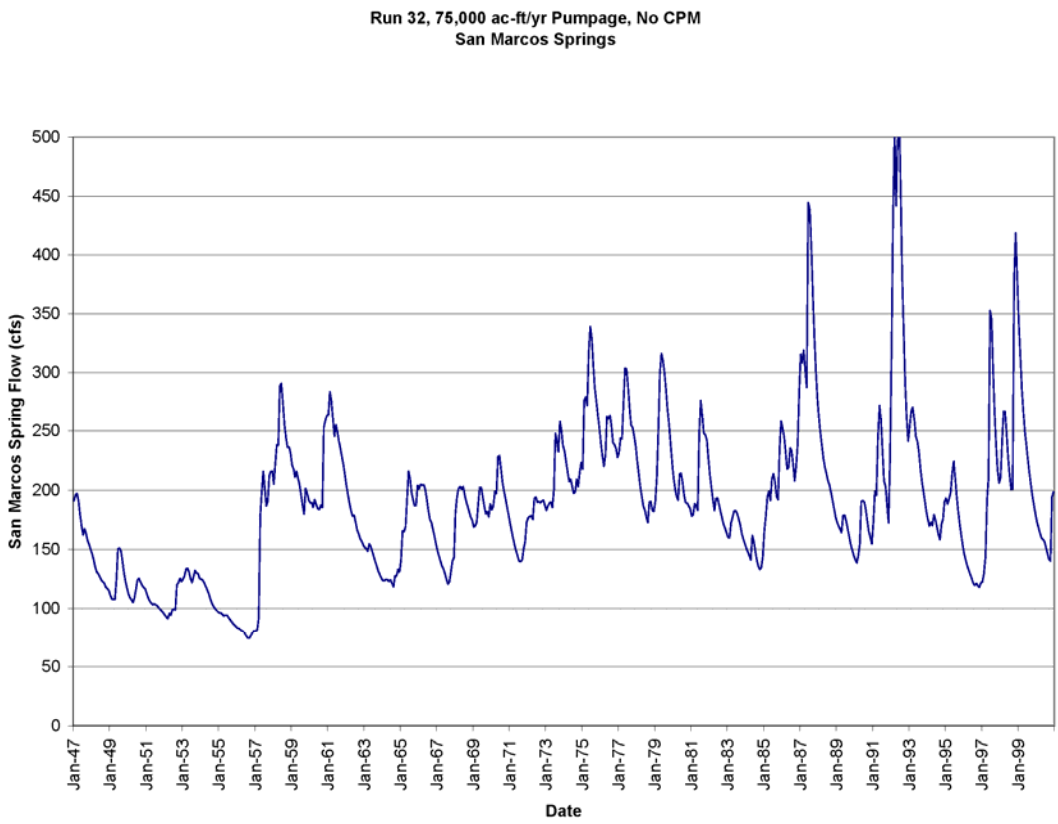

Run 32, 40,000 ac-ft/yr Pumpage, No CPM
Comal Springs
Comal Springs Flow (cfs)
0
100
200
300
400
500
600
700
800
Jan-47
Jan-49
Jan-51
Jan-53
Jan-55
Jan-57
Jan-59
Jan-61
Jan-63
Jan-65
Jan-67
Jan-69
Jan-71
Jan-73
Jan-75
Jan-77
Jan-79
Jan-81
Jan-83
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Date

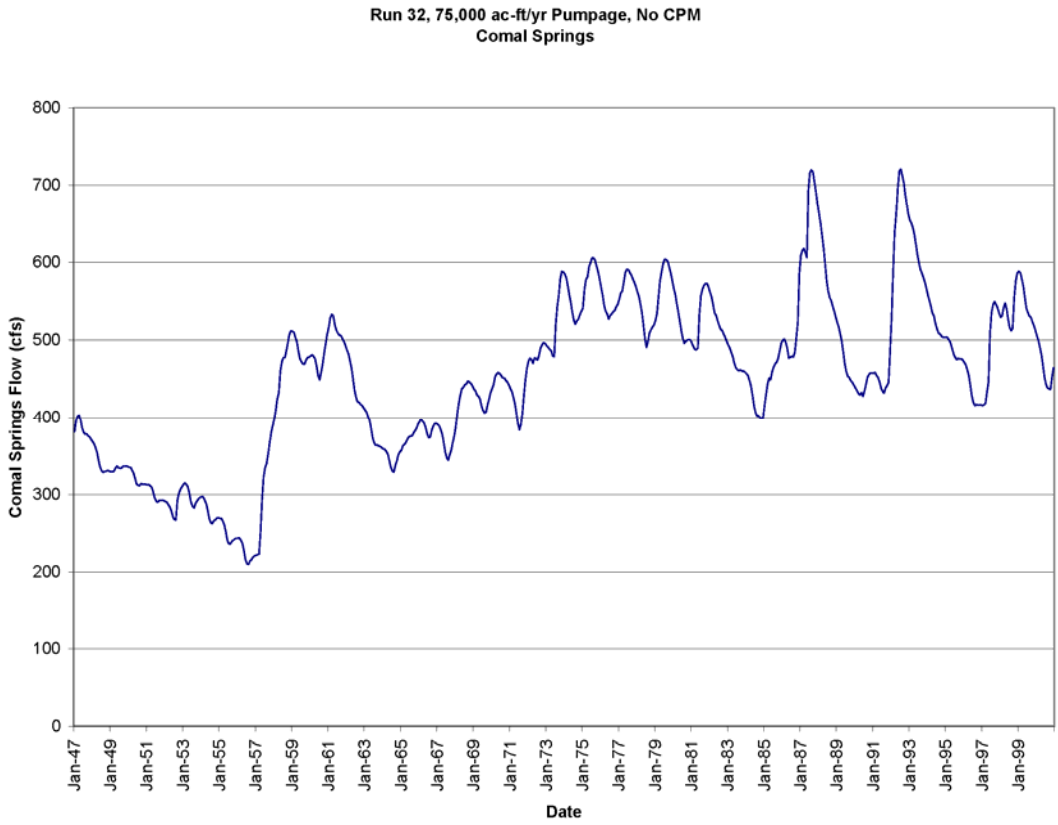

Run 32, 55,000 ac-ft/yr Pumpage, No CPM
San Marcos Springs
San Marcos Spring Flow (cfs)
0
50
100
150
200
250
300
350
400
450
500
Jan-47
Jan-49
Jan-51
Jan-53
Jan-55
Jan-57
Jan-59
Jan-61
Jan-63
Jan-65
Jan-67
Jan-69
Jan-71
Jan-73
Jan-75
Jan-77
Jan-79
Jan-81
Jan-83
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Date

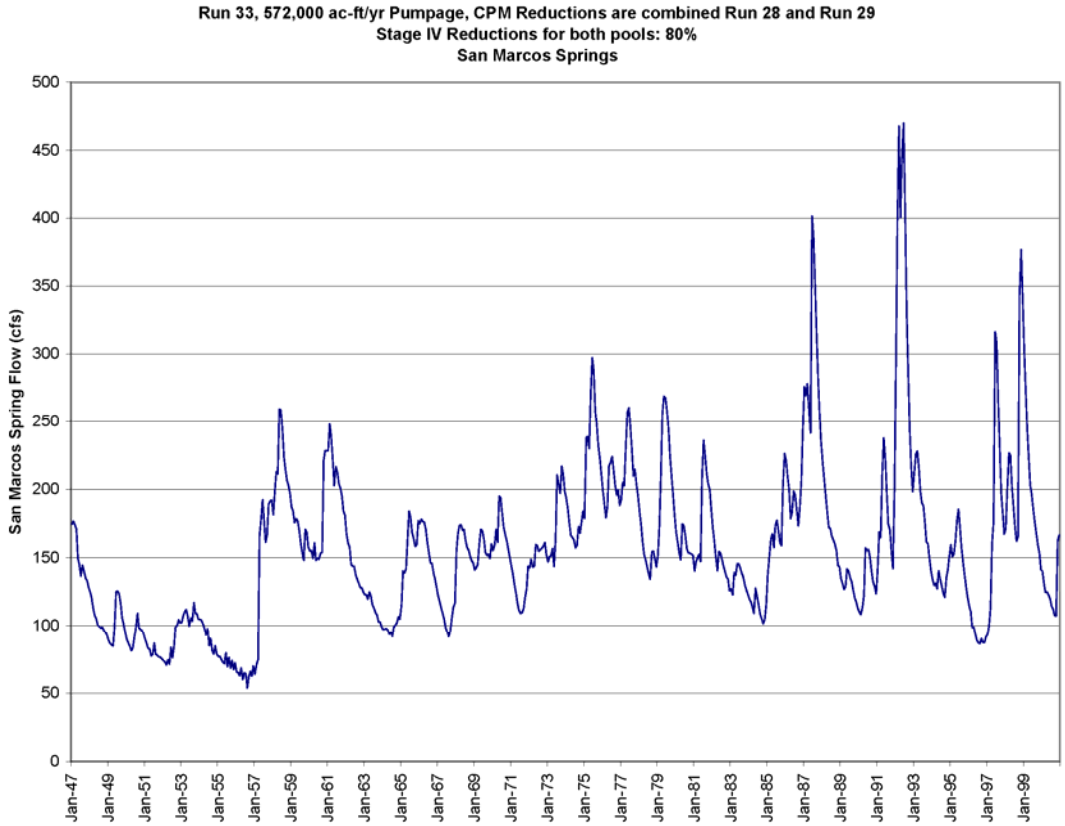

Run 32, 55,000 ac-ft/yr Pumpage, No CPM
Comal Springs
Comal Springs Flow (cfs)
0
100
200
300
400
500
600
700
800
Jan-47
Jan-49
Jan-51
Jan-53
Jan-55
Jan-57
Jan-59
Jan-61
Jan-63
Jan-65
Jan-67
Jan-69
Jan-71
Jan-73
Jan-75
Jan-77
Jan-79
Jan-81
Jan-83
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Date


Run 32, 65,000 ac-ft/yr Pumpage, No CPM
San Marcos Springs
San Marcos Spring Flow (cfs)
0
50
100
150
200
250
300
350
400
450
500
Jan-47
Jan-49
Jan-51
Jan-53
Jan-55
Jan-57
Jan-59
Jan-61
Jan-63
Jan-65
Jan-67
Jan-69
Jan-71
Jan-73
Jan-75
Jan-77
Jan-79
Jan-81
Jan-83
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Date


Run 32, 65,000 ac-ft/yr Pumpage, No CPM
Comal Springs
Comal Springs Flow (cfs)
0
100
200
300
400
500
600
700
800
Jan-47
Jan-49
Jan-51
Jan-53
Jan-55
Jan-57
Jan-59
Jan-61
Jan-63
Jan-65
Jan-67
Jan-69
Jan-71
Jan-73
Jan-75
Jan-77
Jan-79
Jan-81
Jan-83
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Date


Run 32, 75,000 ac-ft/yr Pumpage, No CPM
San Marcos Springs
San Marcos Spring Flow (cfs)
0
50
100
150
200
250
300
350
400
450
500
Jan-47
Jan-49
Jan-51
Jan-53
Jan-55
Jan-57
Jan-59
Jan-61
Jan-63
Jan-65
Jan-67
Jan-69
Jan-71
Jan-73
Jan-75
Jan-77
Jan-79
Jan-81
Jan-83
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Date


Run 32, 75,000 ac-ft/yr Pumpage, No CPM
Comal Springs
Comal Springs Flow (cfs)
0
100
200
300
400
500
600
700
800
Jan-47
Jan-49
Jan-51
Jan-53
Jan-55
Jan-57
Jan-59
Jan-61
Jan-63
Jan-65
Jan-67
Jan-69
Jan-71
Jan-73
Jan-75
Jan-77
Jan-79
Jan-81
Jan-83
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Date


Run 33, 572,000 ac-ft/yr Pumpage, CPM Reductions are combined Run 28 and Run 29
Stage IV Reductions for both pools: 80%
San Marcos Springs
San Marcos Spring Flow (cfs)
0
50
100
150
200
250
300
350
400
450
500
Jan-47
Jan-49
Jan-51
Jan-53
Jan-55
Jan-57
Jan-59
Jan-61
Jan-63
Jan-65
Jan-67
Jan-69
Jan-71
Jan-73
Jan-75
Jan-77
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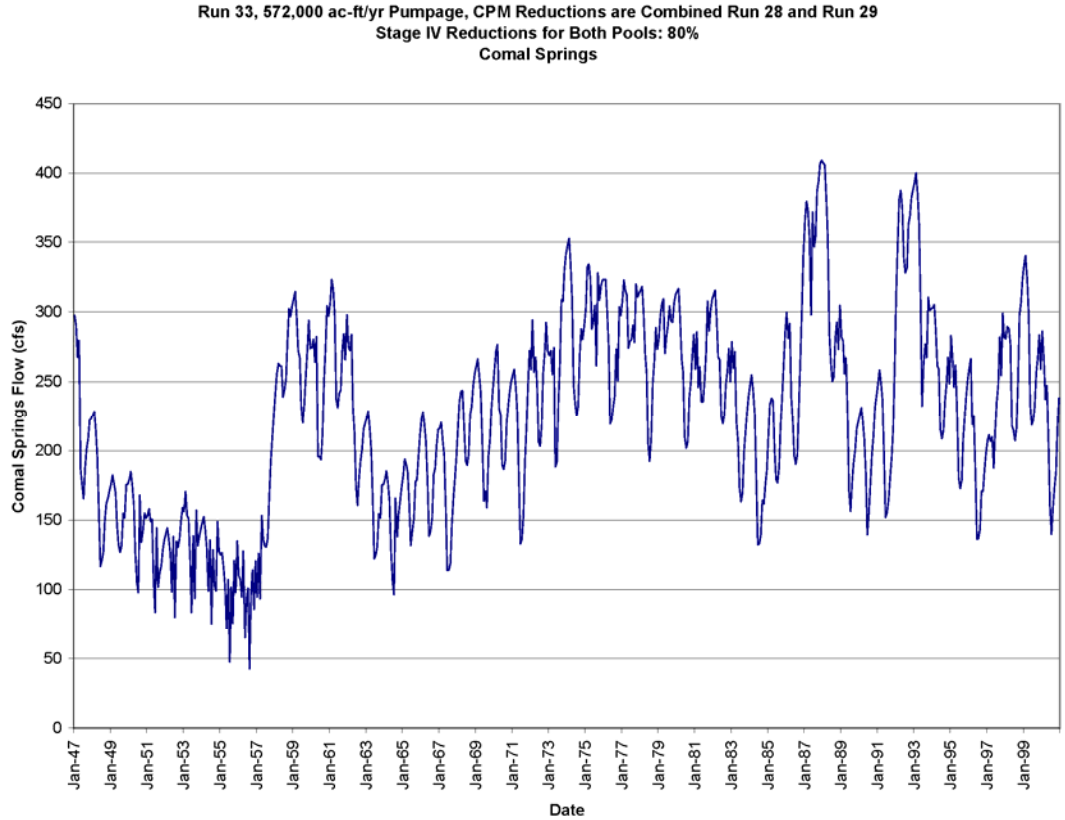
Jan-81
Jan-83
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99


Run 33, 572,000 ac-ft/yr Pumpage, CPM Reductions are Combined Run 28 and Run 29
Stage IV Reductions for Both Pools: 80%
Comal Springs
Comal Springs Flow (cfs)
0
50
100
150
200
250
300
350
400
450
Jan-47
Jan-49
Jan-51
Jan-53
Jan-55
Jan-57
Jan-59
Jan-61
Jan-63
Jan-65
Jan-67
Jan-69
Jan-71
Jan-73
Jan-75
Jan-77
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Jan-83
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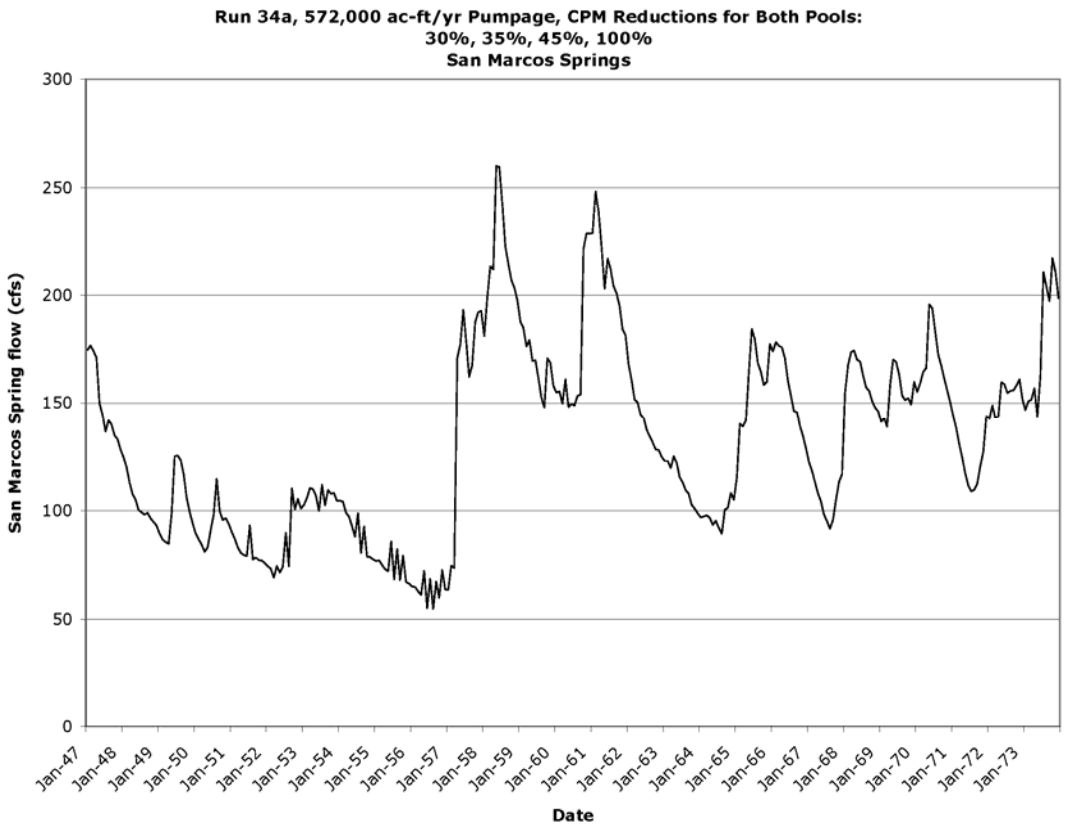
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Date


Run 34a, 572,000 ac-ft/yr Pumpage, CPM Reductions for Both Pools:
30%, 35%, 45%, 100%
San Marcos Springs
San Marcos Spring flow (cfs)
300
250
200
150
100
50
0
Jan-47
Jan-48
Jan-49
Jan-50
Jan-51
Jan-52
Jan-53
Jan-54
Jan-55
Jan-56
Jan-57
Jan-58
Jan-59
Jan-60
Jan-61
Jan-62
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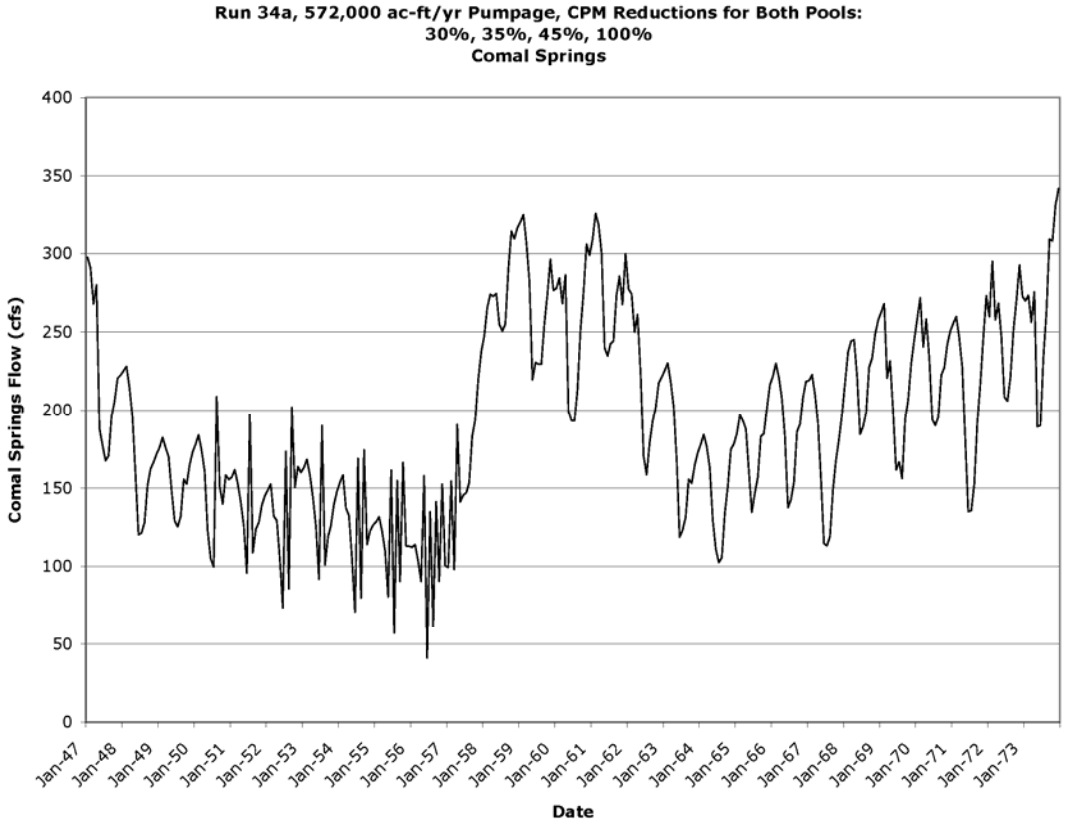
Jan-68
Jan-69
Jan-70
Jan-71
Jan-72
Jan-73
Date


Run 34a, 572,000 ac-ft/yr Pumpage, CPM Reductions for Both Pools:
30%, 35%, 45%, 100%
Comal Springs
Comal Springs Flow (cfs)
400
350
300
250
200
150
100
50
0
Jan-47
Jan-48
Jan-49
Jan-50
Jan-51
Jan-52
Jan-53
Jan-54
Jan-55
Jan-56
Jan-57
Jan-58
Jan-59
Jan-60
Jan-61
Jan-62
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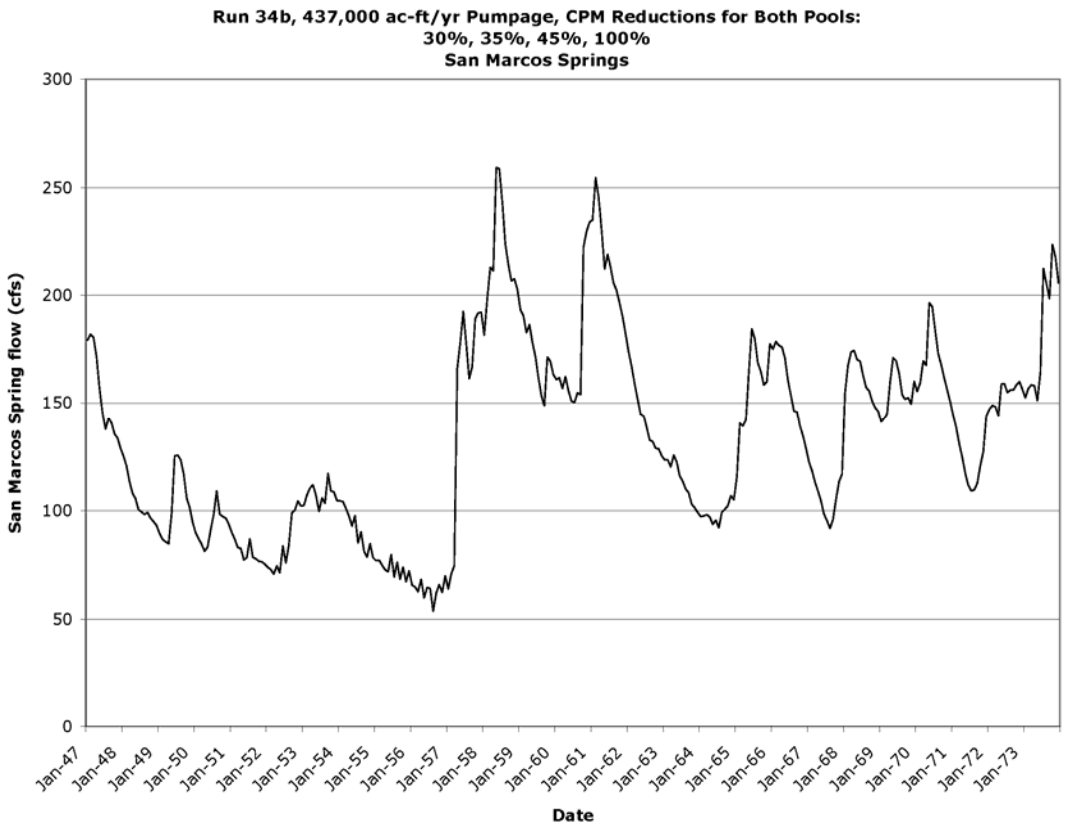
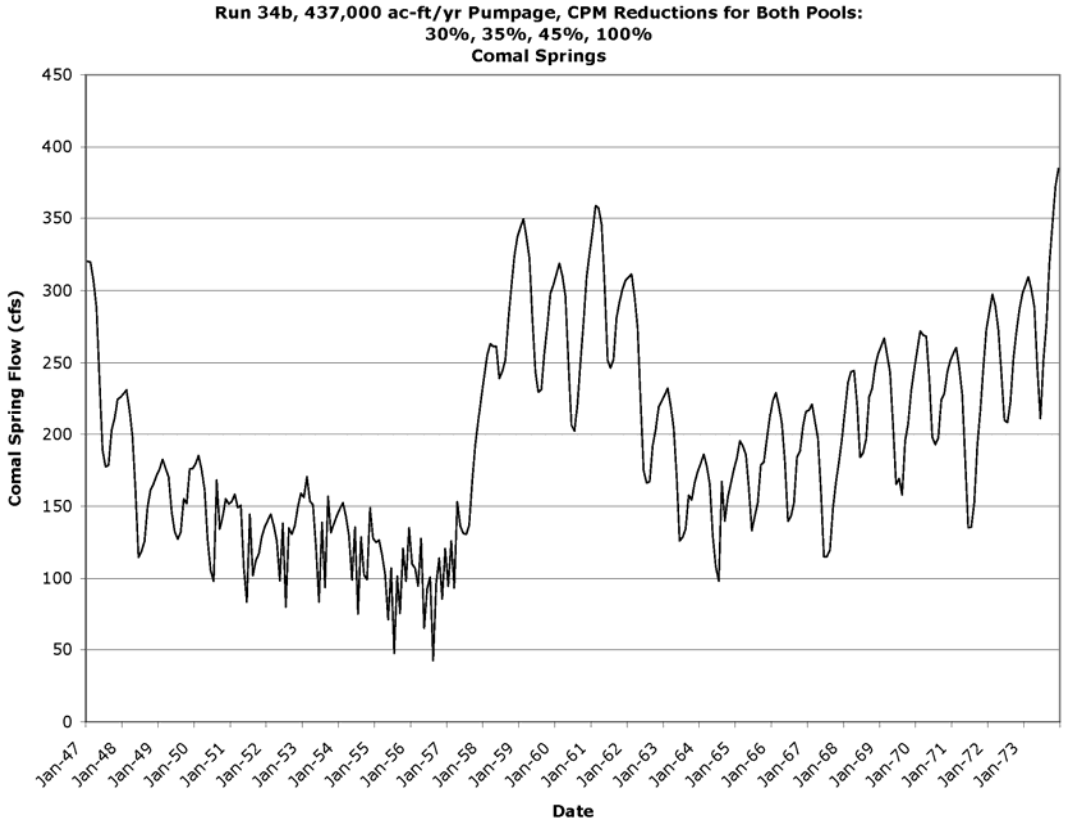
Jan-67
Jan-68
Jan-69
Jan-70
Jan-71
Jan-72
Jan-73
Date


Run 34b, 437,000 ac-ft/yr Pumpage, CPM Reductions for Both Pools:
30%, 35%, 45%, 100%
San Marcos Springs
San Marcos Spring flow (cfs)
300
250
200
150
100
50
0
Jan-47
Jan-48
Jan-49
Jan-50
Jan-51
Jan-52
Jan-53
Jan-54
Jan-55
Jan-56
Jan-57
Jan-58
Jan-59
Jan-60
Jan-61
Jan-62
Jan-63
Jan-64
Jan-65
Jan-66
Jan-67
Jan-68
Jan-69
Jan-70
Jan-71
Jan-72
Jan-73
Date


Run 34b, 437,000 ac-ft/yr Pumpage, CPM Reductions for Both Pools:
30%, 35%, 45%, 100%
Comal Springs
Comal Spring Flow (cfs)
450
400
350
300
250
200
150
100
50
0
Jan-47
Jan-48
Jan-49
Jan-50
Jan-51
Jan-52
Jan-53
Jan-54
Jan-55
Jan-56
Jan-57
Jan-58
Jan-59
Jan-60
Jan-61
Jan-62
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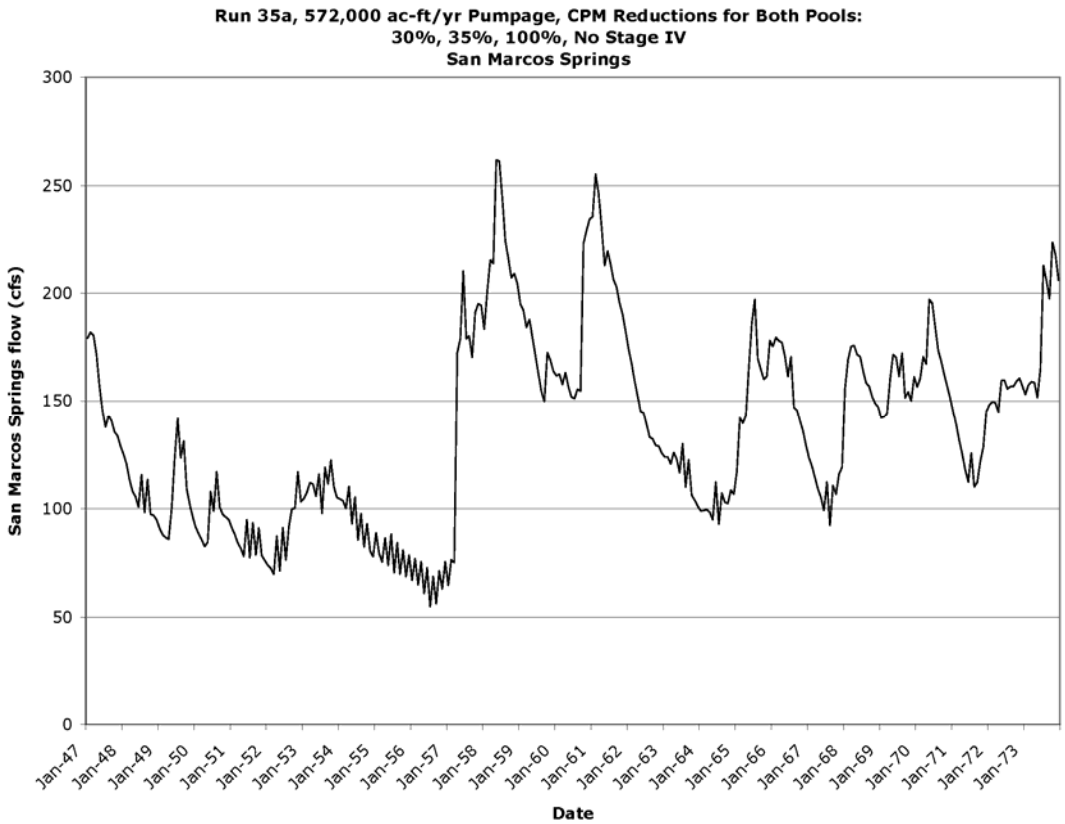
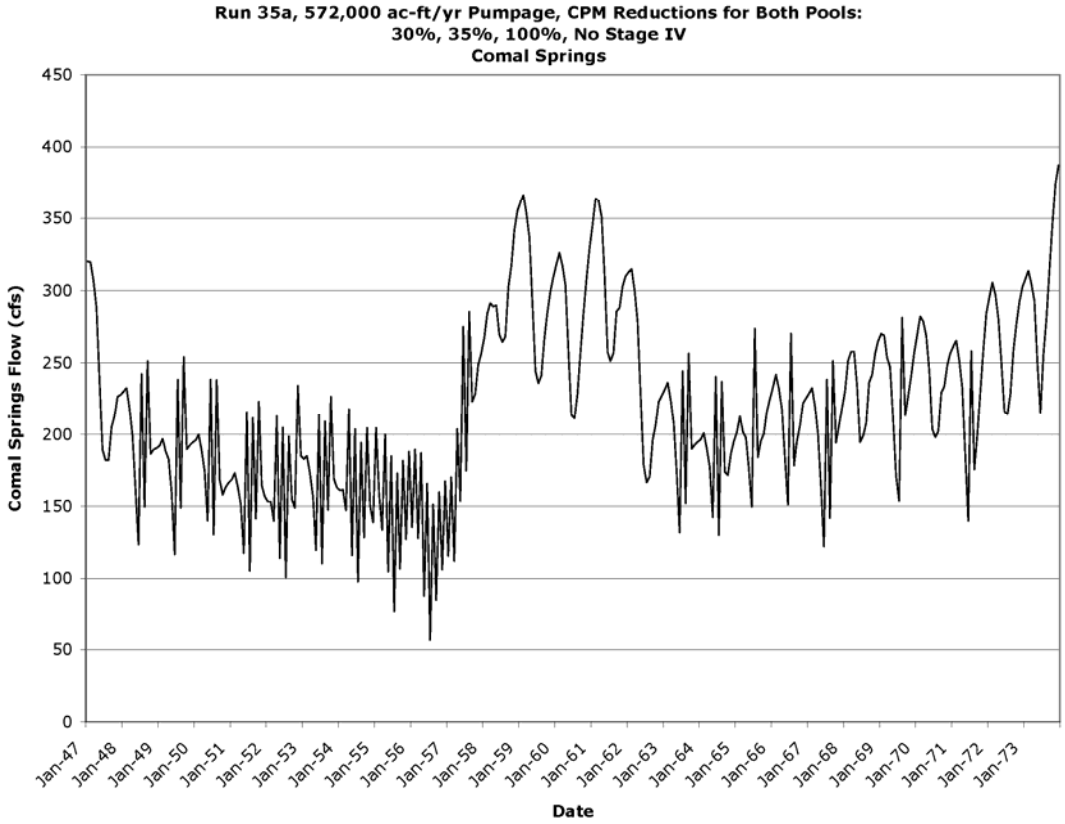
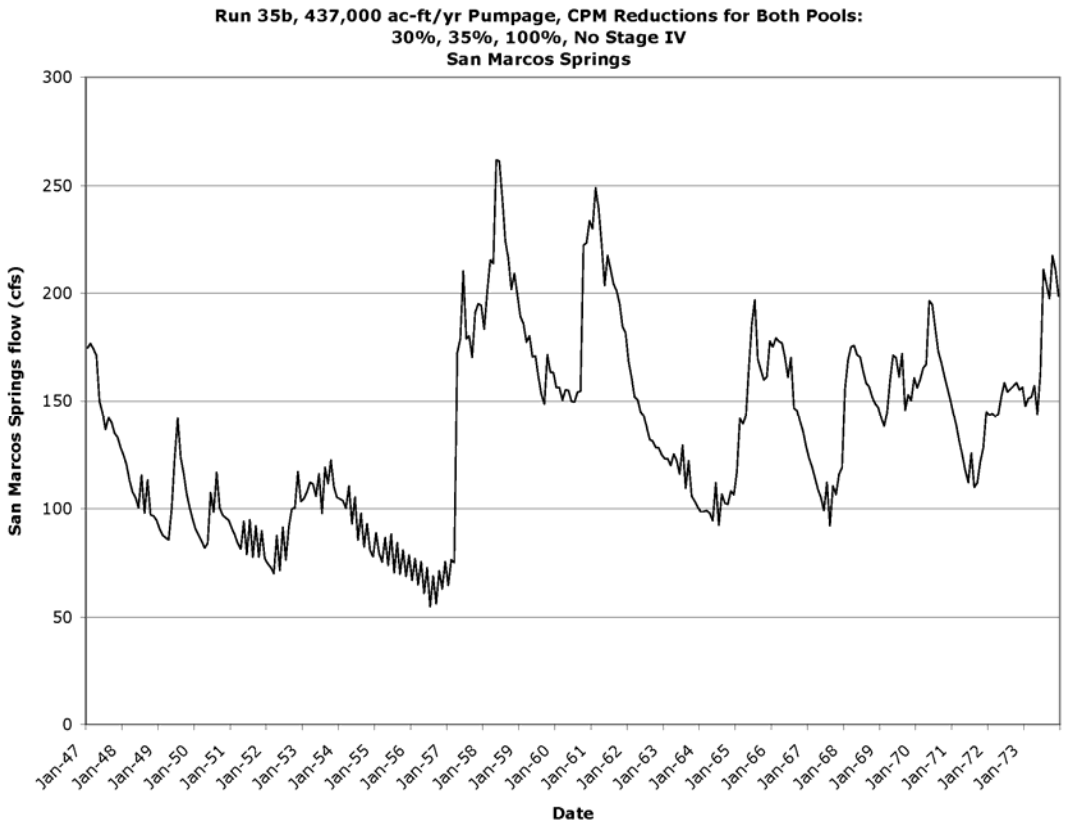
Jan-68
Jan-69
Jan-70
Jan-71
Jan-72
Jan-73
Date


Run 35a, 572,000 ac-ft/yr Pumpage, CPM Reductions for Both Pools:
30%, 35%, 100%, No Stage IV
San Marcos Springs
San Marcos Springs flow (cfs)
300
250
200
150
100
50
0
Jan-47
Jan-48
Jan-49
Jan-50
Jan-51
Jan-52
Jan-53
Jan-54
Jan-55
Jan-56
Jan-57
Jan-58
Jan-59
Jan-60
Jan-61
Jan-62
Jan-63
Jan-64
Jan-65
Jan-66
Jan-67
Jan-68
Jan-69
Jan-70
Jan-71
Jan-72
Jan-73
Date


Run 35a, 572,000 ac-ft/yr Pumpage, CPM Reductions for Both Pools:
30%, 35%, 100%, No Stage IV
Comal Springs
Comal Springs Flow (cfs)
450
400
350
300
250
200
150
100
50
0
Jan-47
Jan-48
Jan-49
Jan-50
Jan-51
Jan-52
Jan-53
Jan-54
Jan-55
Jan-56
Jan-57
Jan-58
Jan-59
Jan-60
Jan-61
Jan-62
Jan-63
Jan-64
Jan-65
Jan-66
Jan-67
Jan-68
Jan-69
Jan-70
Jan-71
Jan-72
Jan-73
Date


Run 35b, 437,000 ac-ft/yr Pumpage, CPM Reductions for Both Pools:
30%, 35%, 100%, No Stage IV
San Marcos Springs
San Marcos Springs flow (cfs)
300
250
200
150
100
50
0
Jan-47
Jan-48
Jan-49
Jan-50
Jan-51
Jan-52
Jan-53
Jan-54
Jan-55
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Jan-58
Jan-59
Jan-60
Jan-61
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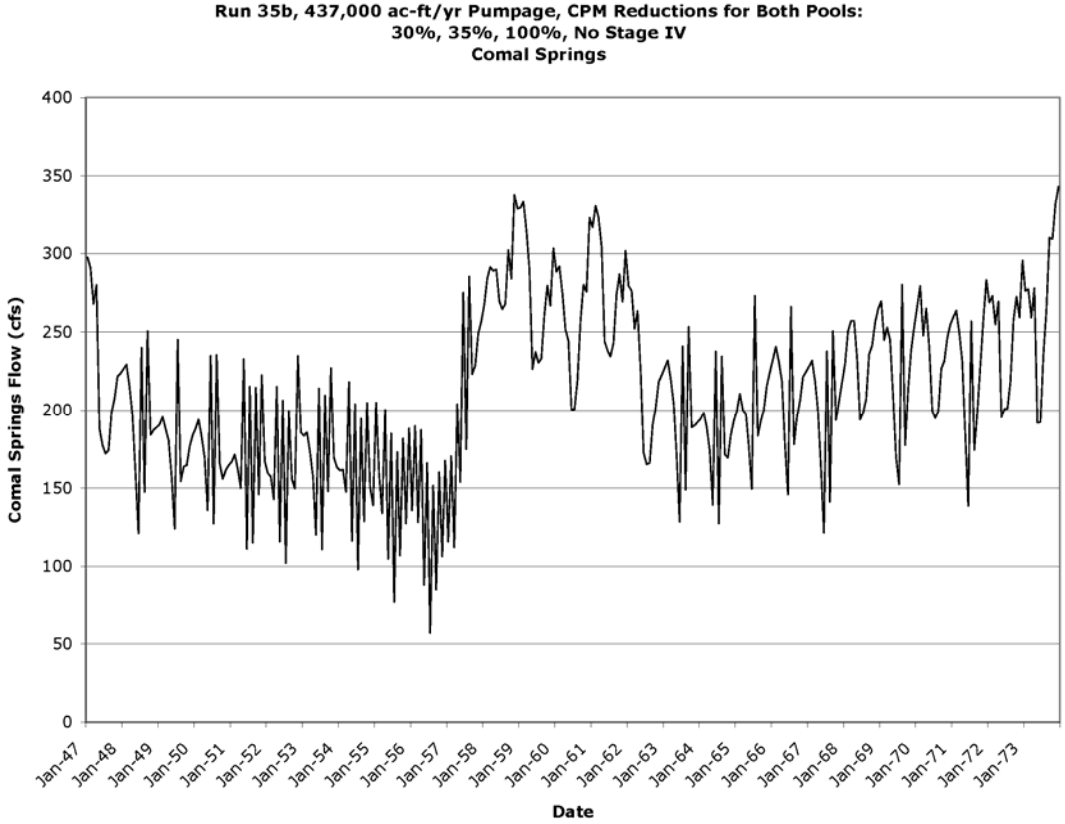
Jan-73
Date


Run 35b, 437,000 ac-ft/yr Pumpage, CPM Reductions for Both Pools:
30%, 35%, 100%, No Stage IV
Comal Springs
Comal Springs Flow (cfs)
400
350
300
250
200
150
100
50
0
Jan-47
Jan-48
Jan-49
Jan-50
Jan-51
Jan-52
Jan-53
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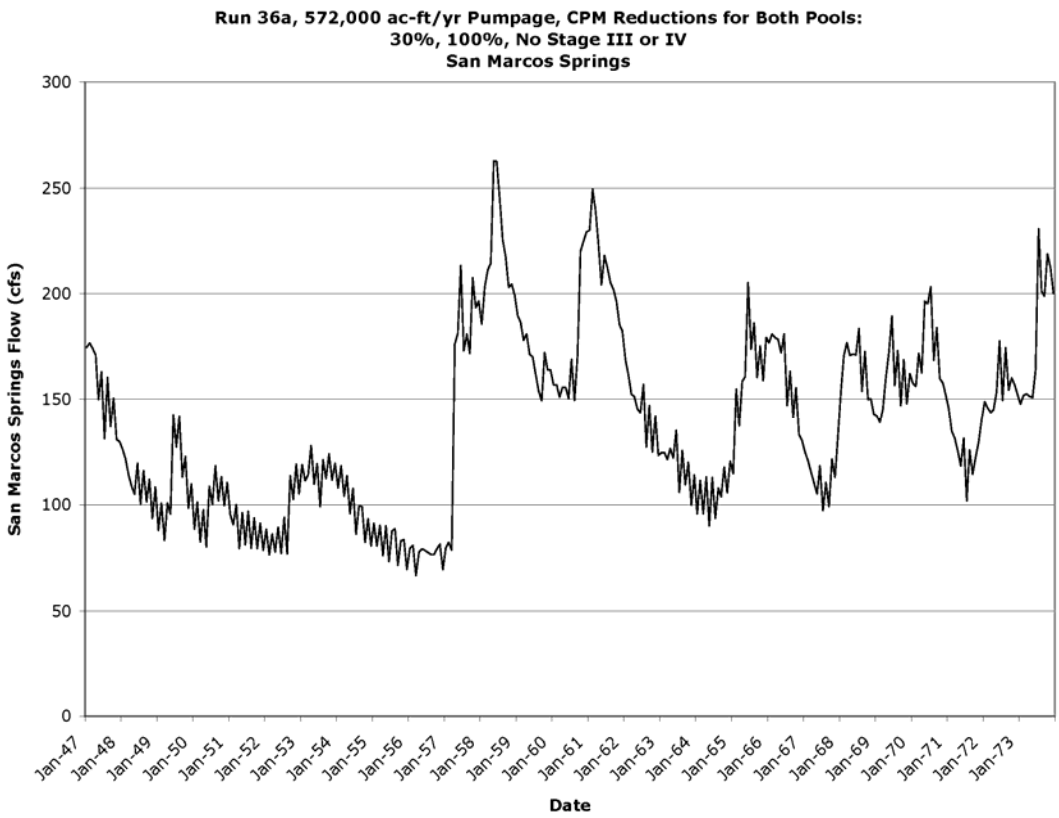
Date


Run 36a, 572,000 ac-ft/yr Pumpage, CPM Reductions for Both Pools:
30%, 100%, No Stage III or IV
San Marcos Springs
San Marcos Springs Flow (cfs)
300
250
200
150
100
50
0
Jan-47
Jan-48
Jan-49
Jan-50
Jan-51
Jan-52
Jan-53
Jan-54
Jan-55
Jan-56
Jan-57
Jan-58
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Jan-60
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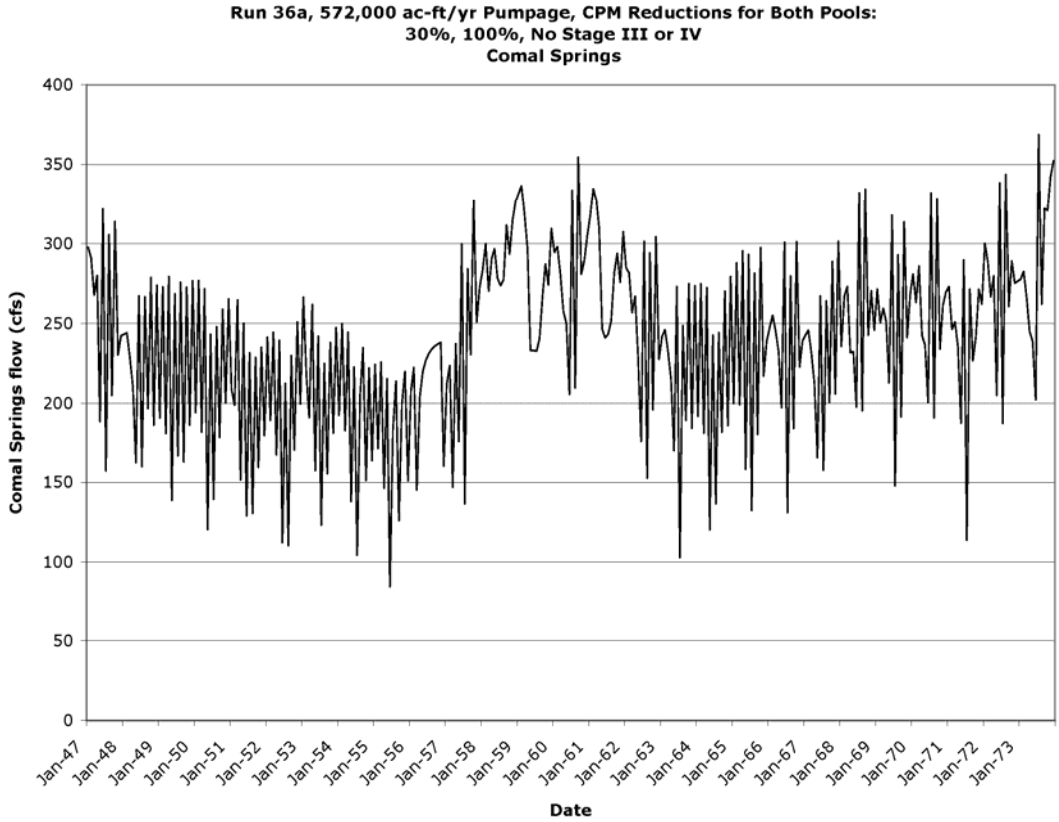
Jan-71
Jan-72
Jan-73
Date


Run 36a, 572,000 ac-ft/yr Pumpage, CPM Reductions for Both Pools:
30%, 100%, No Stage III or IV
Comal Springs
Comal Springs flow (cfs)
400
350
300
250
200
150
100
50
0
Jan-47
Jan-48
Jan-49
Jan-50
Jan-51
Jan-52
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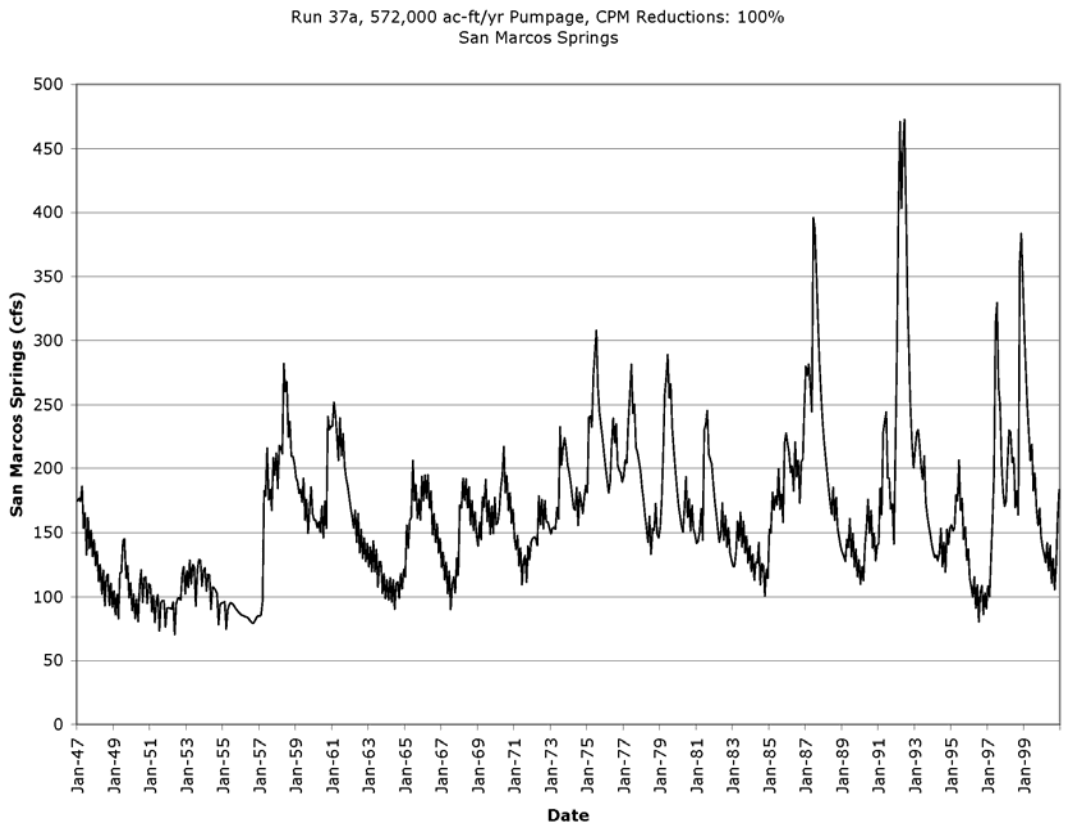
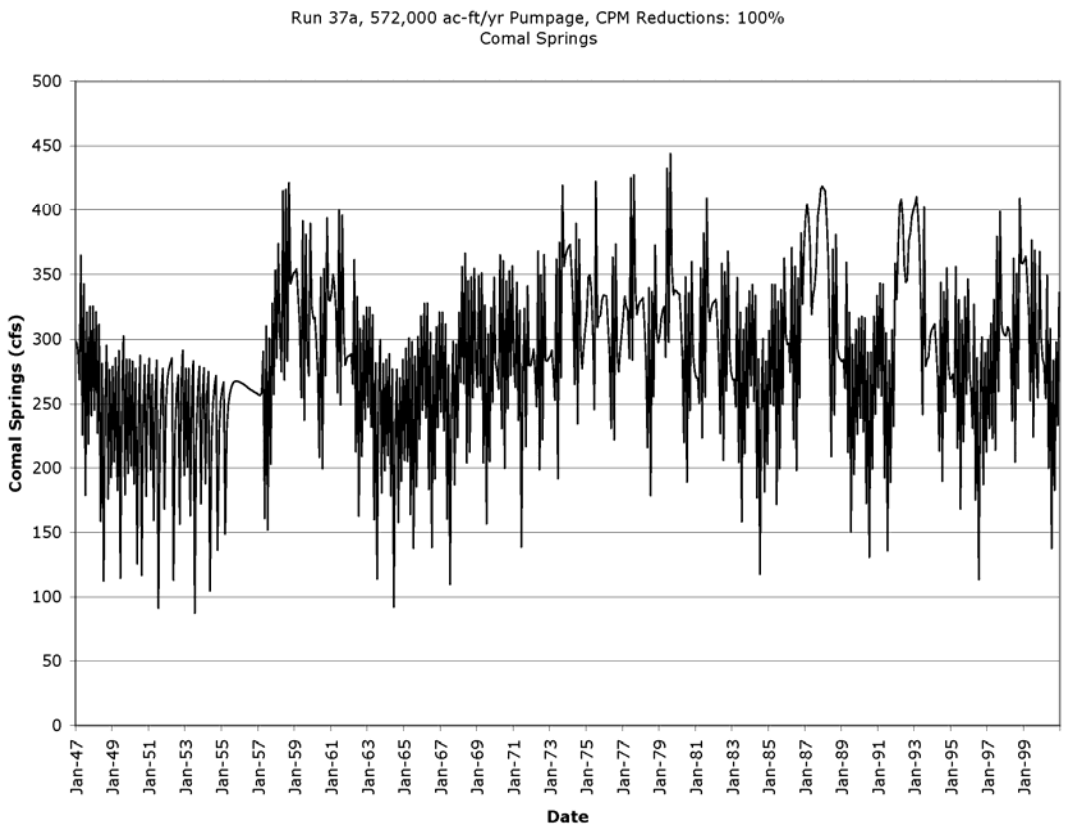
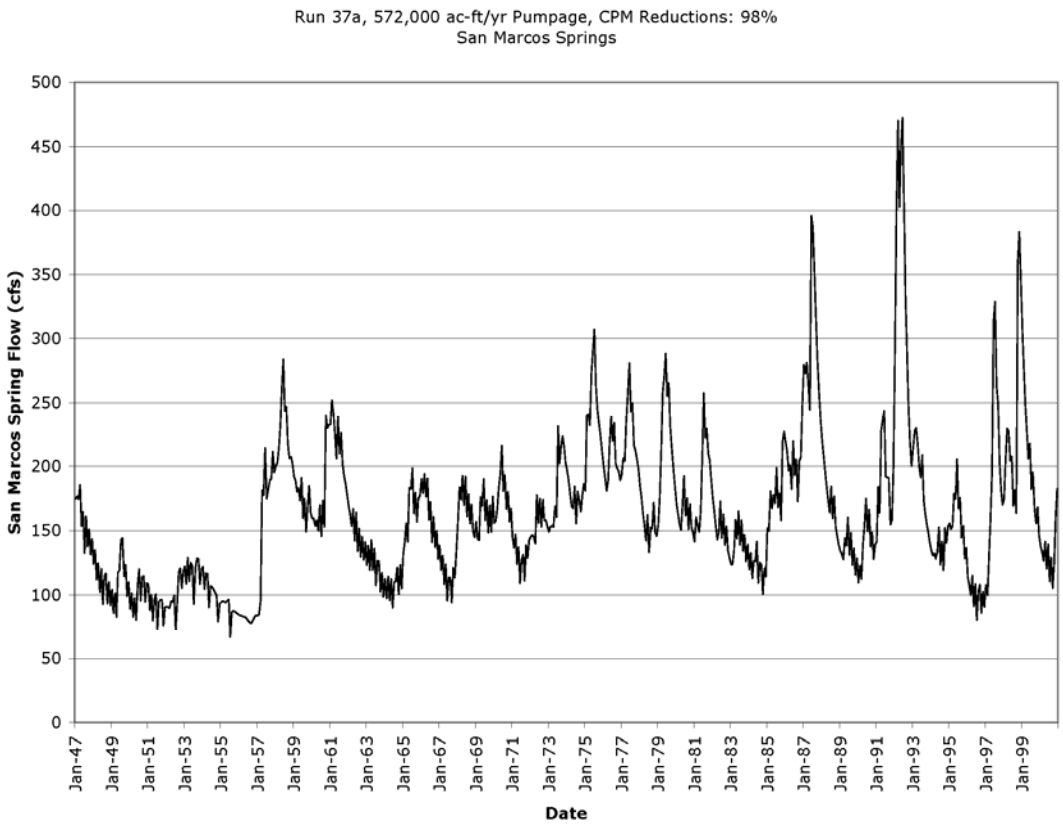
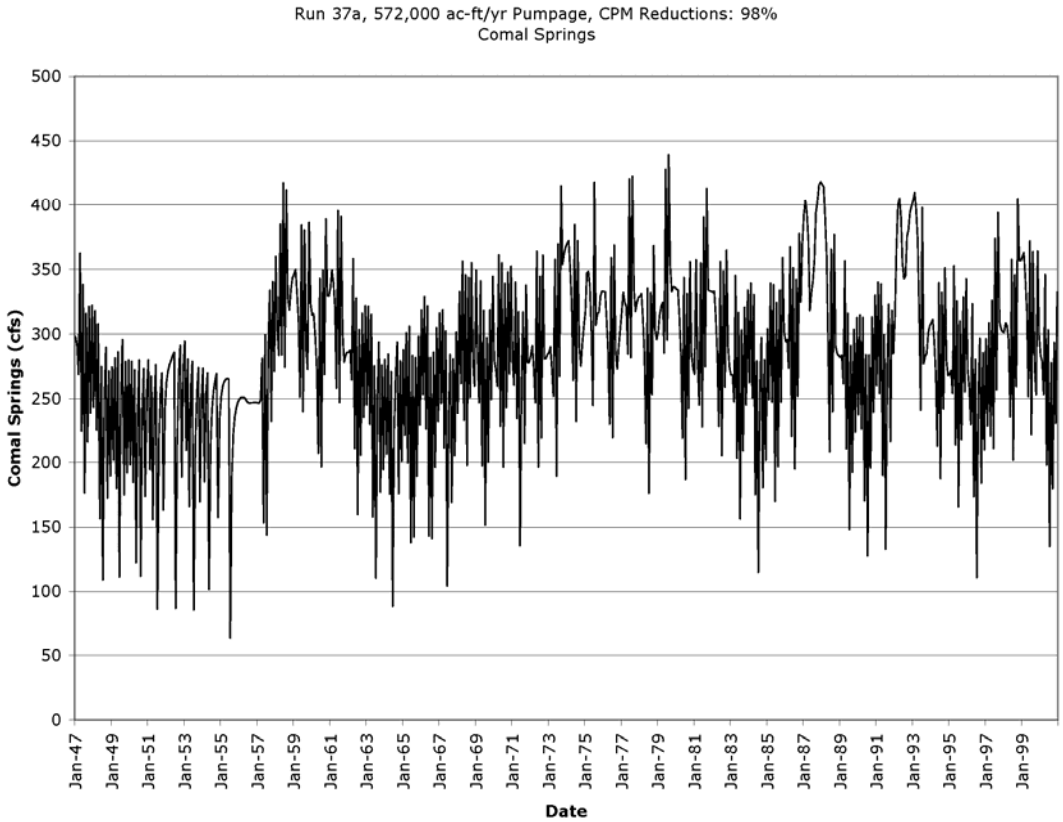
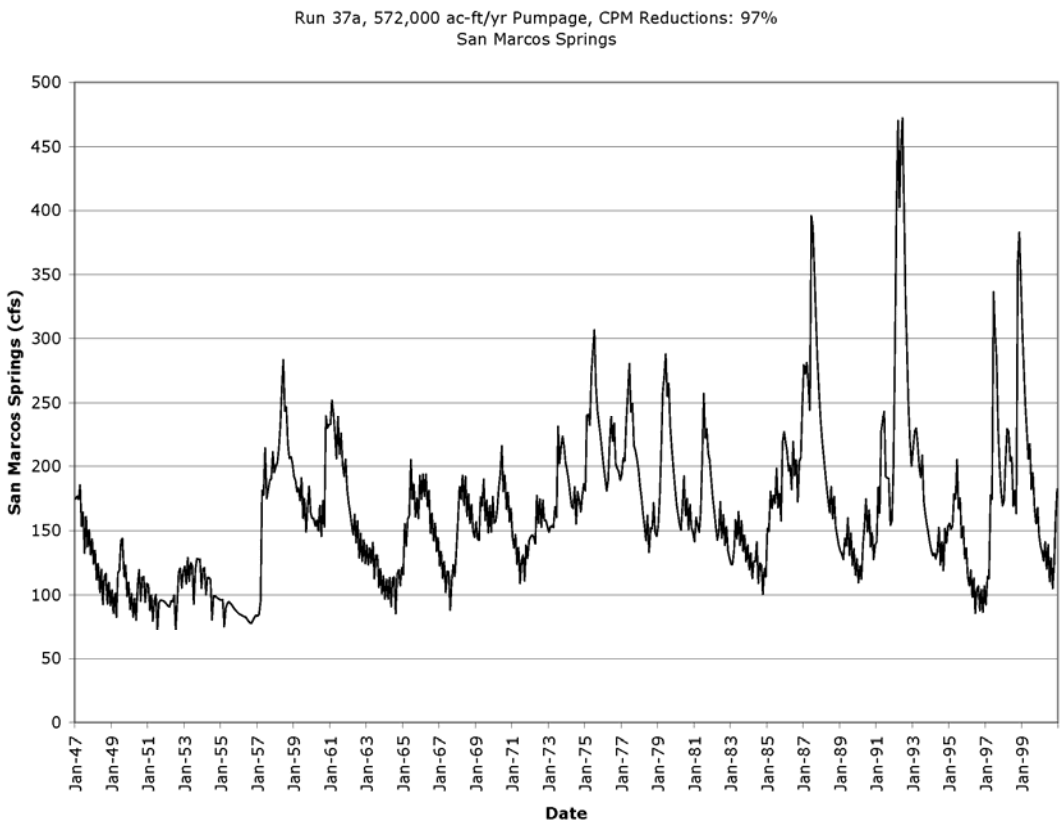
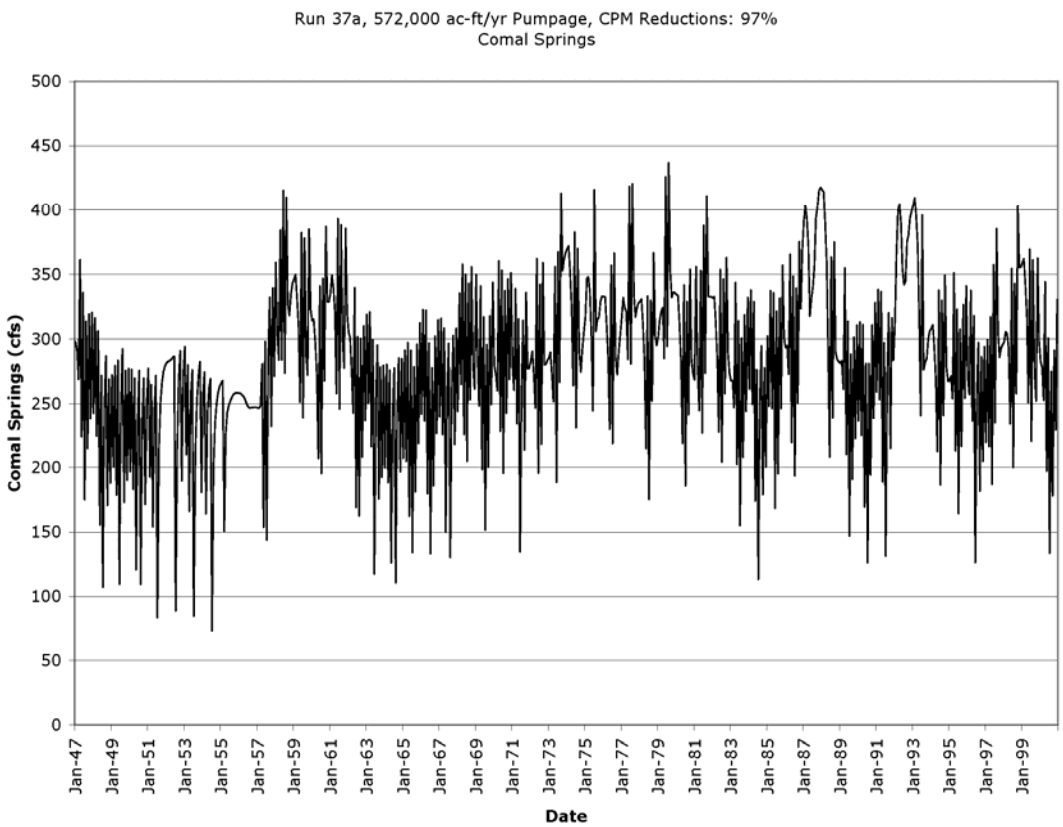

Run 37a, 572,000 ac-ft/yr Pumpage, CPM Reductions: 100%
San Marcos Springs
San Marcos Springs (cfs)
Date


Run 37a, 572,000 ac-ft/yr Pumpage, CPM Reductions: 100%
Comal Springs
Comal Springs (cfs)
Date

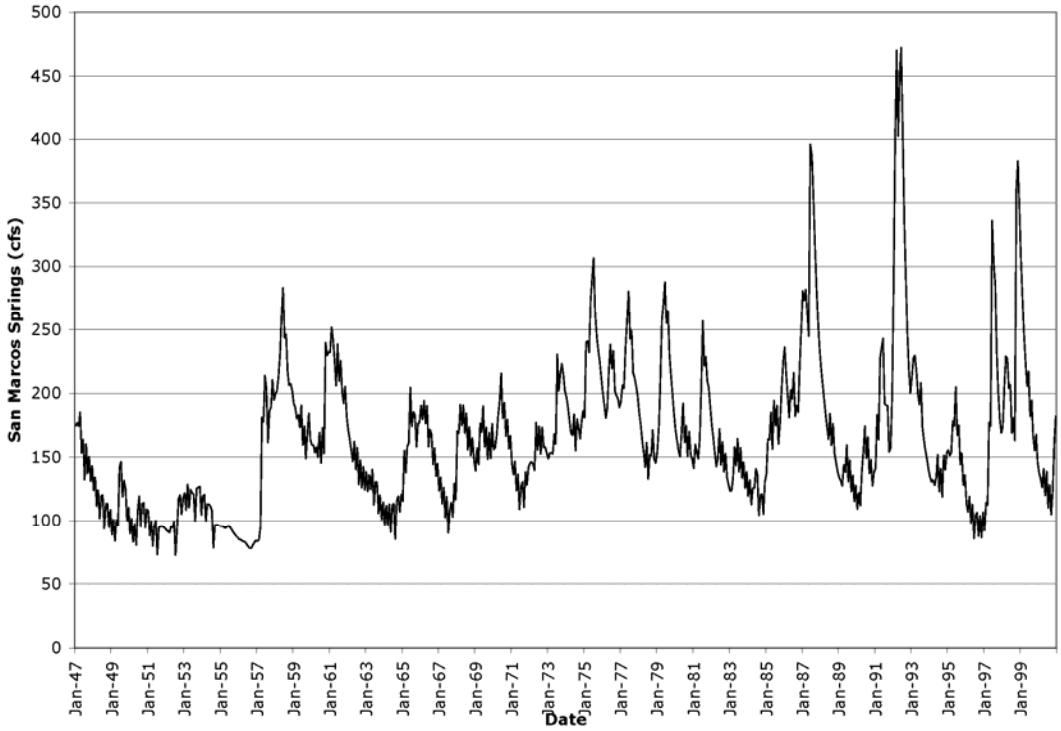

Run 37a, 572,000 ac-ft/yr Pumpage, CPM Reductions: 98%
San Marcos Springs
San Marcos Spring Flow (cfs)
Date


Run 37a, 572,000 ac-ft/yr Pumpage, CPM Reductions: 98%
Comal Springs
Comal Springs (cfs)
Date

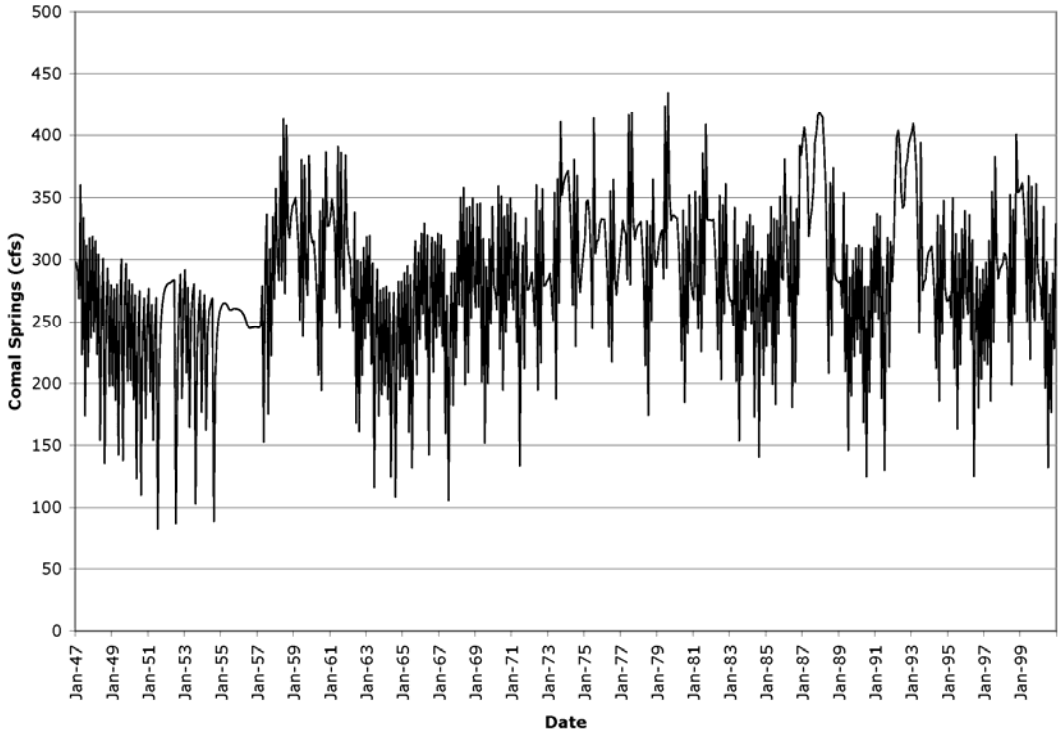

Run 37a, 572,000 ac-ft/yr Pumpage, CPM Reductions: 97%
San Marcos Springs
San Marcos Springs (cfs)
Date

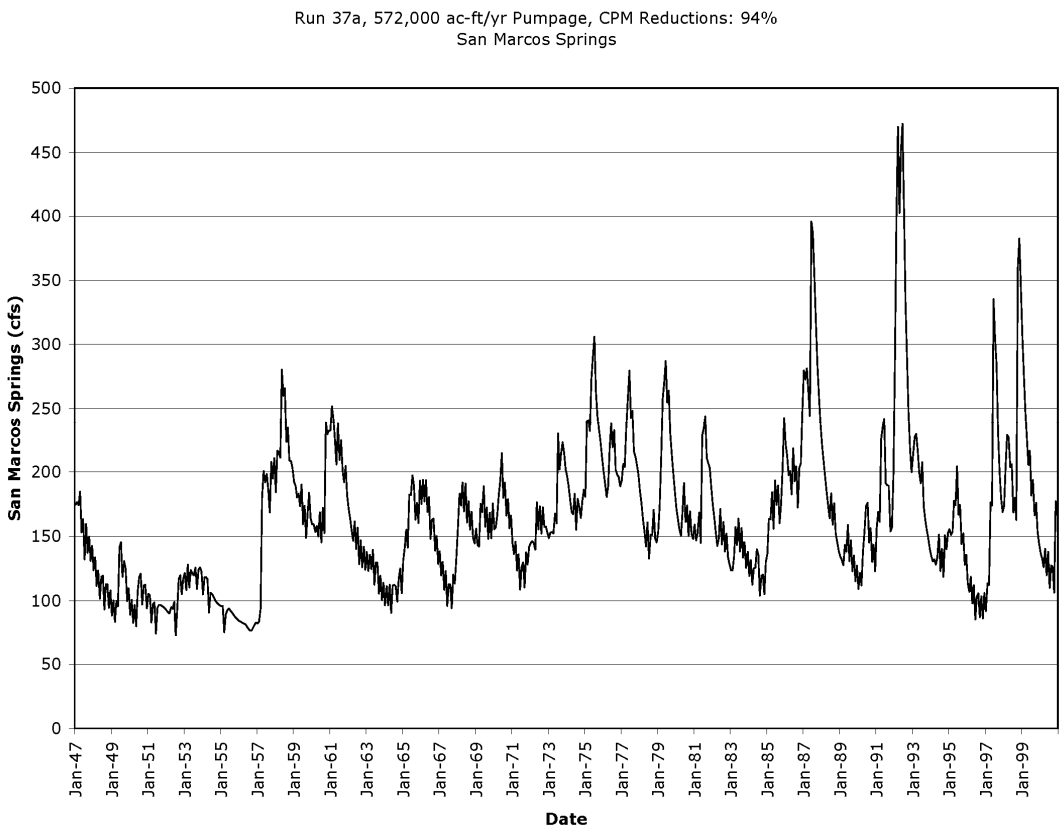

Run 37a, 572,000 ac-ft/yr Pumpage, CPM Reductions: 97%
Comal Springs
Comal Springs (cfs)
Date

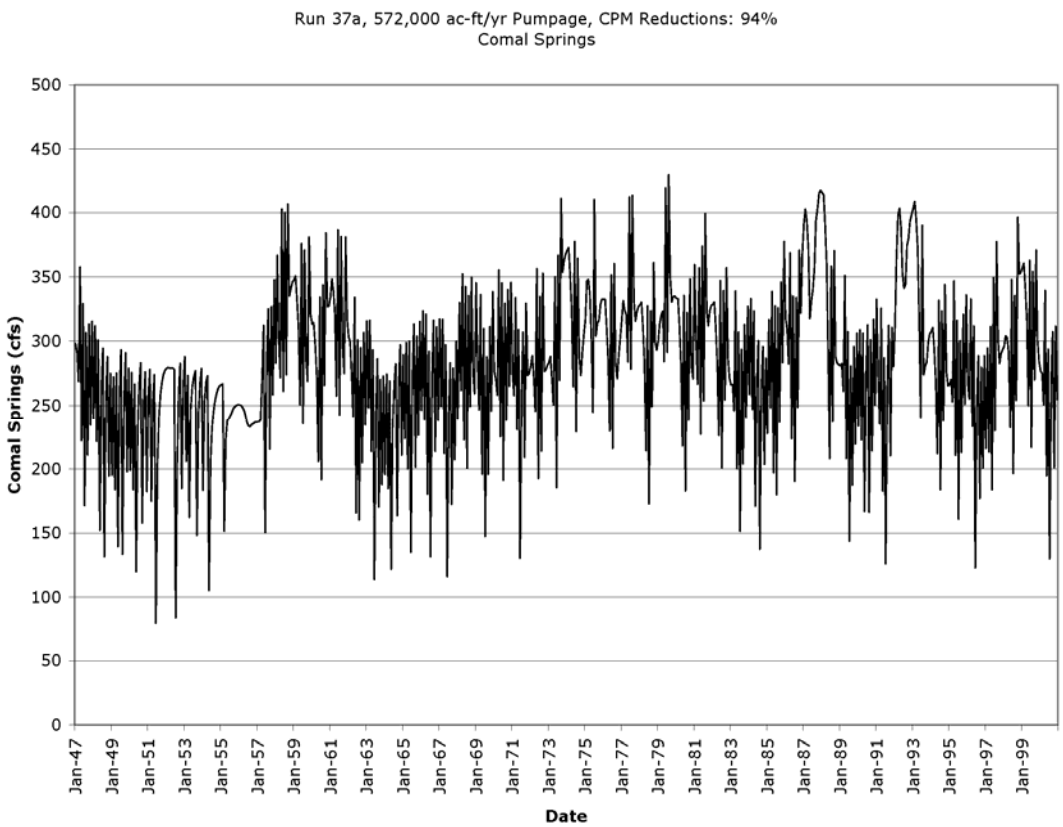
Run 37a, 572,000 ac-ft/yr Pumpage, CPM Reductions: 96%
San Marcos Springs

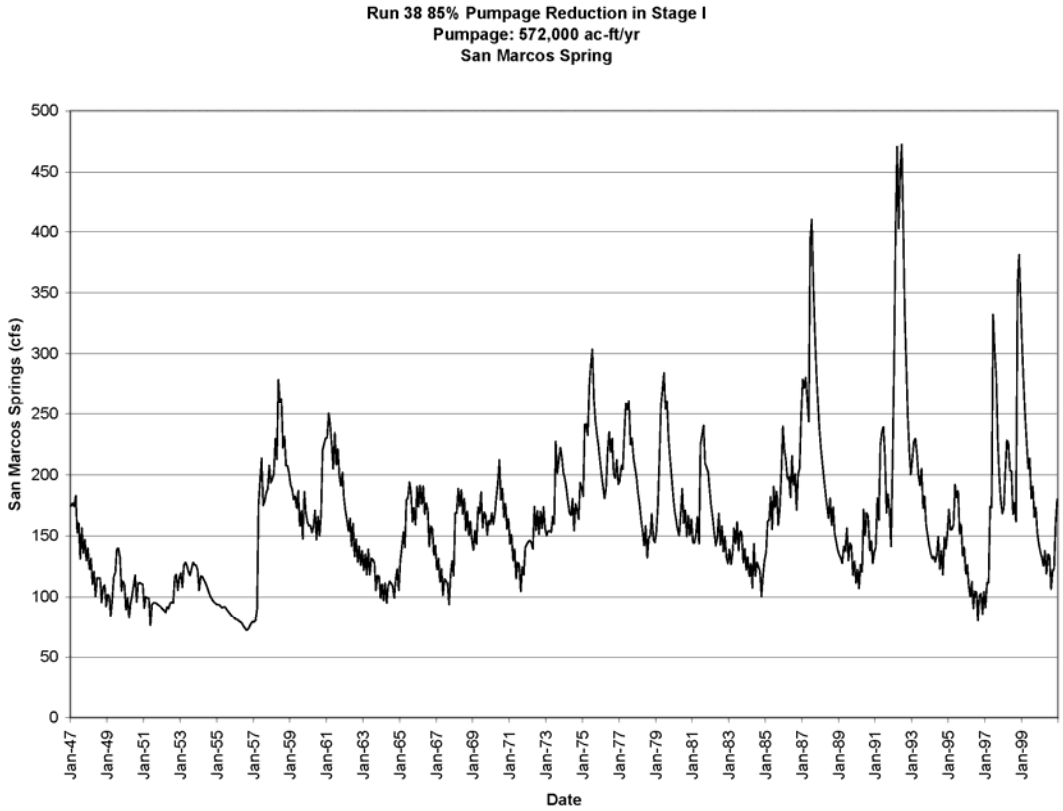


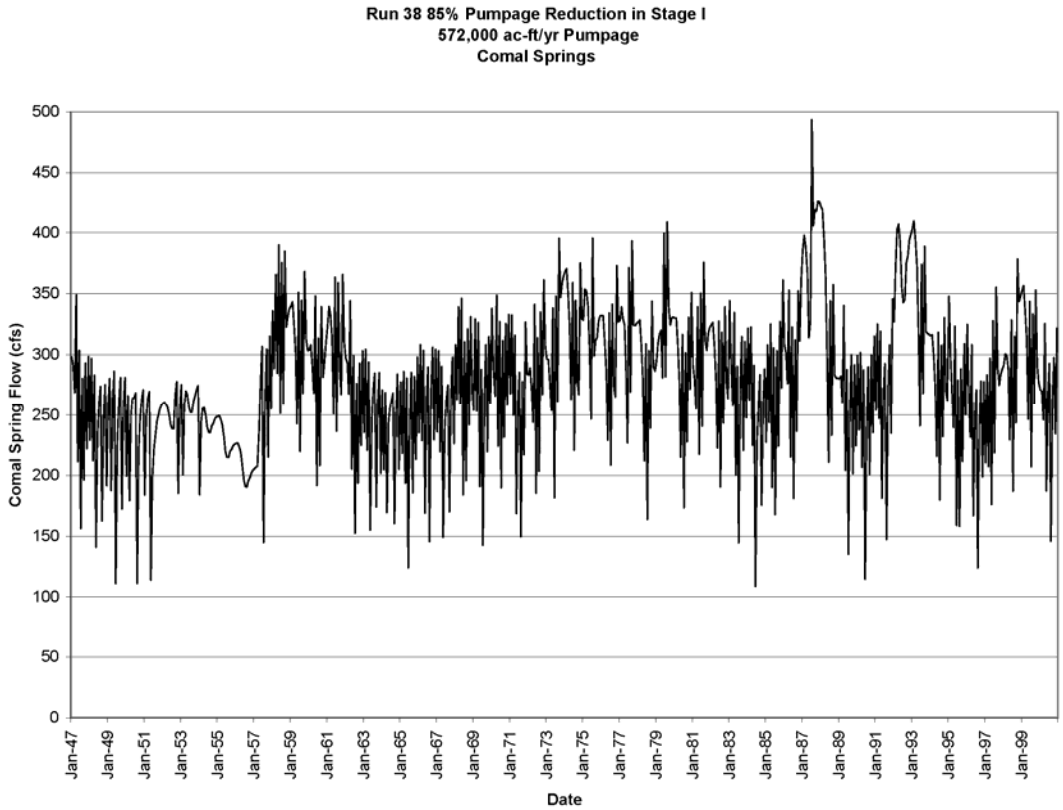
Run 37a, 572,000 ac-ft/yr Pumpage, CPM Reductions: 96%
Comal Springs




Run 37a, 572,000 ac-ft/yr Pumpage, CPM Reductions: 94%
San Marcos Springs
San Marcos Springs (cfs)
Date


Run 37a, 572,000 ac-ft/yr Pumpage, CPM Reductions: 94%
Comal Springs
Comal Springs (cfs)
Date


Run 38 85% Pumpage Reduction in Stage I
Pumpage: 572,000 ac-ft/yr
San Marcos Spring
San Marcos Springs (cfs)
Date


Run 38 85% Pumpage Reduction in Stage I
572,000 ac-ft/yr Pumpage
Comal Springs
Comal Spring Flow (cfs)
Date

Appendix H.
Edwards Aquifer model run reports and output files

See attached compact disk or folder of files.

APPENDIX E:

ANNEAR ASSOCIATES, LLC, "PEER REVIEW OF THE EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM'S SCIENCE SUBCOMMITTEE RECOMMENDATIONS AND THE HARDY STUDY," MAY 28, 2010

PEER REVIEW OF THE EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM'S SCIENCE SUBCOMMITTEE RECOMMENDATIONS AND THE HARDY STUDY

By

Annear Associates, LLC

Submitted

May 28, 2010

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Executive Summary

Review team comments were based on ecological principles advocated by the Instream Flow Council (IFC) that rivers are characterized by the unique combination of hydrology, geomorphology, biology, water quality, and connectivity components and processes (Annear et al. 2004 and Locke et al. 2008). The overall approach, analyses and conclusions contained in both reports took great strides to begin to address these elements.

The Subcommittee was given a difficult and complex assignment and did a thorough job of data assimilation, analysis, evaluation, and recommendation development using widely accepted scientific methods. The "j charges" report clearly addresses the two tasks the Subcommittee was asked to perform. The flow recommendations are based on the best available science and are presented in a form that is widely used within the scientific and water management community. The general approach taken for arriving at recommendations (i.e. consideration of monitoring data, model output, hydrologic records, and professional judgement) is acceptable and exemplifies the proper way to approach such a complex study. The review team recommends that further investigation into seasonal needs of the listed species and their life stages be carried out with a focus on future management actions related to preserving, or restoring seasonal and water year variability.

Given the recommendations from Task 1, Task 2 was accomplished in a logical and thorough manner using an approach that is both scientifically valid and defensible. The options considered a broad range of water use and management scenarios. Results provide guidance for meeting the flow levels and stages recommended in Task 1. The review team supports the flow and stage triggers as described in this report and recommends they be implemented on an interim basis pending future model improvement and ongoing research.

Overarching Comments

Report Strengths

Overall these two reports represent a relatively sophisticated approach to dealing with a complex and contentious situation that exceeds the level of analysis and consideration of the majority of similar studies in North America today. This is one of the few programs where there is such a strong commitment to the recovery and expansion of endangered species. Though there are additional things that could have been done, we found these reports to be valid, defensible, science-based presentations of what is known regarding the physical habitat-flow relationships of the primary target species (fountain darter, Texas wild rice, Comal Springs riffle beetle) in the San Marcos and Comal Rivers. As such, the reports present a solid basis for describing these aquatic ecosystems and are a valuable contribution to the Science Subcommittee and recovery effort.

The interim recommendations in the reports provide reasonable information to ensure that the species will not become extinct. However, it is the opinion of the review team that they do not provide enough information to ensure full protection and expansion of the species' populations. For example, elements like watershed inputs to surface and ground water quality, as well as recreation contributions to sedimentation, turbidity, physical disturbance, and associated impacts to aquatic vegetation, need additional research leading to management. The information in these reports represents a good starting point from which to design additional studies and analyses to further refine the existing recommendations. Additional study leading to improved triggers and other appropriate management procedures as recommended in the document would resolve more of the uncertainty associated with species recovery and expansion. In the review committee's opinion, this is one of the few studies where there is this level of commitment to management of the long-term survival of the species.

We fully endorse the technical analysis and output of the flow dependent characteristics of physical habitat for target aquatic species within the Comal and San Marcos Rivers. Developing influence diagrams for the three target species provided a valuable tool to understand both intrinsic and extrinsic factors that affect the target species. Providing the historical information along with the updated modeling based on new information (temperature and dissolved oxygen) and physical habitat for Texas wild rice, Comal Springs riffle beetle, and fountain darters, demonstrates improvement to the science. Using group workshops to seek consensus appears to have been an effective strategy and is to be commended. Carrying out model validation to predict locations of animals against observed locations of animals is considered "best practice". The tools and methods of analysis employed, with respect to fish habitat, are appropriately used based on best available information. The modeling was improved by using

empirical data such as vegetation distribution based on historical vegetation mapping results. Additionally, considering other factors such as non-native species of plants and animals, parasites, recreation, anthropogenic impacts due to watershed development, and inclusion of genetic analysis where appropriate (e.g., to explain population patterns in riffle beetle), shows a depth of investigation that is not commonly seen in other studies of this type. Recognizing the importance of developing a water management solution that reflects principles of the natural flow paradigm was appropriate; however this goal was only partially addressed by the recommendations.

The review committee finds no serious flaws or errors in the team's methodology, findings, and recommendations. Assumptions of the approach are well documented and are reasonable given today's understanding of aquatic ecosystems. The tools and methods of analysis employed, with respect to habitat modeling, are appropriately used based on best available information. We believe the report addressed the stated goal (focus of the work) and provided information necessary to begin to address targeted elements within the Edwards Aquifer Authority Act.

As noted above, the development of influence diagrams was a good way to recognize the many possible factors and pathways that comprise habitat for and affect the distribution and abundance of the target organisms. The more useful influence diagrams are those that reflect multiple pathways and inter-relationships among the various elements (as opposed to those that reflect independent, direct effects) because they realistically convey the complex interactions of real-world ecological processes. Though the reports do a good job of exploring the relationships between a relatively few selected environmental variables, these diagrams clearly show that recommendations could be improved by considering more factors, and their interactions, than have been addressed to date.

Balancing the needs of a multitude of species-specific requirements is a common issue in making one overall flow regime recommendation. The process undertaken by the team of taking the higher flow requirement for any particular species in each case, and then to assume this requirement would not negatively impact the other species or overall ecosystem integrity is a common approach used in many other studies. Subsequent monitoring to test this assumption is appropriate. These two approaches are consistent with current thinking, understanding of flowing aquatic ecosystems, and ecological theory.

The commitment to monitoring is an excellent approach to ensuring the long-term survival of the endangered species of the Comal and San Marcos springs and associated aquatic communities.

Guidance for the Final Report

There are only so many things that can be included in any study and it is unrealistic to think that this or any study could look at everything. Those involved in these reports recognize that fact either

intuitively or explicitly. However there are additional elements that should be addressed and integrated for subsequent analyses.

Additional strength could be provided to support and enhance this study through more direct integration of other elements within the influence diagrams. The influence diagram frameworks need to be further refined and formalized based on the comments and reviews received from experts.

Though species survival and abundance is a function of the interaction of many variables, hydrology drives the system. Conceptually, the prospects for species recovery could be enhanced by more thoroughly integrating recommendations with the major elements that influence flow in the springs. Time series analysis, matching the physical habitat modeling with the hydrologic record and ultimately producing habitat duration curves, would help identify bottlenecks and important thresholds and is standard procedure for physical habitat modeling.

For continuity all analyses should be based on the same underlying description of the system hydrology. How the flow is partitioned among the different springs and routed through the system is not only critical for obtaining realistic representations of the hydrology but is the primary driver of the water quality and physical habitat models.

Full characterization of the system hydrology: past, present, and potential including all elements: magnitude, duration, frequency, timing, and rate of change is necessary.

Establishing water year categories through 1) development of annual flow duration curves, 2) delineating water year strata (e.g. dry, normal, wet), 3) classifying each water year of the period of record into a specific stratum, and 4) then using that classification in a time series analysis to develop adaptive water management strategies would help refine recommendations. Additionally, hydrologic data should be stratified for water quality analysis according to cool, normal, and hot climatic conditions.

The ten additional research needs identified on page 90 of the "j charges" report are appropriate. Inclusion of this information and complete hydrologic analysis are features we look for in any significant flow-oriented study to provide all study teams with a common fundamental basis for their work. We found the level of hydrologic analysis lacking in both the Hardy report in which we find no mention of hydrology as well as the "j charges" report where consideration of natural vs. historic vs. existing hydrologic processes were not addressed as directly as they could have been considering that hydrologic alteration is one of the key factors that is involved with the status of the target species. The various computer runs in the appendix of the "j charges" report were good but the team felt more could have been gleaned from the analysis by at least contrasting each run with run #2 for each system (no pumping).

The review team was unclear what additional studies are to be included in this process, but note several places in the "j charges" report that led us to believe additional work was under way to further refine the recommendations in this report. For example page 63, paragraph 3, last sentence speaks of additional work to refine existing models and obtain more accurate estimates of flow needs. The section titled *Further Studies* on page 66 led us to believe that additional effort was underway or imminent to address the call for additional understanding outlined in that report and modify the recommendations in the "j charges" report. It is unclear how much of this work could be done by what we inferred was a final report, if indeed an additional formal report is part of this process. Attention to the Subcommittee's recommendations noted above provides a critical basis for all future work; providing an accepted, common hydrologic database. This common database should be completed for the existing gages and for all points of ecological interest using an appropriate water routing model to":

- Examine intra-annual flow variability. Each water year class hydrologic data should be partitioned to further define the range of variability by month or season and,
- Stratify the hydrologic record by water year (e.g. dry, normal, and wet) as a basis for future collaborative management of the resource where all parties involved in managing water and wildlife resources work together better. Each water year should subsequently be assigned to one of these classes of water availability.

Once the hydrology time series is completed, this becomes the primary input to conduct water quality (including temperature) and physical habitat modeling through time and space. Thermal criteria should be used to develop seasonal flow criteria. Physical habitat analyses start with the need for converting hydrologic time series data to habitat time series and the presentation of habitat duration plots representing the total system as well as specific reaches. In Figure 45 of the technical assessment report by Hardy, the flow/habitat relation is curvilinear. Typical for this kind of relation any time series analyses and duration plots for system hydrology and physical habitat would be quite different. In these cases (really all cases) it is important to translate the hydrology time series into physical habitat time series and subsequent summations and duration plots. When searching for potentially limiting habitat events this conversion is necessary.

Figure 46 of Hardy (2009) is an excellent way of presenting model results with actual field observations and should become standard practice in complex systems with high water use and where maintenance or recovery of aquatic species is the goal. With system wide analyses driven by time series, illustrations of the distribution of highly suitable physical habitats by season and year can be produced. With this information the investigating team can start teasing out potential limiting events (and duration) that influence species' life stage development and population response. Once these life stages and the

timing and duration of limiting events are understood management schemes can focus on control of water diversions and pumping to maintain areas and timing of highly suitable physical habitat conditions at appropriate seasons and places (even improving the extent and duration of suitable conditions if recovery or restoration is the goal).

Excellent first steps are presented in this report illustrating model use. Following suitable physical habitat time series study and identification of potential limiting events the most appropriate comparison of field observations on species distribution would be with those simulated conditions and areas shown to be most favourable during critical life stage events. For wild rice, good correlations with actual field observed distributions would be very unlikely at the discharge and quality conditions found at the time of field observation. Rather it is likely that past events and duration have greater influence on the observed distribution. One would expect a much greater correspondence with areas experiencing repeated and sustained highly suitable conditions. This can only be illustrated via time series simulations.

As noted throughout the report, expansion of life history information would benefit the understanding of flow requirements. Integrating existing knowledge of the timing of life history events, particularly for the fountain darter and Texas wild rice, with hydrologic and habitat time series would lead to better understanding of these endangered species' flow needs and seasonally appropriate decision making. Differences between "old HSC" and "new HSC" curves are quite dramatic and illustrate the significant changes in suitable physical habitat area that may occur between 40 cfs and 150 cfs. To maintain or enhance conditions for the darter populations through time series analyses of past habitat conditions the analyst can determine **when** (seasons and years) and **where** (reaches having highly suitable as well as stable conditions with longer duration at critical times) physical habitat conditions occurred that had the potential for supporting healthy populations. From a management perspective the important question often becomes: "can those conditions be maintained or even improved with similar timing and distributions in the future?" The converse is equally true for identifying conditions of most unsuitable physical habitat conditions. Can the timing and duration of unsuitable events be reduced? Fine tuning HSC curves to these species' distribution plots is the preferred way for calibrating and verifying suitable physical habitat mode output.

The report goes to considerable detail to calibrate and verify the water quality model. This is laudable and represents standard practice in this discipline. However, similar verification for the hydro-dynamic modeling is not given. Verification is essential as the velocity distribution predictions are critical inputs to the physical habitat simulations. Proper calibration and verification must be standard practice for stream physical habitat analyses. See National Research Council (2008) for a thorough discussion of formulating and applying models in ecosystem management.

As the influence diagrams clearly indicate, the abundance and distribution of organisms are driven by the interaction of a large suite of factors. Though scientists strive to define these inter-relationships, the fact is that there are no widely accepted models today that are capable of integrating more than a limited number of variables into a single model. In recent years, however, there has been some effort devoted to performing Bayesian Probability Assessments that are structured somewhat like the influence diagrams shown in Hardy's 2009 report. Though such models can require very large data sets, they can also be performed on a conceptual basis relying on consensus-developed assumptions (probabilities) about relationships between and among identified environmental elements. Conducting Bayesian analysis with consensus-developed probabilities is essentially a formalized approach of using professional judgment to make decisions about how systems operate.

Regardless of the specific method(s) used, professional judgment is the fundamental basis for all modeling and is necessary to integrate information across a variety of disciplines that is derived from models. Even a formal acknowledgment of the absence of data, when accompanied by reasonable assumptions, will advance understanding and serve as the basis for refinement of ecosystem needs. This kind of integration requires open communication across disciplines, which appears to be well established with the EARIP.

It appears that the hydrology analyses driving the Physical Habitat and Water Quality modeling as well as the Hydrology analyses central to the Expert Science Subcommitee for the Edwards Aquifer Recovery Implementation Program were developed separately. Because each discipline tends to work independently, the notion of being forced to agree on a common description and model representation of the system hydrology before the different analytical analyses are conducted, remains a central issue for more holistic views of river systems. Programs where there is a lack of a common description of the hydrology through time and space become the primary excuse for not conducting time series analyses of water quality and physical habitat followed by the identification of potential bottlenecks to species' life stage development and population viability. This is unfortunate because these types of analyses of spatial distribution and timing can provide a basis for identifying critical limiting events as constraints to healthy life stage development for aquatic species.

The approach of using metrics defining thresholds for loss of habitat and an instantaneous threshold, below which no water should be taken, is consistent with similar studies throughout North America. The review team had difficulty understanding how seasonal and inter-annual adjustments would be made and when these adjustments would be implemented in a real time operational sense. The review team agrees that pumping reductions to meet these trigger criteria is a positive interim strategy. However, this is a reactive approach and is bound to be difficult to implement in a way that maintains and

enhances the species and habitat conditions in the springs. Again, hydrologic time series analysis and full characterization described above is a fundamental step towards time-sensitive forecasting and proactive water management of this system.

Future Work and Synthesis

A positive indication from the reports is that the Edwards Aquifer Recovery Implementation Program committed to continued monitoring, data collection, and modeling to advance understanding for planning and management of the system. This suggests movement toward Adaptive Management, which is critical for a system of this complexity. We are unsure how much additional work can be conducted prior to a final report, if such subsequent document is underway or planned, and recommendations and whether some of the recommendations we feel need to be addressed can actually be incorporated. However, to the extent that additional work is possible we offer the following discussion and suggestions:

- Global climate models provide an indication of the magnitude of change for each group of hydrologic descriptors (magnitude, duration, frequency, timing, and rate of change) and can provide the basis for sensitivity analysis and refinement of water management decision making. The hydrologic time series analysis suggested above provides the foundation for incorporating climate change information with appropriate sensitivity analysis into management models; where expected changes to each water year type are characterized and used to indicate the range of conditions that may be faced.

- The legal and institutional mandate of the Edwards Aquifer Authority provides a clear legal and institutional basis for additional studies that appear to allow for changes to the water management plan, *"if it is later revealed that significant impacts are not captured in the model results. . ."* When coupled with additional water quality and physical habitat data, future system modeling efforts can provide valuable support for an adaptive management approach. Important first steps toward a viable Adaptive Management Program are presented in both the "Hardy" and the "j charges" reports. As long as the stakeholders and management agree to periodic (2-5 year) updates of the data bases along with repeated model runs, the program should reach a common understanding of limiting conditions and consensus on what would be necessary to protect or even enhance system conditions allowing recovery of the target endangered species. However, agreeing on actual implementation measures to achieve protection or recovery may be practically difficult or politically unacceptable.

- Monitoring and the means to adapt the future findings are appropriate and critical to meeting the overall goal of this effort. We emphasize that good science can lead to common understanding

and agreement on the conditions that are controlling the biological response of species and populations of concern. Disagreements may well arise over management measures and the political will to implement control over water use. An adaptive management program, of which monitoring is a critical piece, should move away from disagreements over the science and help focus discussion toward understanding potentials for protection by preventing further degradation (or even enhancing) by addressing the limiting system conditions found to be critical for maintaining viable species populations.

- One potential stressor on endangered species that should be addressed is the spread of aquatic invasives, such as zebra mussels.

Influence Diagrams for Target Species

P. 4; The Subcommittee is to be commended for conducting a series of workshops involving a multidisciplinary team of biologists to develop influence diagrams. We also commend the Subcommittee for keeping a meticulous record of the conversations. One of the most overlooked tasks in carrying out these types of studies is to "document your logic". This step was critical for identifying the key issues and the creation of influence diagrams was effective for displaying the complexity of all factors and how existing knowledge could help guide them in the modeling.

P. 4 -13; A recurring comment applicable to all species regarding the diagrams is the importance of "connectivity". Fragmentation of river systems and the resultant loss of genetic diversity and increased potential for extinction is a well recognized aspect of meta-population ecology and research. These systems are physically and thermally fragmented and physical barriers are plotted in the diagrams as a part of the "big picture" for each species except fountain darters. References here and elsewhere to "connectivity" are unclear as to which of the 4 aspects is involved (longitudinal, lateral, vertical or temporal). This issue may be dealt with in future studies but it would be helpful to discuss the applicability of each of these aspects. Figure 8 and the few other references we found in the report discuss connectivity primarily as it relates to dispersal of the organism of interest; but it would be good to relate the role of connectivity to other important environmental variables such as (seasonal) thermal barriers, sediment import/export, nutrients, and energetic materials.

P. 8, Figure 6; This is a good illustration of the relationships affecting water quantity and quality that is applicable for all species and an important determinant for these systems.

P. 11, Figure 10 (and others); Channelization and urban encroachment are also influencing factors that should be included.

P. 11; A better understanding of the overall habitat processes could be achieved by providing more information as to why or how flooding and drought are considered. Depending on the situation, these hydrologic processes can have both positive and negative influences. Per the natural flow paradigm, intra- and inter-annual flow variability are key drivers for most organisms and their habitat.

Hydrodynamic Modeling

P. 14; It is noted that a flood in 1998 altered the channel geometry and greatly affected the vegetation of the San Marcos River. Analysis of subsequent cross sectional data was judged that "the channel changes could potentially impact modeling results enough to warrant remapping of channel topographies". Later in the report analyses illustrate a scale change in the flow/physical habitat relations but little change in the overall shape of the relation. However, the scale is very important when conducting time series analyses. As the program progresses it would be important to periodically update the data base by resurveying the topography when significant channel change has occurred. As a way of determining when significant channel change is evident we recommend that the river be geomorphically stratified and permanently monumented cross sections be established and periodically surveyed within each strata.

Remapping the distribution of vegetation over time is likewise important. As the time series is put together, the different channel topographies and vegetation distributions would be entered into the data base at appropriate intervals to represent the channel for specific time periods in the series.

P 17; Most 2-dimensional models do a reasonably good job of simulating velocities under the range of flow conditions noted but one important component that should be addressed is how they model edge effects. Because many species are associated with the edge of rivers, an accounting should be provided for how the RMA2 model deals with edge effects. This is another reason the review team emphasizes the need to calibrate and verify velocity distributions using empirical data.

P. 18; It is not clear how the partitioning among springs from Brune (1981) compare with the hydrology analyses discussed in this report. It is very important that the same description of the system hydrology, including partitioning among spring flows and routing water through the system, be used for all water quality and physical habitat analyses as the WUA results and conclusions are based on this assumption.

P. 23; Each vegetation species was assigned a unique hydraulic roughness except Texas wild rice, for valid reasons. Recognizing the sensitivity of Texas wild rice to velocity, it is important that these data be estimated based on at least some empirical data over a range of flows and seasons to verify modeled velocity distributions.

P. 25; 1st paragraph; The resultant velocities from the 2-D model are still modeled values, not "actual values," whether they are adjusted by the velocity ratio or not, emphasizing again the need for verification of velocity predictions.

Water Quality and Temperature Modeling

P. 25; The modeling exercise using maximum dissolved oxygen values would likely have been more meaningful had minimum or daily average values been used. Also, since an optimum temperature range was defined for fountain darters, it would appear that modeling diel temperature values might also be insightful, especially if seasonal analysis were to be undertaken.

P. 29; The basis for the assumption at the bottom of Table 6 about the level of spring flow in the upper portion of Landa Lake is unclear. This reinforces the need for a common descriptor of how water is routed through the system.

P. 30; Dissolved oxygen levels are typically lowest just before daylight as a function of extended respiration of aquatic plants and periphyton over night. The influence of other limiting factors such as BOD would be reflected then too so it would not be necessary to factor out specific causes of low DO. It is not necessary to track diel DO levels but if the study only focuses on one time of day it should be tied to daybreak, which at least in theory could be a potential bottleneck. The report does not say what time of day DO relates to, which raises some question about whether the number presented is truly a limiting factor.

P. 30; Given the urban setting and relative lack of apparent riparia to absorb runoff contaminants, dissolved oxygen modeling should be performed with the effect of ammonia, nitrate oxidation, sediment oxygen demand, phytoplanktonic algae/macrophytes, and associated respiration, growth, nutrient effects, and BOD. This lack represents a key area of future integration tying the watershed, water quality, and usable habitat of the endangered species.

P. 30-31; The presentation of calibration and verification data for the water quality modeling as illustrated in Fig.23 represents the long established practice among water quality experts. This must also be included for the hydrodynamic (hydraulics) models. Also noted here is reference to modeling DO. Later in the report emphasis is placed on needing to know if DO depletions may occur during the night time. These water quality models are useful for such analyses of diel predictions by season and climatic condition.

P. 31; Inclusion of twenty one segments of 100 feet in length, each similar reaches is an example of strong technical work.

Habitat Suitability Curves

P. 35; This paragraph represents a strength of this work and approach: the scientific community were apparently actively engaged in the collection or review of the information used. The HSC for wild rice

were based on work by Saunders et al. (2001); Hardy et al. (1998) established the basic sampling protocols for HSC for fountain darters; there was additional data available on vegetation use (by darters) but not useable because of vagaries in vegetation coding schemes. According to the report, this issue is being addressed through ongoing vegetation mapping that will allow incorporation of the long-term data for fountain darter vegetation suitability curves. In addition, the annual monitoring data collaboratively collected by TPWD and USFWS for Texas wild rice (TWR) were used to evaluate the existing TWR HSC and based on that review, were not modified.

P. 35; Here and other places in the report identify the importance of aquatic vegetation as habitat features for darters. Habitat modeling for these vegetation types should also be continued for future analyses.

P. 36; Normalizing the HSC curves, and resultant habitat versus flow curves is a very common and accepted practice. The amount of data considered is comprehensive relative to many similar types of studies. The combination of modeling data with empirical data which is then thoroughly discussed with all stakeholders represents an excellent way to develop HSC curves.

P. 36, 37; From the report: this beetle occurs in gravel substrate and shallow riffles in spring runs and upwelling spring orifices. They may, like many Elmid species, require 6 months to 3 years to complete a life cycle, and usable water depth is 1 to 4 inches. These life history pieces, along with the 1950's drought experience, suggest that the species can survive low flow conditions, but also may be susceptible to water quality changes (contaminants) or sediment influxes. The final paragraph on this page, discussing decreased genetic variability as strong evidence for isolation coincides with meta-population ecology and, again, points to the importance of additional emphasis to address connectivity in this system (from watershed to groundwater recharge and surface water runoff to spring to channel and downstream). The rationale for depths, given what little is known, is logical and acceptable. All of this argues for additional, basic research into the life history and habitat requirements of this species.

P. 37, top 2 paragraphs; If flowing water is important for survival of beetles, clarification is needed to explain why velocity (even if described by a binary function) was not also used for habitat modeling.

P. 37, 4th paragraph; If sufficient information been gathered over the years to develop a relationship between Texas wild rice presence or abundance and turbidity it should be incorporated into the habitat modeling analysis for wild rice. Nutrient availability is known to be an important factor in growth for other species of wild rice. The importance of this factor for Texas wild rice should be studied for use in future decision making.

P. 37; It is admittedly a challenge to determine the relative efficacy of the two sets of suitability curves presented here, but it seems the USFWS-USU curves may do a more conservative job of reflecting flow

needs for this species. The TPW curves give the appearance of being more precise however it is unclear what the various HSC steps are based on other than perhaps an effort to narrow the range of suitable flows (for depth) or give more weight to lower flows (based on velocities). However verification of model outputs with actual stands of wild rice will determine the appropriate HSC for this species (see Figure 45).

Current understanding clearly suggests that protecting this species should also address turbidity in a quantitative manner. Criteria of some sort are needed to manage flow, recreational activities, or runoff in the watershed to maintain turbidity below some defined level. Development of these criteria will require additional studies to establish the relationship(s) between these variables.

Also, as noted above, there is no recognition of the need for different flows at different times of year for different life history needs. The relative merit of extremely high flows could possibly be deduced by an explanation of re-colonization processes following the 1989 flood. Delineation of water year strata as recommended by the review team for full description of the hydrology, coupled with life cycle periodicity of Texas wild rice would provide information on the intra- and inter-annual habitat requirements for recovery of this species.

P. 39, Figure 27; The extension of optimum water velocity (SI = 1.0) leftward to 0.25 ft/s does not seem to be supported by the 1996 and 1933 observations discussed in the text. Further explanation for this curve modification is needed.

P. 40 -43; The science utilized for HSC modeling of this species is thorough. This species appears to prefer medium to shallow pool depths and we would expect to see a relationship that favors relatively low discharge as affecting depths and velocities. In fact it seems that fountain darter habitat is affected primarily by low flow effects on temperature or on vegetation, which the analysis picks up. Technical team multivariate analysis of habitat associations with depth, velocity, vegetation type, and height of vegetation (likely surrogates for cover) confirm the direction of the analysis, and illustrate the advisability of revised modeling. This section does make the point that this species may spawn at all times of year but it is unclear if flow needs for various life stages vary during the year or if spawning is more prevalent at some times of year or seasons, or is keyed to flow pulses of some sort.

P. 42, Figure 29; This figure does not indicate whether this HSC curve is for mean velocity or velocity near stream bed. Since both were used in the analysis, they should both be shown.

Physical Habitat Modeling

P. 44; The assumption that vegetation/substrate characteristics did not change as a function of flow rate seems counter to the analysis. We know the bed changed, e.g, after floods and upstream watershed

activity. The 'dam removed' option at Cape's Dam showed as much. For the case of the TWR, the point is made that low and high flows are associated with disturbance, either from recreation or the flood flows and sediment scour. With the extensive data monitoring that is currently being done on TWR beds, it would seem data could be collected to reflect the situation better. See comments under P. 14 above.

P. 44; Assigning vegetation type and associated roughness values to each node is acceptable and an appropriate way to assess habitat suitability at nodes.

Physical Habitat Modeling

P. 45; There is apparently a typo for the binary equation used for this macroinvertebrate. According to P. 37, second paragraph, beetles used water greater than 0.02 ft not less than.

Modeling Results and Discussion

P. 46, 47, 48; The report provides no guidance or goal for how much of this segment should be protected. If the goal is to keep temperatures below critical levels over just half the area, then 50 cfs may meet that standard. However, if the goal is to identify the flow that will keep temperatures below critical levels at all times and throughout the entire segment, then a higher flow would seem more appropriate. From previous pages, 78 degrees represents approximately the 0.5 suitability point, and 80 degrees the 0.2 suitability point. Given that almost a mile of stream is brought to 78 degrees or 0.5 suitability at a flow rate of 100 cfs, it appears that this is the point at which degradation becomes significant rather than 60 or 30 cfs.

The statement on P. 47 regarding water temperatures for the main stem is more clear: "*A general warming trend is noticeable for all flow rates but its magnitude is minimized at larger total flow rates of 150 to 300 cfs.*" According to Figure 33, "minimized" means over a mile of stream – the approximate length that is 78 degrees or slightly above at 150 cfs total flow rate. The report notes the large number of control structures and their influence on water temperature – an important point related to overall system connectivity. The review team feels that this information may not have been given sufficient consideration in the "j charges" report, and should be.

Additionally, if water temperature varies seasonally, the influence of such variations on physical habitat quality and availability should be included. For example the higher temperatures predicted for most flows in Landa Lake would negatively impact reproduction of fountain darters. Previous comments were made that this species has been found to reproduce at all times of year. Considering that highest temperatures such as those modeled here only occur during late summer or early fall, it would be helpful to know the proportion of contribution to the population that might be affected by reducing seasonal recruitment. Detailed time series analysis and knowledge of variation in recruitment would quantify potential impacts.

P. 48, 49, 50; Diel fluctuations in DO would be expected and it is good to see the reference to unpublished data from vegetation beds in Landa Lake and discussion, albeit brief, of potential effects of BOD and respiration. Plants typically respire at a fairly constant rate however they only produce oxygen when stimulated by daylight. So it is logical that evidence of high production of DO during the day would be countered by high respiration at night. Decay of plant material is a secondary means of oxygen depletion but certainly not the only one. Additional DO data that reflect concentrations at their lowest level (at sunrise) would seem appropriate to include in the model, especially in consideration of the unpublished data referenced here. The opinion that DO doesn't appear limiting (so was not used in the analysis) is probably reasonable for present conditions but additional analysis may show otherwise for low flows and is needed to resolve this uncertainty.

It is unclear what concentrations of DO would be limiting, but some standard should be identified and further explored. These effects would be greatest in heavily vegetated pools and less of an issue in flowing portions where reaeration occurs. It is likely this pattern would change throughout the year.

The role of control structures on maintaining DO through reaeration seems apparent. If system connectivity issues are addressed through channel restoration, these reaeration benefits must be kept in mind (e.g., through incorporation of built 'natural riffle' structures).

P. 50-52; The additional simulation runs based on criteria developed from collection data on riffle beetles in the main spring is a good follow-up idea. The sampling design employed is robust. The results reinforce the conclusions that the greatest rate of habitat decline is around 100-150 cfs. Discussion dealing with the question of 'why are the beetles still here if they are so affected by low flows, and what do the results indicate (directionally)," is comprehensive and direct. There are two approaches discussed. One is a flow versus wetted surface area; the other is based on criteria developed from data in the main spring runs as an alternative to the surface area analysis. The review team could not determine which approach carried more weight in this analysis.

P. 52-59; Fountain darter habitat is strongly constrained by temperature not physical habitat; highest WUA under the modeling for max daily temps in Comal River occurred at a flow of 150 cfs. Revised HSC increased the amount of WUA realized over the Bartsch et al. HSC (Table 11). The discussion of caveats relative to the modeled split flows (into the old channel and new channel) and results and updated modeling currently underway, was confusing. If the channel changes that were not reflected in the current analysis include topography and vegetation (caveat 1) and they show a strong physical habitat association with flow and darter habitat as well, the statement that thermal effects are more limiting than the amount of physical habitat will have to be withdrawn. If the use of a spring orifice temperature as a boundary condition (caveat 2) is important, would it affect the conclusion(s) as well?

One statement indicates that this thermal effect results in potentially reduced larval survival. Here is one of the few times the report emphasizes life stage events. As the program matures, such attention to the timing and duration of potentially limiting life stage events on species of interest should become routine practice. Time series of maximum daily water temperature distributions through the system by season (under simulated ambient air conditions representing hot, normal, and cool years) would be most informative.

P. 60 and 61; Figure 43 does not highlight habitat relations for darters between reaches.

P. 62; There is agreement with the concern for potential depressed DO levels during night time respiration at low flows, in highly vegetated areas, likely at high temperatures, (typical of drought time). This is a very reasonable recommendation given that systems that have abundant vegetation experience large diel fluctuations in DO as the daytime water temperature approaches that of the air temperature. It should be addressed in on-going modeling efforts.

Texas wild rice habitat shows a consistent upward trend with increasing discharge, except in areas with backwater affects and other velocity limitations. The report does a good job of walking through the data results, step by step. The note under State Hatchery A, concerning flow rates near the historic mean having velocities still in range for wild rice are an argument for their existence and persistence there. The summary for this section is clear and reasonable.

P. 63; Texas wild rice in Spring Lake clearly has declined since original accounts which suggests that it may be more limited by factors such as water quality than quantity. It seems apparent that something has changed. If the management goal is to do more than just protect remaining stocks of organisms (e.g. to actually restore or increase stocks to some established level), then it seems that more effort is needed to understand why this shift in abundance has occurred.

P. 65; The absence of this endangered species from a particular section may not be reason to omit that section from consideration or study. If restoration of habitat and populations is a goal of this study, additional studies may be needed to better understand why this species is no longer in its historic range and then take steps to correct that problem. If however, the river is so constrained by factors such as urbanization and flow depletion that simply cannot be altered, then it would be important to acknowledge such constraints.

P. 66; From the discussion it appears the argument is made that below 30 cfs Texas wild rice is associated with modeled suitabilities below 0.5; and above 65 cfs, Texas wild rice occupied cells with suitabilities greater than 0.50. It is stated, *"This appears to be a systematic bias in the modeling results at lower flows that should be examined in more detail . . ."* The review team agrees, it would be highly

recommended to invest more effort to understand why this occurs. The review team agrees with the last sentence that the number of simulated flows should be increased to enhance resolution of flow-habitat relationships.

P. 67-68; Figures 45 and 46 are useful to illustrate the value of physical habitat modeling through time and space. See our comments above at the bottom of page 5 and top of page 6 on these figures and the role of time series analyses.

P. 68, Figure 46; The scale of the figure is such that it is difficult to see if the red dot occupies a low or high suitability cell. A statistical analysis of presence/absence would improve verification.

P. 70; The summary comments are reasonable, however, the review team agrees there should be more simulations to refine the curve in the lower flow range. More mention of some seasonally adjusted flow recommendations vs. a single number for this and other species would be helpful. One other factor that is not addressed (and causes all such studies some difficulty) is the matter of understanding whether less high quality habitat has the same value and more lower quality habitat (since each condition can in theory generate an identical WUA score). This phenomenon could explain some of the reason why rice is found where it is in Figure 46.

P. 71-75; Use of the MODFLOW-NR for Task 2 is state-of-the-art for groundwater modeling. As a finite-difference model, the grid node points and boundary conditions are of key interest relative to the strength of the data being used to specify values of transmissivity and storativity. Specifying the boundary conditions, whether of known head or flux, is mandatory for solving the groundwater-flow equation(s). In some cases, the boundary conditions will be mixed, with some portions of the aquifer having known head and some portions having known flux. GIS layers can be used to specify cell parameters, layers (e.g., conductivity at depth). These conditions may vary over time as well, as a function of aquifer stage and the specifics of conduits to and from other formations, requiring (or allowing for) even more layers, cells, and cell parameters. This can become exceedingly complex, in reality, and to model. And, even when current computing can handle it, *the question is: has the complexity increased the level of groundwater understanding?* (see Bredehoeft, J. 2010. Models and Model Analysis. Ground Water 48(3):328). Good decisions are based on complete understanding – of what we know, and just as importantly, what we don't.

For these reasons, additional information specifying the uncertainty surrounding the estimates of springs flows from the aquifer modeling effort is an important area of further disclosure. Because the spring flows are an expression of the state of the aquifer, a thorough description of baseline hydrology is imperative. Full characterization of the system hydrology: past, present, and potential, including all elements of characterization: magnitude, duration, frequency, timing, and rate of change would improve

the report and ultimate acceptance of management prescriptions derived from it. Confronting the degree that these elements have been altered, as well as the likely watershed changes (e.g., trends in population growth, i.e. impervious cover has been correlated to population size/density), effects on aquifer recharge rate and other hydrologic effects (e.g., climate change) that will influence the hydrology further are important areas of further discovery and delivery.

P. 74-76; The use of empirical data to confirm the predictive modeling outputs is excellent. However, the team was not completely clear on why the two analyses were not combined or only one was presented. Along with the results from the Bartsch et al. (2000) simulations, the updated simulation results are also being presented and include the updated HSC and channel topography changes but are caveated by noting that they rely on original temperature simulation results. This issue is addressed in a subsequent section – top of page 83, which firmly establishes that, based on both these simulations, HSC and channel changes can shift the relationship of habitat to flow. While providing both simulations and analysis could be viewed as an example of thoroughness, since this is a basic premise of physical habitat modeling, it also may be considered extraneous and is certainly confusing, if only momentarily.

Table 14 shows that total WUA declines slightly from 135 to 170 cfs. However this is due to a trend in 6 of the 8 sites, which make up less than 32% of the total WUA. According to Table 14, two sites, Spring Lake and Rio Vista, comprise 69% of the total WUA at 135cfs and 70% of the total WUA at 170 cfs. The importance of these two sites for fountain darter habitat is not clear in the text, which would seem to contradict the numbers in Table 14.

The results for Mill Race section and discussion are insightful and bring up an interesting issue: the hydrilla which predominates vegetation at this site is non-native, but a preferred vegetation type for native fountain darters (suitability 0.6, tied for 9th place in a list of 22 species, see Figure 30). Inferring from the influence diagrams (Figure 8 – TWR; Figures 9, 10, 12, FD), invasive plants may negatively impact Texas wild rice (hence the call for plant restoration), but be benign or even beneficial to the Fountain Darters. The principles guiding management of this situation are complex but extremely important, in light of the charge to protect the system.

P. 78, Figure 51; It is not clear why the No Dam alternative was so low, in terms of WUA, especially given the prevalence of backwater effects decreasing available habitat in all the other applicable sections. Interpretations and data presentation appear acceptable. Providing increased resolution in modeling between 35 and 100 cfs is an excellent suggestion.

P. 82, Figure 55; See our comments at the bottom of page 6 and top of page 7 regarding the differences between "old HSC" and "new HSC". Overall this is a good section that further establishes the 65 cfs cutoff.

Other Native Aquatic Species

P. 83, 84; The text provided is useful background when enough is known about the species to draw firm conclusions. For many of the species covered, this was not the case. Exceptions included the Texas blind salamanders, which even though subterranean, are dependent on watershed-level protection of the ground water, particularly in terms of contaminants.

P. 83 – 84; If predictive models are not developed for spring-dwelling species then, the assumption that maintaining flow regimes for surface dwelling species likewise protects spring dwelling species appears reasonable. However, it appears San Marcos salamanders would be affected by any watershed land or water use that increases fine sediment loading, not just recreation. The proposed monitoring should test this assumption.

Non-native Species

P. 84-87; This is a good, albeit light, discussion of non-native species and potential impacts on native flora and fauna. Collectively, inclusion of this section is a powerful argument for maintaining a natural regime; many of the non-native species thrive in low flow conditions, or concentrated impacts occur under low flows (e.g., competition, predation). Active vegetation management, formally managing for inter-annual hydrologic variability, and restoring system connectivity may well be the best long-term approaches to managing the suite of invasives already present to levels that do not exacerbate negative interactions with the native species. The number and breadth of introduced/exotic species already in these systems (7 introduced/exotic, 18 native in Comal River; 9 introduced/exotic, 19 native in Sam Marcos River), represent an ominous threat to the remaining biota if a 'perfect storm' of degrading spring conditions is allowed to occur. Ground water contamination from within the watershed, sediment- or contaminant-laden runoff, drought and hot weather, excessive pumping, and unmanaged low-flow recreation represent a few of the potential "storm elements" that should be considered when managing the system and 'buffering' for the unforeseen.

Recreation

P. 88; This section is well-grounded and raises a couple of key points. It seems quite likely that human use in and adjacent to the springs and streams is a potentially significant issue that should be dealt with more specifically and managed more directly. Increased human population level is one thing that has definitely changed since 1933 and elicited a variety of changes. Though these are spring systems, the

issue of disturbed silt and silt deposition on vegetation suggests that a varied flow regime, to the extent possible, would provide benefits to these systems. This matter also raises again the question of seasonality of impacts. If, for example, fountain darter spawning is more prevalent at a certain time or times of year, then recreation and watershed management could focus on those periods.

P. 89; These recommendations are all pertinent and if followed should lead to improved understanding of system limitations and species distributions and trends over time. This report represents a good beginning for building a collaborative understanding of the ecology of the system.

Peer Review Team Comments For: Analysis of Species Requirements in Relation to Spring Discharge Rates and Associated Withdrawal Reductions and Stages for Critical Period Management of the Edwards Aquifer. ("j Charges" Report)

Task 1 Analyze species requirements in relation to spring discharge rates

P. 3 – The flow criteria in the table do not make any distinction as to time of year. In most other aquatic systems, different flow rates or levels at different times of year are needed to maintain or restore aquatic species.

P. 4; It is legitimate to assume that adequate flows for surface dwelling aquatic organisms will likely address needs of aquifer-dwelling species. This is intuitive because the species are "pool" species that key on lentic habitats more characteristic of aquifer conditions even if they exist in flowing portions of the aquifer. The list of environmental attributes should also include longitudinal and vertical connectivity. Longitudinal connectivity refers to connectivity processes over space within the existing channel (and springs) of a water body. Vertical connectivity is a reference to the manner in which a surface water is connected to ground water. Connectivity is multi-faceted and can relate to the ability of organisms to actively or passively move up or downstream or through gravel from groundwater to channel bed, as affected by the presence of barriers or features that impede (or facilitate) their movements. Barriers to the movement of biota can include physical, thermal, or chemical obstructions. Impervious cover over a landscape can constitute a barrier for vertical connectivity, impeding water and nutrient flow from the surface to groundwater. Connectivity can also relate to non-biotic elements such as water quality elements (pollutants or sediment) and geomorphic processes (bed load transport). It is clear that the authors of the "j charges" report recognize the importance of this diverse concept, but we felt that because of its importance in affecting the distribution and abundance of the endangered species, it would be effective to specifically mention and address this key ecosystem attribute. Connectivity can be a key driver in determining the distribution and colonization of species throughout a system and directly affect their ability to re-populate areas that may have become temporarily unusable.

Approach

P. 6; The "workgroup" approach described at the top of this page, as well as the "subcommittee" approach used to develop this report, are strengths of the approach taken to develop the spring flow recommendations and indicative of the application of the best available science.

P. 6-10; This list of monitoring reports and programs is unique and provides this study with much more information upon which to analyze model outputs and apply professional judgment than exists for the

great majority of other flow studies. The wealth of information described on pages 6 - 11 further attests to the best available science being applied.

Natural Flow Theory

P. 11; It is a reasonable assertion to suggest that a recommendation to restore the natural flow regime would be impractical. These species have survived, to some degree for the last 150 years in altered flows, so it is imperative that this entire period of record be used for describing hydrologic variability and making flow recommendations.

P. 11, last paragraph; A conservative strategy should be no less than the lowest observed flow especially considering that these species are endangered for the very reason that such low flows are part of the reason for their classification. A more appropriate conservative strategy would be to pick some higher flow with less duration than was observed historically. The complexity of stream ecosystems makes setting an absolute low number very difficult but those closer to the river and issues doubtless have a sense of a proper range based on their professional judgment.

Professional Judgment

P. 12. This approach, including use of professional judgment, represents the state of the art / science for these type of studies. There are no models that provide precise answers without the application of some degree of interpretation and professional judgment. The team is to be commended for clearly articulating the process and the very real fact that professional judgement must be used.

Analysis Assumptions and Recommendations

P. 12 – 13; The approach of using metrics defining thresholds for loss of habitat and an instantaneous threshold below which no water should be taken is consistent with similar studies throughout North America. The review team had difficulty understanding how seasonal and inter-annual adjustments would be made and when these adjustments would be implemented in a real time operational sense. There is no evidence, such as a time series analysis of any hydrologic period or periods against which these criteria have been overlain or plotted to show how these metrics will support necessary intra- and inter-annual variability.

P. 13; The report notes, *"...the frequency and duration of these extreme events are of critical importance and, if extended beyond the natural tendency of the system, can be detrimental to the resident ecological community."* The assumption being made here that the variability of the flow record of the past 150 years is a reasonable representation of the longer term record may not be reasonable given the declining nature of the endangered species in this system.

P. 13; The use of average statistics is risky. While the various time intervals have merit in terms of maintaining flow regime characteristics, most species are affected by instantaneous low or high flows. The use of average statistics can mask potentially serious bottlenecks associated with short-term low (or high) flows.

The allowed or expected frequency of the minimum 6 month average flow and 1 month minimum average is unclear. Certainly the authors do not anticipate back-to-back periods of these conditions but it would be good to clarify what they think allowable limits might be.

The authors' logic about natural precipitation events providing for higher flow pulses may be acceptable however future studies should address the potential for additional water development in the region that might capture additional surface flow and alter spring flows. In addition, future reports should offer recommendations about how much additional water development is allowable within various parts of the watershed.

The issue of seasonality should be more specifically addressed – the report should at least acknowledge the level of natural seasonal variability that existed prior to development to support the statement that the specified strategy will approximate those conditions. This was a major point of discussion in the review team's overall comments.

P. 14; The report notes, *"...high flow pulses are very important . . . in both . . . ecosystems to flush the system, remove vegetation mats, move sediment, and occasionally scour out vegetation . . . We evaluated high flow pulses within the context of each of the threatened and endangered species and made the determination that as these events are driven by precipitation, they would occur naturally."* The team is to be commended for not just focussing on the average to low flow range but including the higher flow ranges as well. Many studies overlook this very important aspect of river ecology. We caution, however, that a simple assumption that pulses will occur naturally is not a means of ensuring these events will occur. An additional, higher statistic than those listed is needed to address this flow level.

P. 14, last paragraph; The process of analysis omits mention of historic / natural conditions and appears to use existing conditions as a starting point. This approach accepts the existing condition as the default standard which seems like a tenuous perspective given the fact that the species have become endangered under these conditions and return to flow patterns and processes closer to historic levels would seem necessary.

P. 14; A seasonality component is necessary and should be included.

Comal Springs Analysis and Assumptions

P. 15; The fact that fountain darters had to be reintroduced here from San Marcos Spring clearly indicates that connectivity is important. Connectivity to habitat that could sustain them under drought conditions (thermal refugia) was a function of water flow from the spring, which was affected by pumping. Since being reintroduced, the fountain darters have flourished. In terms of zoogeography, we assume that the same fish species in a region were distributed through hydrologic connections that may or may not be apparent today. In essence, the reintroduction established a population by (artificial) connection to a fountain darter refuge (San Marcos Springs). We make the point that insuring conditions that allowed habitat refugia, and the connectivity to them, to exist within the springs, would go a long way towards ensuring fountain darter persistence. Meaningful, or full, recovery should involve the ability of organisms to re-colonize any areas of suitable, historic habitat without human intervention.
P. 18, paragraph 4; Given the status of this organism and the expressed goal as stated on page vii, paragraph 3 of this report that says "*Our interpretation of a protective flow regime is one that will ensure the "survival and recovery of the species in the wild". To accomplish this goal, the subcommittee determined that the recommended flow regime must sustain an overall trend of maintaining or increasing the populations of the threatened and endangered species*", acceptance of up to a 40% reduction in habitat seems too high.

P. 20 last paragraph; Discussion about the reduction in parasite prevalence following flood events suggests that such events are important. Flow management strategies to address this issue should be included in recommendations regardless of potential conflicts with any other endangered species. Because the range of flows during studies of cercarial abundance were relatively limited (no more than 441 cfs) it is unclear if higher pulses of flows would indeed have the speculated effect of reducing their numbers.

P. 21, last paragraph; Simply monitoring Ramshorn snails will not ensure protection or enhancement of habitat for fountain darters. If this species really does pose a threat, their populations should not only be monitored, but strategies and efforts to control their abundance and distribution should be identified and adopted.

P 22, second full paragraph; This discussion of potential effects associated with recreation suggests that some level of habitat degradation is acceptable in Comal Springs, which is a questionable position when dealing with recovery of endangered species. In many cases like this there is zero tolerance for takings unless specific levels are identified and justified in recovery plans.

P. 25 first two paragraphs re: Comal Springs Riffle Beetle; These observations about the ability of this organism to survive natural drought periods are logical. However, it would not be prudent to prescribe or allow those conditions any more frequently than they occur naturally. Sometimes when water managers

accept or recommend an instream flow level that is substantially lower than existing flows (or is based on the lowest flow on record), the result is in essence the same as a prescribed drought. Managers should be careful not to indicate an acceptance of low flows that approximate historic low flow levels on the basis that organisms have survived those conditions in the past. We appreciate that the Science Subcommittee is sensitive to this fact and offer encouragement to implement flow regimes that exceed drought levels. Prescribed drought is never an acceptable condition for perpetuating aquatic organisms. The recommendations provided by Hardy (2009) seem defensible and acceptable for this species.

P. 25, Comal Springs dryopid beetle; Comments about the habitat and flows needed to perpetuate this organism are logical and defensible. Additional data collection would be helpful to affirm these observations.

P. 26, Peck's Cave Amphipod; It is not uncommon for invertebrates like this and the beetles to experience wide swings in population numbers within or between years. Flow is probably only one of the drivers behind these swings. Water quality is likely also involved. It is unclear to this point in the report how or if water quality in spring flow is affected by surface management practices in the Edwards Aquifer drainage area. If there are input areas of concern these should be identified.

Comal Springs Flow Regime Recommendations

P 26-27, Figure 5; Final recommendations deviate from the long-term average, 6 month minimum, and 1 month minimum statistics. The process details resulting in the recommendations of 225, 75, and 30 cfs are not completely clear and undoubtedly relied on professional judgement. We support professional judgment but descriptions of the logic and decisions that led to these changes must be documented more thoroughly. We can envision how these recommendations could be used as reactive strategies but it is unclear how these recommendations could be used to pro-actively manage the system. This issue is addressed in more detail under the review team's comments for Task 2.

No biological rationale is given for allowing the absolute minimum to go down to 5cfs except for the implication that this flow is greater than 0 cfs. In the absence of additional information or discussion about the basis for this prescription, this flow level does not support the goal for survival and increasing populations of the fountain darter in Comal Springs.

There are many unknowns that could affect the actual achievement of species recovery and this is an excellent example where continued monitoring and study is warranted. Monitoring alone is not enough as water managers should also put in place authority and financing to implement emergency protective actions if future study shows it necessary. Of course, criteria should be developed to define the meaning of "necessary".

P. 28, 2nd paragraph; the goal should be not just be "survival", but "recovery".

P 29, Next to last paragraph; " . . . *we have elected to recommend flows higher than the historically observed low flow statistics at Comal Springs because of the extirpation of the fountain darter following the 1950' drought* . . ." This statement is in contrast with the information on page 28 regarding the selected absolute minimum of 5cfs discussed above. Additional discussion is needed to clarify this apparent discrepancy.

P. 30; As stated previously, it is interesting the Subcommittee made the decision not to incorporate a margin of safety. The EARIP should ensure the legal and institutional capacity allows for changes that may be necessary in the future if it is determined that flow regimes need to be more conservative.

P 30, 2nd paragraph; The recommendation for monitoring should not be just for study at critical low flow periods, but for other flow levels as well so that suitable comparisons can be made and conclusions drawn.

San Marcos Spring Analysis and Assumptions

P 32, 3rd paragraph; Future studies should document the level of recreation use between years.

P. 34, 2nd paragraph; The review team agrees that consideration should be given first to monitoring data, then to model results. This is a strength of the approach used.

P. 35, paragraph 1; SNTEMP is a useful tool for assessing thermal dynamics in streams and is generally known to be relatively insensitive to air temperature. More influential drivers are shading and groundwater inputs. It is important to include the most accurate data possible for all sensitive drivers.

P. 36, 1st paragraph; A short explanation of how Saunders et al. determined "importance in the ecosystem" would be helpful.

Page 39-40, Figure 9; The Subcommittee should use a finer scale of flow increments between 30 and 80 cfs to see if there is a discernable inflection or change in the slope of the curve over this range of flows.

P. 41, line 5; Reference to the effect of flood retention dams on fluvial geomorphic processes (siltation) is an important factor. Hydrologic events that have led to this condition are just as important as those processes that perpetuate vegetative growth and physical habitat for endangered species. It would be appropriate to develop recommendations that relate to this trend and construction of additional flood retention dams in the future.

P. 48-50; It is obvious that recreational use of the river is having an impact on wild rice and other aquatic vegetation. Studies to quantify these effects at different times of year are needed to incorporate in

development of flow regime recommendations. Based on the outcome of these studies, specific management measures may need to be developed.

P. 50, 1st paragraph and P. 51; Data are not provided to determine whether the differences between years and seasons are statistically significant. Also, if there is a natural late-season die-back of Texas wild rice that might contribute to seasonal changes, this aspect of the species' life history should be described.

P. 53, 3rd paragraph; The percent reductions in WUA do not appear to be substantial given the changes in flow, especially given the inherent measurement error in both flow measurement and hydraulic modeling. Our reference to "substantial" relates to numeric changes and the relatively small change in WUA with change in flow. We appreciate that WUA is only a relative indicator of physical habitat suitability and the relationship between that metric and organism abundance is unique for each stream or system. As a consequence, even a small change in WUA in some streams could result in a relatively large impact (or benefit) for some species. In light of this fact, additional discussion would help explain why the relationship between flow and WUA may or may not be an important consideration as opposed to simply another piece of evidence.

P. 55; If the WUA estimates are credible, over time one would reasonably expect the plants to become established in more than 9 and 17% of the habitat. A time-series analysis would be helpful here to further investigate this linkage.

P. 55; This discussion provides additional indication of the need to consider connectivity of habitats and time series analyses when analyzing or setting flow recommendations. In this instance, we affirm that in addition to longitudinal, vertical, and lateral connectivity, it is important to also consider the temporal aspect of this attribute per time series analysis. The importance of addressing and managing for appropriate intra- and inter-annual connectivity patterns and processes is well established and can be a major driver for many aquatic organisms.

P. 56, 1st paragraph; These statements provide a compelling basis for placing an emphasis on the human component of biotic effects as it relates to habitat needs for the endangered species. Not many instream flow studies rely on this kind of criteria but it seems clear that human-caused degradation is a significant driver here. Professional judgment would be a useful tool to set a flow regime recommendation on this basis.

Pp 56-59; The assumptions in this section are scientifically valid.

Historical Flows at San Marcos Springs

P. 60; It is not clear what is meant by "*rarely be experienced*". Perhaps the long term average flow target of 140 cfs could be presented graphically so that the frequency and duration for an appropriate time step, say monthly or whatever best suits the assemblage of flora and fauna, can be seen to better illustrate the point.

P. 60, 4th paragraph; The goal should be recovery as well as survival. In the last paragraph, the WUA-flow relations developed by Hardy (2009) for fountain darter do not support the claim made in the 2nd sentence about the 140 cfs flow. More detail regarding the professional judgment that went into this recommendation would be helpful.

P. 61; The review team notes that the overall strategies used by the Subcommittee for recommending flows is to pick statistical values as the flow limit and then use habitat modeling and other information to justify the highest value without going above the statistic. This is an acceptable strategy but it does not appear that this protocol was consistently followed. The review team thinks the present recommendations are acceptable interim guidelines but additional information is needed to explain the deviations.

P. 62, Table 11; As suggested above, more detail regarding professional judgment would be helpful to explain how specific recommendations were derived. Results presented by Hardy (2009) and Saunders et al. (2000) by themselves do not appear to be supportive of the 140 cfs recommendation for the Long-term Average flow prescription.

The Subcommittee chose to exceed the historically observed flow statistics at San Marcos because of uncertainty associated with stochastic events that might significantly impact species. Of particular note is the 1-month average minimum of 60cfs with an absolute minimum of 52 cfs. This contrasts with the low flow recommendation for the Comal Springs where the lowest flow reached since reintroduction of the darter has been 26cfs.

P. 64; Additional rationale is needed to explain why this calculation was used, as opposed to other methods to set the 1-day minimum flow.

P. 65- 66; As with our previous comments, it is clear the Subcommittee thoroughly discussed this issue and it is clear they chose not to factor in a safety margin in view of the uncertainty. And to reiterate, it is not known if the legal and institutional setting will allow for changes to the water management plan if it is later revealed that impacts are occurring and the flow needs to be increased. Ultimately, this is a decision about how the Subcommittee wants to manage risk.

P. 66-68; The Subcommittee's recommendations for future study are certainly appropriate for developing a better understanding of the system and should be pursued. Increased sedimentation and recreational pressure are confounding issues that need to be specifically addressed during future study of the San Marcos Springs.

Task 2: Analyze withdrawal reductions and stages for critical period management

P 69-74; The MODFLOW-NR represents the state-of-the-art and is appropriate for evaluating Task 1 minimum flows and stages. Accounting for groundwater and surface water is a very complex undertaking and the Subcommittee outlined very clearly how this was done in the context of evaluating a number of flow alternatives. The Subcommittee is to be commended for addressing this complexity in a comprehensive and reasonable fashion. The review team found that conducting the 40-odd runs was a useful exercise that illustrated how the present management model can be used in meeting Task 1 flow recommendations.

P. 75; The report clearly shows the Subcommittee attempted to address the very uncertain topic of climate change. If the climate models show the possibility of decreased flows in the future, the Subcommittee could create simulation runs representing a range of possible flow conditions and examine the effect on flow recommendations. Addressing climate change when making flow recommendations presents an enormous challenge and is not unique to this basin. We suggest the Subcommittee consider looking at a number of climate change models and once they agree to one that predicts less water in the future, they could calculate the return intervals for whatever time period is most appropriate.

P. 79; The sensitivity analysis is a good scientific tool for examining possible scenarios.

P. 81-84, Table 13 and Figures 22 to 24; The various pumping scenarios and how the various runs do or do not meet Task 1 flow recommendations are logically presented. Figure 24 is particularly informative as it shows how the operating criteria would influence flow statistics.

P. 85; The recommendations would reduce pumping only during Stage I. It is unfortunate that changes in other stages could not be evaluated due to lack of time, though this is understandable given the manner in which Task 2 was conducted. We agree that additional evaluations are needed, especially for Stages II and III.

P. 89; These "real time" operational issues should be addressed in the next phase. These operational issues however, are valid and we agree with the Subcommitte's assessment. We assume that real time operational issues will be addressed including possible adjustment by forecasting, water year, and season.

P. 89, last paragraph; Comments about the need to understand the effects of rapid flow fluctuations may be warranted as all of the endangered species appear to have an affinity for stable conditions of a spring flow environment. It would seem that Texas wild rice is the species that would benefit most from specific studies of the effects of higher than average flows.

P. 90; Further studies; computer models all have limits and the current analysis is no exception. There are many unknowns in how this system really works and how pumping at various levels from a variety of locations really affects spring flow. In fact, the relationship between groundwater level, pumping, and spring flow likely exhibit naturally dynamic characteristics associated with a variety of factors that are beyond the ability of managers to accurately measure. That said, most of the additional studies mentioned in this section are all appropriate and would help develop a better understanding of how to manage pumping processes over time. These recommendations are well thought out and appear to be consistent with modern scientific opinion regarding the use of modeling in water planning and management as is discussed by the National Research Council (2008).

Specific recommendations for the next generation of water quality and physical habitat modeling and guidance for addressing seasonal and inter-annual variability through improvements in modeling and time series analyses are outlined in our review of the Hardy 2009 report. The continued integration of these modeling efforts as improved by ongoing and future monitoring would provide a firm foundation for producing conservation plans in support of the Endangered Species Act. Depending on how these studies are conducted and the legal and institutional constructs within which they occur, we perceive a very good opportunity to refine flow regime recommendations using a scientifically based adaptive management approach. We acknowledge that this kind of approach is probably not yet in place, but we suggest that such a program, if properly designed and implemented, could be effective.

P 94; There appears to be a critical shortcoming between how the water consumption licences are administered and what it means to flows in the system. The recommendation that *". . . .the Edwards Aquifer Authority . . . consider modification of its rules to provide for more immediate responses to critical period management triggers."* is reasonable and needed.

Appendix G.

The utility of the graphs of scenario runs would be greatly improved by plotting a reference condition (for example Run 2) with each run. This would provide a direct comparison of the magnitude and pattern of change each scenario relative to a common base line.

References

Annear, T., I. Chisholm, H. Beecher, A. Locke and 12 other authors. 2004. Instream Flows For Riverine Resource Stewardship, *Revised*. Instream Flow Council, Cheyenne, WY.

Locke, A., C. Stalnaker, S. Zellmer, K. Williams, H. Beecher, T. Richards, C. Robertson, A. Wald, A. Paul, and T. Annear. 2008. Integrated approaches to riverine resource stewardship: Case studies, science, law, people, and policy. Instream Flow Council, Cheyenne, WY.

National Research Council. 2008. Hydrology, Ecology, and Fishes of the Klamath River Basin. The National Academies Press. Washington, D C.

Reviewer Qualifications

Thomas C. Annear is the water management and instream flow program coordinator for the Wyoming Game and Fish Department. He has worked for the department since 1981 and helped develop and implement their instream flow program. He has led or assisted with studies that led to filing over 100 instream flow water rights and conducted or coordinated aquatic impact assessments for every major water development project in the state since 1983. In 2003 he helped form an inter-divisional water rights management team to address water rights issues associated with the acquisition, disposal, and management of Game and Fish commission lands and serves as team chairman. From 1992 to 1994 he chaired the instream flow technical subcommittee for the Colorado River Endangered Fishes Recovery Program. Mr. Annear is a co-founder of the Instream Flow Council (IFC), served as that organization's first president, and is an active member of the Executive Committee. He was project manager and senior author of the IFC book *Instream Flows for Riverine Resource Stewardship* (2002 and a revised edition in 2004), is a co-author of the IFC book *Integrated Approaches to Riverine Resource Stewardship: Case Studies, Science, Law, People, and Policy* (2008), and was the project leader for IFC's International Instream Flow Program Initiative (2009) that assessed the status and effectiveness of state and provincial fish and wildlife agency instream flow programs in the U.S. and Canada. He has written over 150 scientific reports, numerous publications and popular articles on river management; been an invited speaker at international symposia; and helped address instream flow issues on a variety of projects in the U. S. and Canada. Mr. Annear has a bachelor's degree in fisheries and wildlife management from Iowa State University and a master's degree in aquatic ecology from Utah State University.

Ian M. Chisholm is the Supervisor of the Minnesota Department of Natural Resources' Stream Habitat Program. He has developed the program since its inception in 1989, shortly after he began work for the MN DNR's Division of Ecological Resources. The primary focus of this team of eleven scientists is to understand river and stream systems, increase the appreciation and understanding of ecosystems, and promote the use of science in decisions affecting natural ecosystems. He has worked with instream flow issues since 1983 and has been an active founding member of the Instream Flow Council since 1995. Mr. Chisholm chaired the science subcommittee that produced the IFC's book, *Instream Flows for Riverine Resource Stewardship*. Current research and work includes: creating, developing and delivering a GIS-based watershed assessment tool for Minnesota's major watersheds; developing a calibrated and validated erosion index for Minnesota rivers; conducting a watershed-wide (HUC 8 scale) assessment of river stability and sediment supply; continuing to develop and maintain a HSC library for MN fishes, now covering 102 species and 257 species life-stages (162,500 individual fish observations); maintaining long-term biological monitoring sites on five (5) rivers, first sampled in 1987; administering a stream restoration priority list for capital bonding funding; conducting review and comments on FERC-licensed hydropower projects for the MN DNR's divisions of Fish and Wildlife and Ecological Resources; surveying, designing and supervising stream restoration projects (over 100 completed statewide) following a natural channel design approach; and, providing training and materials on river systems, including 4 week-long courses on fluvial geomorphology. Mr. Chisholm earned a B.S. degree in water resources and fisheries science from the University of Wisconsin/Stevens Point (1980) and a M.S. in Zoology (fisheries science) from the University of Wyoming (1985).

Dr. Clair B. Stalnaker has been a key player in the instream flow arena for over 30 years—in research, method development and implementation, and policy. He organized and served as leader of the Cooperative Instream Flow Service Group (and various subsequent titles) under the U. S. Fish and Wildlife Service and Geological Survey. This program brought together an interagency group of multidisciplinary scientists for the purpose of advancing state-of-the-art science and elevating the

field of instream flow management to national and international prominence. The primary focus of this group was toward a more holistic view of river science addressing the major components of instream flow management, namely hydrology, geomorphology, water quality, and aquatic biology and promoting instream flow regimes (incorporating intra- and inter-annual variability) rather than "minimum flows". He retired as a senior scientist with the U.S.G.S. where he was chief of the River Systems Management Section, Midcontinent Ecological Science Center, Fort Collins Colorado. He earlier served as Assistant Professor, Fisheries and Wildlife Science (1966 to 1976) and as Adjunct Professor in the Department of Civil Engineering at Utah State University and more recently as Adjunct Professor in the Departments of Earth Resources and Fisheries and Wildlife at Colorado State University. He has served on national and international technical advisory committees and task forces and authored numerous publications focusing on the instream flow aspects of water allocation and river management. He served on the Water Science and Technology Board of the National Research Council committee report on "Water Transfers in the West: Efficiency, Equity, and the Environment" and the National Research Council, Board on Environmental Studies and Toxicology report on "Hydrology, Ecology, and Fishes of the Klamath River Basin". He is an Honorary Life Member of the Instream Flow Council and was awarded the Instream Flow Council's Lifetime Achievement Award in 2008. Since 2004 he has served as a member of the Science Advisory Board for the Trinity River Restoration Program, California.

Allan Locke has worked as a fish habitat protection biologist in Ontario and Alberta over the past 30 years. His work has encompassed the fields of fish habitat restoration, habitat protection, conservation biology, river, wetland and lake ecology and most recently, instream flow needs. In 1981, Allan joined the Alberta Fish and Wildlife Division as the Provincial Aquatic Habitat Protection Biologist. His responsibilities were to develop fisheries habitat protection guidelines with the intent to provide industry, governments, resource managers, and the public with an understanding of fisheries concerns regarding specific land use activities. Gaining knowledge and experience in the science of instream flow needs, Mr. Locke went on to develop a provincial program to address the important issue of protecting Alberta's rivers and creeks with respect to water use. In 1998, Mr. Locke succeeded in getting Alberta to become a founding member of the Instream Flow Council. From 1998 to 2000, Allan served on the Instream Flow Council Executive Committee as the first Director of Region 5 (Canadian Provinces). From 2004 to 2006, he was president of the Instream Flow Council. As a member of the Instream Flow Council, Allan volunteered his time as a co-author on the Council's first book, *Instream Flows for Riverine Resource Stewardship* and the second revised edition. Mr. Locke was the project manager and senior author for the Council's third book, *Integrated Approaches to Riverine Resource Stewardship: Case Studies, Science, Law, People, and Policy.*

Dr. Thomas A. Wesche has over 35 years experience as an Aquatic Habitat Biologist and Hydrologist. Dr. Wesche has been a leader in the areas of fish habitat evaluation and monitoring, instream flow analysis, habitat improvement, stream, riparian and watershed restoration, and channel maintenance/flushing flow determination. He has authored over 300 professional reports, research papers, and book chapters on these subjects and has designed, implemented and monitored numerous fish habitat restoration programs. Dr. Wesche has served as a technical expert for salmonid habitat assessment and restoration on two large Natural Resource Damage Assessments, the Couer d'Alene River basin of northern Idaho and the Clark Fork River of western Montana. Dr. Wesche also developed and instructed a week-long training course for the Bureau of Land Management National Training Center entitled "Aquatic Habitat Restoration and Enhancement" for a number of years. He currently serves as a member of the San Juan River Recovery Program's Biology Committee and has been active in the Middle Rio Grande Endangered Species Act Collaborative Program for many years. He routinely deals with passage issues for salmonid and non-salmonid fish species, including the design and implementation of bypass channels around major diversion structures. Dr. Wesche is presently involved in the development of the Stream Management Plan for Grand County, Colorado,

the development of a site specific selenium standard for a confidential client, the restoration of Flat Creek through Jackson, Wyoming, and the Laramie River Restoration Project through Laramie, Wyoming.

Annear Comments on J Charges report

Over-arching comments

- Influence diagrams are important and show complexity of ecosystems and the limitations of modeling them. There are no existing models that integrate all of these factors. The best way to address influence diagrams is to model those elements for which reasonable models exist and make professional judgments about how the other elements factor in. Even this approach is limited and omits some important factors.
- Review team comments were founded on ecological principles espoused by the IFC that rivers are characterized by the unique combination of hydrology, geomorphology, biology, water quality and connectivity. In general, the "J" charges did address most of these elements, with the exception of connectivity, though they didn't specifically separate them out in this format.
- One important factor that received too little consideration was physical and hydrologic connectivity as related to movement, distribution, and recolonization of species in both systems. The duration, timing and role of connectivity should be considered. Still, this environmental element would likely not change the flow recommendations but might help with management of the springs and streams within the specified flow regimes.
- Recommendations aren't really a flow regime; they're just flow triggers that aren't tied to seasons or address historic intra- and inter-annual flow patterns. Being springs, this pattern is less than a snow-melt driven river (for example) but some acknowledgment of hydrologic pattern and process (even if it's a minimalistic pattern) should probably be considered.
- There is little mention of life history duration. How long does it take each organism to complete its life cycle? How does Texas wild rice expand or become established? How long do fountain darters live (so how often can it skip a period of reproduction)?
- One point worth clarification is that comments about thermal maxima as a function of low flows appear as if they should just relate to the warmest periods in late summer. Thermal criteria should be adjusted seasonally to develop seasonal flow limits in fall, winter, and spring when air temperature is cooler.
- Another point that needs more emphasis is that while the endangered species may have survived the 1950's drought (except fountain darters in Comal Springs), that fact does not suggest that such a low flow could or should be prescribed on a permanent or regular basis. Trained scientists can easily comprehend this fact but casual readers may not intuitively understand that higher flows are needed at most other times in order for species to persist over the long term.
- One of the more important elements that was not studied as it affects any of the endangered species was in-channel recreation. Indeed a defensible argument would appear reasonable to maintain high flows primarily to limit recreation in sensitive areas of both streams.
- One potentially significant oversight in the report is the lack of direction for the frequency and duration of when the average 6 month and minimum monthly flows would be allowed. The authors need to provide more guidance than to say these levels would hopefully only be reached on "rare" occasions. The frequency of these low flow levels needs to be tied in closely with information about life history requirements and cycles of all the endangered species.
- Though some species such as Ramshorn snails do not presently appear to be negatively affecting endangered species or their habitat, the potential certainly exists that such may not always be the case. Monitoring populations of aquatic invasive species alone will not ensure

protection or enhancement of habitat for fountain darters. If these species really do pose a threat they should not only be monitored but strategies and efforts to control their populations should be identified and adopted. This is true for the latest wave of aquatic invasive species such as zebra mussels. In addition to focusing on flow issues, managers should develop and implement protective strategies to prevent introduction of this and other non-native aquatic species immediately.

- In brief, recommendations are based on best available science. There is a relatively high level of professional judgment involved in selecting the precise numbers for each level of protection and it would seem a case could be made for slightly higher or lower numbers by a casual observer. Professional judgment is a valid and often superior scientific tool that can and should be used in situations where detailed models do not provide clear threshold recommendations. Computer models often give the illusion of precision but most address only a limited range of inputs and bear their own degree of error that is often overlooked. Professional judgment in combination with extensive empirical data, used properly, is an appropriate way for senior scientists with many years of experience to consider multiple inputs and formulate comprehensive conclusions and recommendations. While the review team could identify other possible flow levels, the great body of knowledge and study that have been done for this system compels us to defer to the authors of the report. Again, their recommendations are certainly not out of line with the range of possible flows that appear needed to achieve the recovery of these species. I find no fault with the authors' contention that they have used the best available science or that the flows are either inflated or too conservative..
- The hydrology analysis and determination of triggers is valid and defensible although additional study might refine that analysis somewhat. It seems unlikely that triggers and conclusions would change greatly, however, considering the level of pumping that currently occurs and the trend to increase that level as population increases.

P vi, paragraph 2 – The subcommittee chose to address our charges within the context of ***a flow regime*** *for the protection of all listed species as well as the* ***integrity of each ecosystem****. Our interpretation of a protective flow regime is one that will ensure the "survival and recovery of the species* ***in the wild****". To accomplish this goal, the subcommittee determined that the recommended flow regime must sustain an overall trend of* ***maintaining or increasing the populations*** *of the threatened and endangered species. This by definition means that conditions cannot go beyond thresholds necessary for survival of any of the listed species.*

These criteria are appropriate and necessary when dealing with endangered species.

P vii, 1st full paragraph, last sent. - One thing is clear, long-term monitoring is essential and further study and research specifically during critical low-flow periods (or simulated critical low flows) are needed to accurately determine the potential impacts to the species.

Monitoring and the means to adapt to future findings is appropriate and critical to meeting the overall goal of this effort – recovery of the species.

p. viii - We believe further study is needed to (1) improve springflow measurement, (2) conduct sensitivity analyses, (3) run optimization models, (4) estimate the probability of recurrence of the 1950s drought, (5) evaluate the potential effects of climate variability on recharge, (6) conduct additional runs to refine withdrawal reductions, (7) update the model, (8) refine the calibration of the model, (9) enhance the management module, and (10) refine model calibration between San Marcos and Barton springs.

These recommendations are all appropriate and necessary. Modeling to date has reduced uncertainty but has not eliminated it.

Introduction, Task 1, p. 3 – Flow criteria don't make any distinction to time of year. Are all times of year of equal importance to target species? In most cases different flows at different times of year are appropriate.

P. 4 Interpretation of the task – good to couch study in these 3 terms. Though an ecosystem issue, it's ok to focus on the main driver (hydrology) and also look for flow regime vs. minimum flow.

P. 4 Interpretation of the task, par 1 – it's legitimate to assume that adequate flows for surface dwelling aquatic organisms will likely address needs of aquifer-dwelling species. This is intuitive because the species are "pool" species that key on lentic habitats more characteristic of aquifer conditions even if they exist in flowing portions of the aquifer.

P. 4 Interpretation of the task, last par – the list of environmental attributes should also include longitudinal and vertical connectivity. Connectivity can be a key driver in distribution and colonization of species throughout a system and be a driver in the ability to re-populate areas that may have become temporarily unusable causing the temporary loss of individuals.

P. 5 First full paragraph – logic behind various flows needed to ensure recovery of species is sound and appropriate. A single minimum flow rarely maintains any species let alone leads to its recovery or expansion.

Pp 6-10 - This list of monitoring is unique and affords this study with much more information upon which to analyze model outputs and apply professional judgment than exists for the great majority of instream flow studies in the U.S. and other countries.

P 11 last paragraph – A conservative strategy should be no less than the lowest observed flow especially considering that these species are endangered for the very reason that such low flows are probably part of the reason for their classification. A more appropriate conservative strategy would be to pick some higher flow with less duration than was observed historically. The complexity of stream ecosystems makes setting an absolute low number very difficult but those closer to the river and issues may have some sense of a proper range based on professional judgment.

P 12 Professional Judgment – In spite of the critiques directed at professional judgment by some, this tool can be highly effective and should not be minimized in terms of its relevance and accuracy for identifying what's going on in some situations and how organisms respond to particular flows and flow regimes.

P. 13 Flow Regime – use of average statistics is risky. While the various time intervals have merit in terms of maintaining flow regime characteristics, most species are affected by instantaneous low or high flows. The use of average can overlook this potential serious bottleneck. Instantaneous flows of prescribed duration would seemingly be a better tool.

The allowed or expected frequency of the minimum 6 month average flow and 1 month minimum average is unclear. Certainly the authors do not anticipate back-to-back-to-back periods of these conditions but it would be good to clarify what they think allowable limits might be.

The authors' logic about natural precipitation events providing for higher flow pulses may be acceptable however the report might recognize or address the potential for additional water development in the region that might capture additional surface flow – or make recommendations that would limit future developments.

The issue of seasonality should be more specifically addressed – at least acknowledge what natural seasonal variability was prior to development to support the statement that the specified strategy will approximate those conditions.

P. 14, last paragraph – the process of analysis omits mention of historic / natural conditions and appears to use existing conditions as a starting point. This approach accepts the existing condition as the

default standard which seems like a tenuous perspective given the fact that the species have become endangered under these conditions and return to flow patterns and processes closer to historic levels would seem necessary to at least consider.

P. 15 Comal Springs analysis and assumptions – the fact that fountain darters had to be reintroduced here from San Marcos spring clearly indicates that connectivity is perhaps just as important a habitat consideration as other riverine elements such as flow, water quality, vegetation, etc. Connectivity may not be needed on a continuous basis but probably should be managed for on a regular basis in most if not all years.

P. 17, first full paragraph, last sentence – how is "habitat" defined in terms of reduction at 150 cfs?

P. 17, last paragraph – If vegetation the only feature that limits habitat for and populations of fountain darters in the Old Channel, it might suggest that the flow would have a different benefit or value to fountain darters if vegetation communities were managed to encourage return of native species.

P. 18, paragraph 4 – This account suggests a tolerance for a relatively high amount of habitat for this endangered species (between 60% and 75%). Given the status of this organism and the stated goal of the study to not tolerate any reduction in habitat for any endangered species, this level of flow seems too low and inconsistent with stated goals.

P. 20 last paragraph – Discussion about the reduction in parasite prevalence following flood events suggests that such events are important and should be included in recommendations in spite of the conflicting statements and observations that Texas wild rice populations may be impacted by such high flows and not recover very quickly. Because the range of flows during studies of cercarial abundance were relatively limited (no more than 441 cfs) it is unclear if higher pulses of flows would indeed have the speculated effect of reducing their numbers.

P. 22, first two complete sentences – simply monitoring Ramshorn snails will not ensure protection or enhancement of habitat for fountain darters. If this species really does pose a threat it should not only be monitored but strategies and efforts to control their populations should be identified and adopted.

P 22, first full paragraph – these observations can be correct but in other systems, high flow events tend to mobilize pollutants to the detriment of riverine organisms. It's unclear what this paragraph is suggesting other than a statement of the obvious. If water quality degradation is an issue it would seem that specific mechanisms should be included here and potential strategies proposed to deal with those threats.

P 22, second full paragraph – this discussion of potential effects associated with recreation suggests that some level of habitat degradation is acceptable in Comal Springs, which is a questionable position when dealing with recovery of endangered species. In many cases like this there is zero tolerance for takings unless specific levels are identified and justified.

P. 25 first two paragraphs re: Comal Springs Riffle Beetle – these observations about the ability of this organism to survive natural drought periods are logical and quite likely correct. However, it would not be prudent to prescribe or allow those conditions any more frequently than they occur naturally. Prescribed drought is never an acceptable condition for perpetuating aquatic organisms. The recommendations provided by Hardy seem most defensible and acceptable for this species.

P. 25 Comal Springs dryopid beetle – comments about the habitat needs and flows needed to perpetuate this organism seem logical and defensible. Additional data collection would be helpful to affirm these observations.

P. 26 Peck's Cave Amphipod – It is not uncommon for invertebrates like this and the beetles to experience wide swings in population numbers within or between years. Flow is probably only one of the drivers behind these swings but water quality is likely also involved. It is unclear to this point in

the report how or if water quality in spring flow is affected by surface management practices in the Edwards Aquifer drainage area. If there are input areas of concern these should be identified.

P. 26 Historical Discharge – While 1927 – 2009 represents the complete record it probably does not reflect well on the historic discharge level. A better gage of historic discharges would be to look at average flows during every decadal interval during this period to identify significant, persistent trends and better appreciate how existing flow relate to historic flows. Documentation of low flow periods over this interval is, however helpful to appreciate the kinds of temporary low flows that have occurred and approximate effect on the endangered species.

P 26 – 30 Comal Springs flow regime recommendations – Overall these recommendations seem reasonable and have a basis in observed trends and modeling. However, the selection of target flows relies largely on professional judgment, which is not a bad thing. Models are developed and used to relieve uncertainty and should not necessarily be relied on solely as the basis for a recommendation. None of the models or studies done for Comal Springs were of a sort to provide a single flow or flow regime output. Given the characteristics of these species, the many confounding factors and available scientific tools, it would be difficult to make more precise recommendations. Those presented here are reasonable and will achieve the objectives of the charge.

Figure 5 – It is hard to tell precisely how each of these flow levels is determined or what the basis is (for example) for a "minimum 6 month average flow". One point worth clarification is that comments about thermal maxima or response to lower flows relate to just the warmest periods in late summer. Thermal criteria should be adjusted seasonally and probably not used to develop seasonal limits in fall, winter and spring.

The recommendations do not provide a particular flow regime as the section heading suggests, though probably would maintain some semblance of a natural flow regime by allowing natural flows above the defined limits. However if depletions are allowed that reduce spring flows to the specified levels, the present formula would not seemingly afford maintenance of a flow regime. Considering that most of the endangered species are essentially pool species, some individuals of which have ventured to lotic habitats suggests that lower flows would be acceptable as long as water temperatures achieve seasonal objectives. The recommendations could do a better job of using temperature as a way to secure a flow regime since maximum temperatures are only observed at a limited time during the year. As a consequence higher flow may be needed during late summer to attenuate temperatures and lower long-term average and even 6-month average flows might be acceptable at other times of year.

One thing that this section is lacking and should provide is a recommendation for the frequency and duration of recommended flows. This could be based on life history requirements (such allowing a low flow condition no more often than once in every life history cycle of the organism with the longest period between recruitment periods).

It is not surprising that there are many unknowns that could affect the actual achievement of species recovery and this is an excellent example where continued monitoring and study is warranted. Monitoring alone is not enough as water managers should also put in place authority and financing to implement emergency protective actions if future study shows it necessary. Of course, criteria should be developed to define the meaning of "necessary".

P. 35, paragraph 1 – SNTEMP is a useful tool for assessing thermal dynamics in streams as is generally known to be relatively insensitive to air temperature. More influential drivers are shading and groundwater inputs. It's important to use the most accurate data possible but especially important to have good data for these major drivers.

P. 35, Table 4 – It is important to specify what minimum spring flow is either in the table or text preceding the table.

P. 41, top par. - Reference to the effect of flood retention dams on fluvial geomorphic processes (siltation) is an important factor. Hydrologic events that have led to this condition are just as important as those processes that perpetuate vegetative growth and physical habitat for endangered species. It would seem appropriate to develop recommendations that relate to this trend and construction of additional flood retention dams in the future.

P. 55 – this discussion provides some additional indication of the need to consider connectivity of habitats and time series analyses when analyzing or setting flow recommendations.

P. 56, 1st paragraph – these statements provide compelling basis for placing an emphasis on the human component of biotic effects as it relates to habitat needs for the endangered species. Not many instream flow studies rely on this kind of criteria but it seems clear that human-caused degradation is a significant driver here. Professional judgment would be a primary and useful tool to set a flow regime recommendation on this basis.

P 56. San Marcos gambusia – the assumptions in this section are scientifically valid.

P. 56 Texas blind salamander – the assumptions in this section are scientifically valid.

P. 57-58 San Marcos salamander – the assumptions in this section are scientifically valid.

P. 59 Comal Springs riffle beetle – the assumptions in this section are scientifically valid.

P. 59 Historical flows at San Marcos Springs – the observations here are appropriate. Given the changes to the system, it would seem improper to support low flows at historic levels as to their ability to maintain the endangered species. Duration and seasonality are concerns that would need to be addressed.

P. 60 San Marcos Springs flow regime recommendations, last paragraph – the general strategy here is valid however use of average flow as a criteria suggests that periodic, instantaneous lower flows would be acceptable, which could cause problems with species survival. It is also a concern that the report does not identify criteria for what "rarely" means in terms of the frequency of lower flow levels.

P. 62-65 and Table 11. - The recommendations presented here seem justified in terms of meeting the overall goals described for the project and report. There is a relatively high level of professional judgment involved in selecting the precise numbers for each level of protection and it would seem a case could be made for slightly higher or lower numbers by a casual observer. Professional judgment is a valid and often superior scientific tool that can and should be used in situations where detailed models do not provide clear threshold recommendations. Computer models often give the illusion of precision but most address only a limited range of inputs and bear their own degree of error that is often overlooked. Professional judgment in combination with extensive empirical data, used properly, is an appropriate way for senior scientists with many years of experience to consider multiple inputs and formulate comprehensive conclusions and recommendations. While the review team could identify other possible flow levels, the great body of knowledge and study that have been done for this system compels us to defer to the authors of the report. Again, their recommendations are certainly not out of line with the range of possible flows that appear needed to achieve the recovery of these species. I find no fault with the authors' contention that they have used the best available science or that the flows are either inflated or too conservative.

Task 2: Analyze withdrawal reductions and stages for critical period management

This section overall appears to be thorough and well based. Assuming the groundwater model is reasonably accurate, the authors of this section have developed most of the data needed and done a credible job if interpreting model outputs.

P. 89, last paragraph – comments about the need to understand the effects of rapid flow fluctuations may be warranted as all of the endangered species appear to have an affinity for stable conditions of a

spring flow environment. It would seem unlikely that specific studies are needed of the effects of higher than average flows, except perhaps for Texas wild rice.

P. 90, Further studies – computer models all have limits and the current analysis is no exception. There are many unknowns in how this system really works and how pumping at various levels from a variety of locations really affects spring flow. In fact, the relationship between groundwater level, pumping and spring flow may exhibit naturally dynamic characteristics associated with a variety of factors that are beyond the ability of managers to accurately measure. That said, most of the additional studies mentioned in this section (perhaps with the exception of predicting the likelihood of the return of a 1950's-level drought) are all appropriate and would doubtless help develop a better understanding of how to manage pumping processes over time from the aquifer.

Annear comments on Hardy Report

Over-arching observations:

- Most of the influence diagrams are good ways to recognize the many possible factors at play in terms of affecting habitat for and the abundance of the species studied in this report. The more useful influence diagrams are those that reflect multiple pathways and inter-relationships among the various elements because they realistically convey the difficulty of modeling ecological processes. Though these do a good job of identifying potentially significant variables. This study invests most of its direct focus on a relatively narrow range of elements of physical habitat and water quality (temperature). There are no models today that are capable of integrating more than a limited number of variables into a single model. The models used here are widely accepted and appropriate.
- WUA is commonly referred to as "habitat" which is a bit of a misnomer because WUA is a reflection of the combined suitability of only 3 or 4 elements from the entire suite of environmental elements that combine to create this attribute. This is a common practice in modeling with physical habitat models and does not change any of the observations; however, it would be better to refer to or think of these values as physical habitat so as to not minimize the many other important factors that combine to form habitat in its whole.
- There seems to be a lack of effort to integrate connectivity issues (longitudinal and temporal) though there is recognition of vertical connectivity for those organisms that survive low flow (drought) periods by residing in spring upwelling areas and gravels.
- Results reflect instantaneous WUA which is standard but a time series analysis that addresses life history elements and flow availability during the year might help find and assess the potential effect of habitat bottlenecks on these species.
- The report doesn't state goals or objectives for amount of the amount of habitat that should be occupied or is acceptable. Nor is there a goal for desired genetic diversity. These aren't critical elements but would help the reader understand whether or how well various flow levels achieve desired goals.
- This report is not clear as to whether the goal of managing habitat is to just protect species or restore them.
- In many instances, the report simply notes facts such as a lack of vegetation creates low WUA for darters, but offers no additional information about whether vegetation restoration can or should be done as a species recovery strategy.
- The observance that beetles survive periodic perturbations by burrowing into gravels leads one to think that watershed management and prevention of allowing fine sedimentary materials to enter the stream may be as important as managing water quantity. Clearly, complete integration of water quality (chemical constituents, sediment, temperature, and DO) and quantity is critical to this analysis.
- It is also unclear if one species has a higher priority over others or what strategy will be employed to select the most beneficial flow(s)

Fountain Darters

P 10. References here and elsewhere to "connectivity" are unclear as to which of the 4 aspects is involved (longitudinal, lateral, vertical or temporal). This may be dealt with later in modeling but it would be helpful to discuss the applicability of each of these aspects. The influence diagram on this page also indicates that connectivity only relates to dispersal of the organism of interest but it would be good to relate the role of connectivity to other important environmental variables such as sediment import/export, nutrients, energetic materials, etc.

Multiple places – modeling of depth, velocity and substrate can provide analysis of relatively static conditions but to provide an accurate assessment of the role of flow regimes, it's important to develop information about habitat processes at least for those elements that vary over time. These include water quality functions, sediment import/export rates (and effects on channel conditions), and connectivity patterns over time.

P. 11. A better understanding of the overall habitat processes could be achieved by providing some information as to why or how flooding and drought are considered. Are these positive or negative influences? Per the natural flow paradigm, intra- and inter-annual flow variability are key drivers for most organisms and their habitat and more discussion of the timing, magnitude, duration, frequency and rate of change of flow patterns would be helpful – especially comparing those characteristics over decadal periods (or some other specified blocks of time).

P. 13 The above observations would likely improve the general understanding of relationships' effect on fountain darters but overall, the physical habitat characterization was done using industry accepted techniques and is superior in scope and consideration to most other studies like this.

Hydrodynamic Modeling - *Physical Characterization*

P. 14 The issue raised at the end of paragraph 3 is a vexing one. Specifically noting that vegetation development has higher potential for affecting habitat than channel characteristics suggests that the report should invest more effort to quantify this situation.

Water Surface Elevation Modeling - Comal River

P 17. Most 2-dimensional models do a reasonably good job of simulating velocities under the range of flow conditions noted but one important component that should be addressed is how they model edge effects. Because many species are associated with the edge of rivers, an accounting should be provided for how the RMA2 model deals with edge effects. This doesn't make this model a wrong choice but could affect its relative accuracy for quantifying habitat availability and suitability considering that boundary layer habitats such as the margins of streams often contain a relatively large portion of the useable area, especially for fish.

Using HEC-RAS to set computational boundaries is standard protocol for this kind of model.

P 18. Without looking at the Brune report, it appears that this critical element of quantifying flow may be too imprecise. Considering the importance of decisions based on these studies, one would expect a more precise determination of flow from the various spring inputs.

Vertical Velocity Distributions in Vegetation

P 24. Developing vegetation-specific roughness factors is appropriate and would help improve the accuracy of hydraulic modeling and quantification of physical habitat availability (WUA). These roughness values all look to be within an appropriate range.

Boundary Conditions

P. 29. The assumption at the bottom of Table 6 about the level of spring flow in the upper portion of Landa Lake is unclear. Though assumptions are often necessary, it would be good to see the basis of this one by showing the observed velocities and temperatures from the summer of 1996.

Model Calibration and Verification

P. 30. Flow volume isn't presented here but it isn't needed to follow diurnal changes in temperatures. This is a seemingly good correlation but it would be helpful to repeat the analysis at more than one flow.

Dissolved oxygen levels are typically lowest just before daylight as a function of extended respiration of aquatic plants and periphyton over night. The influence of other limiting factors such as BOD would

be reflected then too so it would not be necessary to factor out specific causes of low DO. It's probably not necessary to track dirunal dissolved oxygen levels but if the study only focuses on one time of day it should be tied to daybreak, which at least in theory would be a potential bottleneck especially during times of year when water temperatures are warmest. The report doesn't say what time of day DO relates to, which raises some question about whether the number presented is truly a limiting factor.

Comal Springs Riffle Beetle

P. 36. No mention is made of this species' reproductive periodicity and it is unclear if different flow requirements at different times of year (depth, velocity, flow rate) are appropriate. The report should at least acknowledge uncertainty about this element if there are no data to support a seasonally varied recommendation.

Texas Wild Rice

P. 37 It is admittedly a challenge to determine the relative efficacy of the two sets of suitability curves presented here, but it seems the USFWS-USU curves may do a better and more conservative job of reflecting flow needs for this species. The TPW curves give the appearance of being more precise however it's unclear what the various steps are based on other than perhaps an effort to narrow the range of suitable flows (for depth) or give more weight to lower flows (based on velocities). It is hard to tell if this is an appropriate and acceptable strategy based on the information in the report.

Current understanding clearly suggests that protecting this species should also address turbidity in some quantitative way. This element isn't necessarily tied to flow but some reference is needed about managing flow, recreational activities, or runoff in the watershed to maintain turbidity below some defined level.

Also, as noted above, there is no recognition of the need for different flows at different times of year for different life history needs. Are higher flows needed at times of year for dispersal of seeds or vegetative parts? Are lower flows needed at times of year for seed germination or sprouting? The relative merit of extremely high flows could possibly be deduced by an explanation of re-colonization processes following the 1989 flood.

Fountain Darters

P. 40 Suitability curve development and the justification for modifications is reasonable and an appropriate improvement over previous studies. One matter that should be clarified is whether velocity criteria pertain to mean column velocities or nose velocities. I presume the latter measurement location is what is referenced. There is a comment at the bottom of page 44 that velocity criteria may in fact relate to mean column velocities. Regardless, this point is not clear in the report and is an important consideration because darters typically associate with boundary layers.

This section does make the point that this species may spawn at all times of year but it is unclear if flow needs for various life stages varies during the year or if spawning is more prevalent at some times of year or seasons – or is keyed to flow pulses.

Physical Habitat Modeling

P. 44 Assigning vegetation type instead of roughness values to each node is acceptable and an appropriate way to assess habitat suitability at nodes. Evaluating water velocities at 6 inches above the bottom boundary layer only partly addresses the fact that fountain darters seek low or zero velocity stations associated with boundary layers but this strategy does provide a better indication of suitability than mean column velocities.

Comal Springs Riffle Beetle Habitat Equation

P. 45 This equation appears to be written backwards per discussion later that says a suitability of "1"

was used for all areas greater than 0.02 ft. Information about this species' habitat preferences on page 37 indicate that most individuals are found in flowing areas where depth is between 1 and 4 inches (0.08 to 0.33 ft) even though some organisms are found in deeper water. Assigning a simple binary system as proposed in the report captures this fact, though it's unclear why the lower limit of 0.02 feet was chosen except to reflect that the organism can be found anywhere there is water that is within the technical limit of measurement. Habitat preference information also indicates the species requires at least some flowing water, so suitability would appear to be more accurately defined as the interface of these areas within some defined limits of velocity, probably low. A binary system for velocity could be used as well (flowing vs. non-flowing nodes).

Texas Wild Rice Habitat Equation

P. 45 This approach for determining suitability is industry standard and acceptable. A similar equation should be used for riffle beetles. The results of these calculations will rely on which set of suitability criteria are used. The model could also be run with a value for turbidity included in a manner similar to how temperature is treated for fountain darters because of comments previously that water clarity is an important factor. Reference should be made as to whether flow needs are different for different times of year based on life history needs of the species.

Fountain Darter Habitat Equation

P. 45 This approach is acceptable. As noted, the choice of suitability criteria to use in this equation is the primary factor that will affect the overall relationship between flow rate and suitability. Reference should be made as to whether flow needs are different for different times of year based on life history needs of the species.

Comal – Temperature

P. 46 The last sentence in the first paragraph seems at odds with the data and actually suggests that 50 cfs will only maintain suitable temperatures as far as perhaps mile 2.1. The report provides no guidance or goal for how much of this segment should be protected. If the goal is to keep temperatures below critical levels over just half the area, then 50 cfs may meet that standard. However, if the goal is to identify the flow that will keep temperatures below critical levels at all times and throughout the segment, then a higher flow would be more appropriate.

P. 47 The last paragraph on this page notes that the higher temperatures predicted for most flows in Landa Lake would negatively impact reproduction of fountain darters. Previous comments were made that this species has been found to reproduce at all times of year. Considering that highest temperatures such as those modeled here only occur during late summer or early fall, it would be helpful to know the proportion of contribution to the population that might be affected by reducing recruitment at this time. If most spawning occurs at other times this impact may be relatively less. Even if recruitment occurs equally throughout the year, this loss of recruitment may be tolerable in terms of persistence of the species. Again, it seems appropriate to indicate the goal of temperature management and whether managers want to remain below critical levels throughout the system at all times of year or if some other standard has been identified.

Dissolved Oxygen

P. 48 Diurnal fluctuations in DO would be expected and it is good to see the reference to unpublished data from vegetation beds in Landa Lake and discussion, albeit brief, of potential effects of BOD and respiration. Plants typically respire at a fairly constant rate however they only produce oxygen when stimulated by daylight. So it is logical that evidence of high production of DO during the day would be countered by high respiration at night. Decay of plant material is a secondary means of oxygen depletion but certainly not the only one and probably accounts for less effect than respiration.

Additional DO data that reflect concentrations at their lowest level (daylight) would seem appropriate to include in the model, especially in light of the unpublished data referenced here. The opinion that DO doesn't appear limiting (so was not used in the analysis) is probably reasonable for present conditions but additional analysis may show otherwise at low flows and warmer temperatures.

It is unclear what concentrations of DO would be limiting (as suggested in the report) but some standard should be identified. These effects would be greatest in the springs and less of an issue in flowing portions due to the potential for re-aeration in flowing water. It is likely that this pattern would change throughout the year as a function of water temperature and perhaps average wind speed.

Comal Springs Riffle Beetle

P. 50-52 This analysis and interpretation seems reasonable. While organisms appear to have survived extreme low flow conditions it would be irresponsible to prescribe those conditions on a permanent basis. Periodic disturbance or perturbations such as floods or drought play an important role in the long-term persistence of most aquatic organisms.

Physical Habitat Using Maximum Daily Temperatures

P 54-59 This analysis appears reasonable but should be noted that it applies only to times of year when temperatures are greatest and probably do not relate to other times of year – especially winter and spring.

San Marcos

Dissolved Oxygen

P 62 – observations about oxygen concentrations reflects appropriate awareness by the study team and offers insight that this will be more fully addressed in subsequent studies.

Texas Wild Rice - *System-Wide Physical Habitat*

Spring Lake

Texas wild rice in Spring Lake clearly has declined since original accounts, which suggests that it may be more limited by factors such as water quality than quantity. It is unclear if velocity distributions have changed but it would be helpful to provide more information about physical habitat changes since the 1930's. Is velocity different today? Has the lake filled in? Is substrate different? Or is there some other factor associated with increased human presence in this area that is likely to blame. It is possible that effects could be associated with some seasonal flow factor as well such as timing, duration, frequency (of flow change), magnitude, rate of change. If the management goal is to do more than just protect remaining stocks of organisms (e.g. to actually restore them to some established level), then more effort is needed to understand why this shift in abundance has occurred.

All other study sections – as expected there is variation in the relationship between flow and habitat suitability at each segment, so there is not one best flow that takes care of a longer stretch of stream. It is also not surprising that velocity is a major driver in the river considering that it appears the natural channel was shaped by historic flows to pass relatively high volumes of water. Flows below 100 cfs appear as if they fill the channel increasingly less at lower flow rates.

Revised Upper San Marcos Physical Habitat Modeling

P. 65 The absence of this species from a particular section may not be reason to omit that section from consideration or study. If restoration of habitat and populations is a goal of this study, additional studies may be needed to better understand why this species is no longer in its historic range and then take steps to correct that problem. If however, the river is so constrained by factors such as urbanization and flow depletion that simply cannot be altered, then it would be important to acknowledge such constraints at the very outset of the study.

Comparing WUA changes on a non-standardized basis between segments may be misleading to some readers but it is important to focus on trends instead of actual square feet of usable area. Displaying the combined WUA as a percentage is a preferred way to assess the relative merits of different flows and does reflect the trends of individual sections of stream.

Texas Wild Rice Physical Habitat Summary

P. 70 The summary comments are reasonable and additional, finer-scale increments would provide more information. I'd like to see more mention of some seasonally adjusted flow recommendations vs. a single number for this and other species. One other thing that is not addressed (and causes all such studies some difficulty) is the matter of understanding whether less high quality habitat has the same value as more lower quality habitat (since each condition can in theory generate an identical WUA score). This phenomenon could explain some of the reason why rice is found where it is in figure 46.

Fountain Darter – *System-Wide Physical Habitat*

P 74-76 It remains a concern that references to seasonal needs or the role of a dynamic hydrograph for a variety of purposes is not mentioned. Likewise, it is unclear if vegetation management isn't an important management strategy both in areas where it currently exists at acceptable levels as well as in areas where it appears to be absent. Perhaps flow conditions or channel substrates are affecting vegetative growth but additional discussion or analysis would be helpful.

Upper San Marcos Physical Habitat

P. 76 – 81 Interpretations and data presentation appear acceptable. While it may be possible that WUA for some or all sections may be higher between 65 and 100 cfs, it seems unlikely that it would be significantly different such that one might reach a different conclusion than presented here.

Fountain Darter Physical Habitat Summary

P 83. The basic conclusion made in this section appears well grounded in the available science. However it is unclear how much precision is needed for managers in order to formulate water management recommendations.

Other Native Aquatic Species

San Marcos Gambusia (Gambusia georgei)

The assumption that acceptable flows for one fish may be adequate for another is difficult when both are actually in existence; however this statement is more risky when one fish has not been seen or studied. Clearly if this fish is still in existence it will have a better chance of survival in water at any level than in a dry channel. However the fact that it has apparently gone extinct under the past hydrologic and water management pattern suggests that those conditions were not favorable. It would be more appropriate to not speculate what the flow needs are of this fish and limit discussion to known facts – of which there are few relative to its habitat needs.

Texas blind salamanders *(Eurycea rathbuni)*

The reference to maintaining acceptable levels of water quality is a key for all species and should be a concern to water managers. The report is on solid ground to state that maintaining flow in the aquifer is key for this species – and the others that are the focus of this study.

Non-native Species

It is generally accepted and certainly logical that predation on all species tends to increase as their spatial area decreases and especially as cover (vegetation) declines. There is little doubt that one of the best strategies to minimize negative impacts associated with non-native predators is to maintain physical habitat, vegetation, and habitat diversity. The fact that fountain darters remain in this system

along with non-native predators at this time is an indication of their ability to co-exist. It is unclear if they might exist at higher densities in the absence of predators. Fountain darters are likely spatially segregated from most predators by virtue of their affinity for low velocity habitats near the bottom of the springs and streams whereas most predators often inhabit areas higher in the water column.

Recreation

P. 88 This section is well-grounded and raises several key points. It is quite likely that human use in and adjacent to the springs and streams is a significant issue that should be dealt with more specifically and managed more directly. Increased human population level is one thing that has definitely changed since 1933 and elicited a variety of changes in the quantity and quality of spring flow as well as physical habitat disturbance. Though these are spring systems, the issue of disturbed silt and silt deposition on vegetation suggests that a varied flow regime, to the extent possible, would provide benefits to these systems by helping transport sedimentary materials through the system. This matter also raises again the question of seasonality of impacts. If, for example, fountain darter spawning is more prevalent at a certain time or times of year, then recreation and watershed management could focus on those periods.

A Review of

"Technical Assessments in Support of the Edwards Aquifer Science Committee "J Charge" Flow Regime Evaluation for the Comal and San Marcos River Systems

December 29, 2009 Draft

Prepared for

The Edwards Aquifer Recovery Implementation Program

by

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Prepared by:

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Stated Goal

"The focus of this report is to provide technical analysis in support to the Expert Science Subcommitte of the Edwards Aquifer Recovery Implementation Program to evaluate flow regimes for each river system required under Senate Bill 3 "J" charges." (page 1, second paragraph).

Summary

Overall, I support the science and findings contained within this report. I believe the report addressed the stated goal (focus of the work) and provided information necessary to begin to address targeted elements within the Edwards Aquifer Authority Act.

The reviewed document represents work that is technically strong, fairly wide in scope, with conclusions that are consistent with the study results and current literature and science. It introduces a (peer-derived) overarching framework to ground and place the current work in proper context and help inform additional efforts and input. The report provides necessary information to effectively address species requirements in relation to spring discharge rates and water withdrawal reductions and stages of the Edwards Aquifer. All of these aspects of the report are to be commended.

Specific examples of the technical strengths include: physical characterization of the study area, 2D modeling, and incorporation of vegetation dependant hydraulic roughness, review and update of HSC with more current data, temperature modeling, and inclusion of genetic analysis where appropriate (e.g., to explain population patterns in riffle beetle).

The scope of the work is evidenced by the peer-reviewed influence diagrams, modeling of habitat requirements for a plant, an insect, and a fish (2 kingdoms and 3 phyla), derivation and coordination of the habitat suitability curves and analysis, system-wide temperature modeling and calibration, and integrated treatment of water quality, biology, and elements of geomorphology and connectivity.

As with any endeavour, there is room for improvement, and the report is replete with acknowledgement of that fact throughout. Additional strength could be provided to support and enhance this study through more direct integration of the current study with other elements within the influence diagrams. The influence

diagram frameworks need to be further refined and formalized, based on the comments and reviews received from experts. Additional suggestions follow, below.

- Conceptually, the report could be improved by integrating more thoroughly with the hydrology feeding the springs. Hydrology drives the system. Time series analysis, matching the physical habitat modeling with the hydrologic record and ultimately producing habitat duration curves, would help to further identify bottlenecks, and important thresholds and is standard procedure for physical habitat modeling.
- Full characterization of the system hydrology: past, present, and potential, including all elements: magnitude duration, frequency, timing, and rate of change would also improve the report. To what degree have these elements been altered and what are the likely watershed changes and hydrologic effects (e.g., climate change) that will influence the hydrology further? Because this is such an important aspect, I have to believe it was specifically not part of the assigned tasks of this report.
- Related to additional hydrologic analysis and greater integration with the influence diagrams: more specific geomorphic analysis including channel morphology, dams and channel use (e.g., recreation) and their influence (hydraulic and sediment) on sediment transport and habitat, and the relationship of the current hydrology to the maintenance and construction of habitat. To what extent have the dams, the loss of riparia, and hydrology (e.g., watershed runoff, changing recharge rates, and pumping) influenced habitat and population patterns?
- Expansion of the habitat modeling to include a (habitat) guild representative for each habitat type found in the springs would ensure that habitat connections between target species and key life stages (analysis assumes all life stages of each target species are represented by one set of curves) or food organisms would not be overlooked and possibly severed.
- Additional attention to the loss of species diversity that seems to be evident in both springs. While diversity indices are strongly related to sampling

effort (space and time) up to the asymptote, the tables provided in the report warrant further investigation. Has diversity dropped 28% in the Comal River and 46% in the San Marcos River between 2001 and 2007? The report alludes to introduced species as a factor. Introduced species (invasives) are typically favoured over natives as habitat is artificially disturbed and generalized. Does the presence of dams (fragmenting and pooling river segments) and watershed changes represent the underlying cause? What factors are at play?

- Expansion of the water quality elements to include chemicals and elements common to urban stormwater runoff. Specific modeling of stormwater/water quality inputs and effects requires matching hydrology and WQ elements. For example, salt runoff during winter months when flows are typically lower may represent a negative associative impact (effect of salt is diluted under higher runoff flows and is higher when flows are low), while the impact (scouring vegetation, filling in habitat) of additional sediment inputs may increase with higher runoff volumes.

Specific Comments:

Page 4 -13. Influence Diagrams for Target Species

A recurring comment (applicable to all species) regarding the diagrams is the importance of "connectivity". Fragmentation of river systems and resultant loss of genetic diversity and increased potential for extinction is well recognized aspect of meta-population ecology and research (see Hanski 1999, for example). These systems are dammed and connectivity is plotted in the diagrams as a part of the "big picture" for each species except fountain darters. Given the disappearance of the fountain darter from the Comal Springs system following the 1956 drought, and subsequent re-planting from San Marcos, how has this aspect been overlooked? Are these dams fully passable by this species, during the range of flows? Temperature "disconnects" habitat as well, in the extreme.

Also, Figure 6 (page 8) is applicable to all species: the relationship of the watershed to runoff and groundwater and surface water (spring flows) and its quantity and

quality, and the potential human interaction points (pumping, overland flow, point and non-point pollution) is a constant and important determinant for these systems.

The importance of watershed influences is underscored on page 14, where the report notes that sedimentation is occurring within the channel and has been associated with channel topography changes, brought about by construction activities in the Sessom Creek watershed. Apparently the modeling and analysis has accounted for the channel changes, but not the changes in aquatic vegetation, which has a higher associative potential for suitable darter habitat. Further address of this or explanation is warranted; the relationship between watershed activities, hydrology, and sediment is an ultimate driver of the long-term health of the endangered species and this system.

Page 18. Further establishing the hydrologic partitioning may be important, or at least that the partitioning is constant at the range of studied flows, as the WUA results and conclusions are based on this assumption.

Page 22. The caveat concerning the channel and modeling in the Cape's Dam section: hypothetical results due to heavy sedimentation should be noted as such in the appropriate tables later in the report.

Page 23. Each species was assigned a unique hydraulic roughness *except* Texas wild rice (key species of interest), for valid reasons. But velocity is a key variable for wild rice habitat and hydraulic roughness a mediator of velocity. What is the estimated value used and how sensitive is resultant WUA to this value?

Page 25. Water Quality and Temperature Modeling

The modeling and calibration of water quality models with additional data seems strong. Fountain darter habitat modeling assumed worst case scenario for temperature (hottest 48 hours), in line with a precautionary approach and establishing that the model is calibrated for the extremes, which likely most impact the species.

Page 30. Given the urban setting and relative lack of apparent riparia to absorb runoff contaminants, dissolved oxygen modeling should be performed with the effect of ammonia, nitrate oxidation, sediment oxygen demand, phytoplanktonic

algae/macrophytes, and associated respiration, growth, nutrient effects and BOD. As noted by the author, this lack represents a key area of future integration tying the watershed , water quality, and ultimate habitat of the endangered species.

Page 31. Figure 23. Graph shows match of modeled and observed flows: modeled flows were very close to slightly lower than observed on the higher temperatures (above 78 degrees F) and higher on the lower high temperatures (at or below 78 degrees F). Throughout the simulated period (48 hours) the model nailed the diel swing.

San Marcos River ; Twenty one segments of 100 feet in length, each similar reaches – an example of strong technical work.

Page 35. Habitat Suitability Curves (HSC) This paragraph represents a strength of this work and approach: the scientific community were actively involved in the collection or review of the information used. The HSC for wild rice were based on work by Saunders et al. (2001); Hardy et al. (1998) established the basic sampling protocols for HSC for fountain darters; there was additional data available on vegetation use (by darters) but not useable because of vagaries in vegetation coding schemes. According to the report, this issue is being addressed through ongoing vegetation mapping that will allow incorporation of the long-term data for fountain darter vegetation suitability curves. In addition, the annual monitoring data collaboratively collected by TPWD and USFWS for Texas wild rice (TWR) were used to evaluate the existing TWR HSC and based on that review, were not modified.

Page 36, 37. Comal Springs Beetle

From the report: this beetle occurs in gravel substrate and shallow riffles in spring runs and upwelling spring orifices. They may, like many Elmid species, require 6 months to 3 years to complete a life cycle, and usable water depth is 1 to 4 inches. These life history pieces, along with the 1950's drought experience, suggest that the species can survive low flow conditions, but also may be susceptible to water quality changes (contaminants) or sediment influxes. The final paragraph on this page, discussing decreased genetic variability as strong evidence for isolation coincides with metapopulation ecology and, again, points to the importance of additional emphasis towards connectivity in this system (from watershed to

groundwater recharge and surface water runoff to spring to channel and downstream). The rationale for depths, given what little is known, is logical and acceptable. Note: all surface area with depth greater than 0.02 feet was considered usable.

Page 37, 38, 39 Texas Wild Rice (TWR)

TWR is apparently the riffle species of this analysis, preferring shallower and faster water. In addition, TWR occurs at sites with high water clarity, is susceptible to disturbance, and is adversely affected by shade. These latter data were not available for this analysis but would be areas to refine the modeling further. Again, the relationship between watershed conditions (e.g., activity and stormwater management), riparia, spring flows, recreational activity management schemes and TWR habitat would seem to be fruitful from a long-term management perspective.

Page 40 -43, Fountain Darters

The science utilized for HSC modeling of this species is thorough. This is an apparently medium to shallow pool species and we would expect a very slow or low relationship to decreased discharge, as affecting depths and velocities. In fact it seems that fountain darter habitat is affected primarily by low flow effects on temperature or on vegetation that the analysis picks up through thorough analysis and presentation of these factors. Technical team multivariate analysis of habitat associations with depth, velocity, vegetation type, and height of vegetation (likely surrogates for cover) confirm the direction of the analysis, and advisability of revised modeling.

Page 44, Physical Habitat Modeling

The assumption that vegetation/substrate characteristics did not change as a function of flow rate seems counter to the analysis. We know the bed changed, e.g, after floods and upstream watershed activity. The 'dam removed' option at Cape's dam showed as much. For the case of the TWR, the point is made that low and high flows are associated with disturbance, either from recreation or the flood flows and sediment scour. With the extensive data monitoring that is being done on TWR beds, it would seem data could be derived to reflect the situation better.

Page 45, Comal Springs Riffle Beetle Habitat Equation

There is apparently a typo for the binary equation used for this macroinvertebrate. According to p37, second paragraph, beetles used water down to or >0.02 feet.

Page 46, 47, 48 Comal Temperature

From previous pages, 78 degrees represents approximately the 0.5 suitability point, and 80 degrees the 0.2 suitability point. Given that almost a mile of stream is brought to 78 degrees or 0.5 suitability at a flow rate of 100 cfs, stating that "60 or 30 cfs would reduce suitable darter habitat" is tentative and shouldn't be. According to Figure 32, 5/6 of the total length modeled would be at or above 78 degrees (0.5 suitability) at 30 cfs and over half the channel length would be at 0.5 suitability at 60 cfs.

The statement on P47 regarding water temperatures for the main stem is more clear: "A general warming trend is noticeable for all flow rates but its magnitude is minimized at larger total flow rates of 150 to 300 cfs. According to the graph (figure 33) minimized means over a mile of stream – the length that is 78 degrees or slightly above at 150 cfs total flow rate.

Report notes the large number of control structures and their influence on water temperature – an important point related to overall system connectivity.

Page 48, 49, 50 Dissolved Oxygen

Report acknowledges another detrimental aspect of low flows with high vegetation - potential for low DO. Noted also is the influence of control structures on maintaining DO through re-aeration. If system connectivity issues are addressed through channel restoration, these reaeration benefits must be kept in mind (e.g., through incorporation of built 'natural riffle' structures). The rationale for dropping DO, after review of the modeling results (Figure 34, 35) and reference to observed field values is acceptable, in spite of the very real diel impacts from vegetation.

Page 50, 51, 52 Comal Springs Riffle Beetle

Note text and disparity with binary equation - depths greater than 0.02 feet versus <0.02 feet. The additional simulation runs based on criteria developed from collection data on riffle beetles in the main spring is a good follow-up idea. The

sampling design employed is robust. The results and statement of the conclusions is clear: greatest rate of habitat decline around 100-150 cfs. Discussion dealing with the question of 'why are the beetles still here if they are so affected by low flows, and what do the results indicate (directionally)', is comprehensive and direct.

Page 52-58 Fountain Darter

Fountain darter habitat is strongly constrained by temperature not physical habitat; highest WUA under the modeling for max daily temps occurred at Comal River flow of 150 cfs. Revised HSC increased the amount of WUA realized over the Bartsch et al. HSC (Table 11). The discussion of caveats relative to the modeled split flows (into the old channel and new channel) and results and updated modeling currently underway, left me wondering what to make of it. If the channel changes that were not reflected in the current analysis include topography and vegetation (caveat 1) and they show a strong physical habitat association with flow and darter habitat as well, the statement that thermal effects are more limiting than the amount of physical habitat will have to be withdrawn. If the use of a spring orifice temperature as a boundary condition (caveat 2) is important, would it affect the conclusion(s) as well?

page 62, San Marcos, Dissolved Oxygen.

There is agreement with the concern for potential depressed DO levels during night time respiration at low flows, in highly vegetated areas, likely at high temperatures, (typical of drought time). It should be addressed in on-going modeling efforts.

page 62, 63 San Marcos, Texas Wild Rice

The habitat conditions for this section are reflected in table 12. Given previous (1993) publications note of the decrease in TWR distribution at Spring Lake, narrowing down the cause of these apparently degraded habitat conditions should be a concern.

Texas Wild Rice habitat shows a consistent upward trend with increasing discharge, except in areas with backwater affects and other velocity limitations. The report does a good job of walking through the data results, step by step. The note under State Hatchery A, concerning flow rates near the historic mean having

velocities still in range for wild rice are an argument for their existence and persistence there. The summary for this section is clear and reasonable.

A Review of

" Analysis of Species Requirements in Relation to Spring Discharge Rates and Associated Withdrawal Reductions and Stages for Critical Period Management of the Edwards Aquifer

December 28, 2009 Draft

Report to the Steering Committee
for the

The Edwards Aquifer Recovery Implementation Program

by

The Edwards Aquifer Area Expert Science Subcommittee
for the Edwards Aquifer Recovery Implementation Program"

Prepared by:

Ian Chisholm

Task 1: Analyze species requirements for springflow and aquifer levels as a function of recharge and withdrawal levels.

P. 12; Flow Regime. As recognized inherently by the Subcommittee's work and report, hydrology drives aquatic systems. The Subcommittee "chose to address the legislative charge within the context of a flow regime for the protection of all threatened and endangered species as well as the integrity of the ecosystem." Based on this, overall, the Subcommittee did a credible job. In the complex social and resource context of this system, the results are a laudable first step towards establishing an adaptive management approach for protection of the endangered species in the springs. In terms of addressing the long-term "integrity of the ecosystem", however, much work needs to be done.

P. 13; The trigger criteria seem disjunct from the charge the Subcommittee chose. The triggers are not part of a flow *regime*, which itself (hydrologic conditions, past and present) is not well established in the report. Baseline hydrologic conditions (natural, historic, predicted future) should be firmly

36 described. Further, the report is proposing low flow minimums that, under conditions of demand, do
37 not allow capture natural flow regimes and therefore are not supported by the natural flow regime
38 paradigm. There is no evidence within the report to support that the listed triggers will restore a natural
39 flow regime, which it references. The rationale for choosing the particular metrics is weakly supported
40 within the document, which are then variably applied between San Marcos and Comal springs. As an
41 interim, the use of hydrologic measures is acceptable, particularly for establishing or defining how
42 intact or altered a current hydrology is from a natural or minimally altered condition. In such cases,
43 these statistics should be: simple, non-redundant, easily understood by water managers and the public,
44 account for the 5 major flow characteristics (timing, duration, frequency, rate of change, magnitude),
45 and be linked (even conceptually) to ecological response (Apse et al. 2008). In the case of the report,
46 the 3 statistics chosen specifically do not address the 5 major flow characteristics. The Subcommittee
47 Report does take a major step forward, however, as an interim measure towards an adaptively managed
48 system.
49
50 P. 14; paragraph 1. Regardless of how high flows are supplied, high flows are a necessary part of the
51 natural flow regime, part of the Task 1 charge (to analyze species requirements in relation to spring
52 discharge rates), and should be prescribed. The high flow trigger(s) would establish the means for
53 testing whether or not the high flows are being impacted by management and ensure against unforeseen
54 demand for high flow water. Assuming high flows will take care of themselves seems to be tenuous,
55 given the potential demand for water and various engineering solutions to capitalize on imagined water
56 surpluses.
57
58 P. 15; The description of channel changes within the Comal River Old Channel re-affirms the
59 importance of connectivity in contributing to fountain darter habitat and population strength. The
60 report describes habitat degradation and fragmentation within the study areas: the "reconstruction of a
61 new culvert system on the Old Channel coupled with an extended period of high flow conditions
62 (facilitated by the new culvert system) led to a scouring
63
64 P.18; The statement, "in all probability, the impact of habitat loss in the spring runs is minimal", is
65 arguable, given the report's accounts of changes within the springs and the drivers of fountain darter
66 habitat. Because fountain darter habitat is limited by temperature, which likely increases during hot
67 weather as you move downstream from the springs, fragmentation of habitat and populations is
68 probable. As the resilience of this ecosystem is tested, due to watershed changes (increasing runoff of

water and some chemicals), alteration of hydrology, altered channel characteristics, loss of native riparia, increase in recreational activity, etc., any further decrease in connectivity should be considered alarming. Connection between habitats, particularly refugia, is a critical aspect of healthy river systems.

P. 20; The discussion of low and slowly rising springflows and their relationship to *Melanoides tuberculatus* provides evidence of the strength of the Subcommittee's biological science in this report. At the same time, it is not translated to actual management decisions regarding the recommended regime. Consideration of high flows as part of the natural regime and the recommendations for flows to sustain and promote endangered species may well provide additional protection to these populations and should be included in future recommendations.

P. 22; first full paragraph; these observations can be correct but in other systems, high flow events tend to mobilize pollutants to the detriment of riverine organisms. It's unclear what this paragraph is suggesting other than a statement of the obvious. If water quality degradation is an issue it would seem that specific mechanisms should be included here and potential strategies proposed to deal with those threats.

P. 24-25; Good discussion of the biology and rationale surrounding considerations of comal riffle beetles and flows for their habitat. More and more researchers are relating the importance of connectivity, in both terrestrial and aquatic arenas, as vital for long-term health of ecosystems. Maintaining connectivity in face of increasing use, increased potential for withdrawal stress (e.g., urbanization, climate change) is part of a considered management plan for genetic diversity. So-called sinks can become sources, whereby subpopulations supply genetic material to re-seed and maintain the populations under catastrophic disturbances. Under such a management scheme, environmental stresses are 'absorbed' by each species having access to the full aquatic network and the habitat it can provide.

P. 26; Additional information is needed to address, 1) the water quality trend in the aquifer, 2) the relationship of water quality and discharge.

P. 26; Analysis seems to assume variability and timing of flows are insignificant factors. Plots of gage data would help establish this assumption. Graphs of historical hydrology showing the range of flows or box plots by month are acceptable ways to begin the show the system hydrology.

P. 27; Figure 5; Final recommendations deviated from the long-term average, 6 month minimum, and 1 month minimum statistics for Comal Springs system. The process details resulting in the recommendations of 225, 75, and 30 cfs are not completely clear and undoubtedly relied on professional judgment. I support professional judgment but descriptions of the logic and decisions that led to these changes must be documented. This is true in all cases listed in the table. For example, previous text alludes to a conservative approach; what about negative synergistic effects under future conditions, e.g., long dry spell, hot weather, increased watershed development, decreased connectivity from in-channel engineering, increased demand for water, increased recreation, increased numbers and types of invasives, and increased infestation rates under low flow conditions? All of theses aspects are noted within the report. How these recommendations would be used to proactively manage the system is unclear. Forecasting of water year, based on full statistical description of natural and historic hydrology, antecedent moisture conditions, weather forecasting and agreed-upon decision criteria is being used in other systems to adaptively manage rivers and may have applicability here. Additionally, a "levels of evidence approach", used in epidemiology for years (see A.B. Hill, 1965, The Proceedings of the Royal Society of Medicine), would formalize many of the decisions now being referred to as " professional judgment". Hill (1965) lists and describes 9 causal criteria, in (his) order of importance: strength of association, consistency of association, specificity of association, temporality, biological gradient, biological plausibility, coherence, experimental evidence, and analogy.

P. 28; "The most important aspect of maintaining the long-term average component of the flow regime is that the system would not be able to have repeated 6-month or 1-month events also prescribed in the flow regime." What is the relationship of pumping (demand) and climate; could these two factors combine and negate this strategy?

P.29; The report reiterates discussions emphasizing flow recommendations for Comal Springs are based on best available science and professional judgment. "*We understand that these threatened and endangered species in the Comal Spring System can withstand short time periods of habitat loss and even some direct impact to the species themselves without resulting in long-term harm to the overall population. With that said, several unknowns still exist. One of the questions that remains is: What frequency or duration of these events could be tolerated by these species without long-term consequences?*" The obvious starting point for the answer is natural flow conditions. Even the answer of natural flow conditions also assumes similar watershed, riparia, and channel characteristics, which is

just as clearly not in evidence. The likelihood that connectivity, water quality, geomorphology, and biological conditions are not the same as when historic natural flows occurred stresses the importance of a precautionary approach to recommending flow minimums. And yet, "no flows below 5 cfs" are prescribed.

P. 34; An Appendix listing of all data available for these systems would be an important tool in planning future monitoring and modeling efforts.

P.36, last paragraph, P 38, Table 6; Consideration of meso-habitat conditions at various flows in the San Marcos; showing riffles decreasing below 80 cfs. Again, further evidence of a complete examination of habitat, species, and flow relationships. Riffles very typically are the most hydraulically sensitive to flow changes (along with shallow backwaters) and should, as a general rule, always be examined. This provides strong argument for a cutoff flow around 80 cfs.

P. 40; Text discussion is fairly lengthy and comprehensive, discussing darter and flow relationships with parasites, invasives, declining water quality, and increased sedimentation. System connectivity and its impacts on genetics via fragmentation and meta population dynamics is not touched on, but what is more striking is how the description of available fountain darter habitat being maximized at 65 cfs apparently dominates all other considerations. Because fountain darters are a pool species associating with vegetation, you would expect insensitivity to decreasing flows until depths became restrictive.

P.56; San Marcos gambusia. This species should be removed from the analysis. It is reportedly "likely extinct", and yet the fountain darter habitat "are assumed to be sufficient to support any remaining San Marcos gambusia without incurring harm to the species." Given that fountain darter have always been there, and gambusia are thought to be extinct since 1982, assuming habitat for fountain darter is adequate for them is either in error or is not the limiting factor. Assuming it is accepts a logical weakness unnecessarily.

Task 2: Analyze withdrawal reductions and stages for critical period management.

P. 69; "Among other items, Section 1.14 of the Edwards Aquifer Authority Act states that the Edwards Aquifer Authority shall (1) protect the water quality of the aquifer, (2) protect the water quality of the surface streams to which the aquifer provides springflow, (3) achieve water conservation, (4) maximize

the beneficial use of water available for withdrawal from the aquifer, (5) recognize the extent of the hydrogeologic connection and interaction between the surface water and groundwater, (6) protect aquatic and wildlife habitat, (7) protect species that are designated as threatened or endangered under applicable federal or state law, and (8) provide for instream uses, bays, and estuaries." (Edwards Aquifer Area Expert Science Subcommittee Report, 2009).

Based on this wording, the Subcommittee limited their task to adjusting pumping reduction levels and stages for critical period management. What they didn't do is consider water quality more generally, or protection of aquatic and wildlife habitat downstream or in the estuaries and bays (see quote below).

P. 70; "With respect to the charge, we did not extensively address all elements under Section 1.14 of the Edwards Aquifer Authority Act. Although we considered the need to protect the water quality of the aquifer and that of the aquatic and wildlife habitats in and near the springs with respect to movement of the bad water line and potential contamination, water quality in general was not explicitly considered. We did not consider the protection of aquatic and wildlife habitat in the downstream reaches of the river and its associated bay and estuary. We did not explicitly consider provisions for instream uses (Senate Bill 3 created a separate process . . . .)" (Edwards Aquifer Area Expert Science Subcommittee Report, 2009).

Given the circumscribed work, the report represents a strong interim measure towards active management of the federally listed endangered species.

Approach

P. 71-75; Model runs (simulations) fell into three broad categories. Over 40 different runs were evaluated with various assumptions and sensitivity analyses. This was a most useful exercise that illustrates how the present management the model can be is used for listed species protection. This was a retrospective analysis, where the flow limits and period of flow record were matched to determine what the affect would have been. This does not constitute predictive modeling or enable proactive management of the aquifer.

Use of the MODFLOW-NR for Task 2 is state-of-the-art for groundwater modeling. As a finite-difference model, the grid node points and boundary conditions are of key interest relative to the strength of the data being used to specify values of transmissivity and storativity. Specifying the

boundary conditions, whether of known head or flux, is mandatory for solving the groundwater-flow equation(s). In some cases, the boundary conditions will be mixed, with some portions of the aquifer having known head and some portions having known flux. GIS layers can be used to specify cell parameters, layers (e.g., conductivity at depth). These conditions may vary over time as well, as a function of aquifer stage and the specifics of conduits to and from other formations, requiring (or allowing for) even more layers, cells, and cell parameters. This can become exceedingly complex, in reality, and to model. And, even when current computing can handle it, *the question is: has the complexity increased the level of groundwater understanding?* (see Bredehoeft, J. 2010. Models and Model Analysis. Ground Water 48(3):328). Good decisions are based on complete understanding – of what we know, and just as importantly, what we don't.

For all of these reasons, additional information specifying the uncertainty surrounding the estimates of springs flows from the aquifer modeling effort is an important area of further disclosure. Because the spring flows are an expression of the state of the aquifer, a thorough description of baseline hydrology is imperative. Full characterization of the system hydrology: past, present, and potential, including all elements of characterization: magnitude, duration, frequency, timing, and rate of change would improve the report and ultimate acceptance of management prescriptions derived from it. Confronting the degree that these elements have been altered, as well as the likely watershed changes (e.g., trends in population growth, i.e. impervious cover has been correlated to population size/density), effects on aquifer recharge rate and other hydrologic effects (e.g., climate change) that will influence the hydrology further are important areas of further discovery and delivery.

Just as a complete accounting of the groundwater modeling (data, estimates, uncertainty) would benefit understanding of the aquifer status, springs hydrology, subsequent habitat conditions, and management opportunities, it would also allow wider participation in the assessment of 'future conditions'. One such area of potential expanded consideration is to formally review the impacts of climate change on pumping, watershed conditions, aquifer stages, and spring flows. By looking at global climate models you get an idea of the magnitude of change for each group of hydrologic descriptors (magnitude, duration, frequency, timing, and rate of change) and can provide the basis for sensitivity analysis and refinement of water management decision making. The hydrologic time series analysis suggested for the habitat evaluation(s) provides the foundation for incorporating climate change information with appropriate sensitivity analysis, into management models; where expected changes to each water year type are characterized and used to indicate the range of conditions that may be faced.

In terms of a strong first step to dealing with a complex and controversial issue, the Subcommittee has proposed actions that will likely lead to the protection of endangered species. Further refinement, as noted within the report, and likely resulting from proposed study and monitoring results, is necessary and critical for actual 'recovery' of these species. Additional considerations of all 5 components of the resource (hydrology, geomorphology, water quality, biology, and connectivity) in context with the surrounding watershed, and human dimensions will provide necessary information for long-term management of the ecosystem.

P. 90-95; Further Studies. This is an impressive list of studies and modeling improvements and appears to be thorough. The Subcommittee obviously is at the point where: "further work is indicated". While admittedly unfamiliar with the broader work not presented here (e.g., MODFLOW, demand trends, watershed characterizations) I am compelled to relate several paragraphs from Bredehoeft's editorial on 'Models and Model Analysis' in Ground Water (cited above).

> " There is another way to conduct this investigation many thoughtful modelers advocate. That is to use the model as a tool to organize our thinking. One starts the investigation by assembling all the readily available information. On the basis of this preliminary information, you arrive at a conceptual model, or perhaps several conceptual models of the system. Armed with your concept and the preliminary data, you create a fairly simple numerical model of the system. You run this model, varying both the boundary conditions, and the range of potential inputs; you see how the system responds. For example, you ask: *Can the system sustain the magnitude of planned development?* Usually you realize, during this exercise, that some of your conceptual ideas are infeasible and can be ruled out. In the process, you identify the most sensitive parameters by using optimizing techniques. In this way, you use the model to guide data collection. You are continually running the model to reorganize your thinking as you collect more data. You refine the model as necessary – add more cells, or more layers, but you do this for a reason.
>
> With this method of investigation, you are always in a position to write a progress report. This scenario requires great flexibility – you are following where the information leads rather than a prescribed project plan. Managers have to trust the integrity and the capability of their investigators.
>
> For me, the model is not an end in itself, but rather a powerful tool that organizes my thinking and my engineering judgment. I may be like Don Quixote jousting with windmills; but

> to build bigger groundwater models just because it is feasible, or in vogue, seems to me meaningless – certainly it does not lead to increased understanding."

This may well be the same tack already being followed, and will confirm for outsiders (those, like myself, not intimate with the entire system, data collection, modeling and synthesis effort) that the level of modeling complexity is well matched by the level of groundwater and overall system understanding. If not, perhaps it will stimulate discussion and help increase the degree of shared vision among team scientists and managers.

Appendix G. Utility of the graphs of scenario runs would be greatly improved by plotting a reference condition with each run, providing an immediate view of the magnitude and pattern of change each scenario represents relative to a common baseline.

A Review of

"Analysis of Species Requirements in Relation to Spring Discharge Rates and Associated Withdrawal Reductions and Stages for Critical Period Management of the Edwards Aquifer"

December 28, 2009 Draft

for

Report to the Steering Committee for the Edwards Aquifer Recovery Implementation Program

by

The Edwards Aquifer Area Expert Science Subcommittee for the Edwards Aquifer Recovery Implementation Program

Prepared by:

Allan Locke

Summary

For the sections that I reviewed, I fully endorse the Edwards Aquifer Area Expert Science Subcommittee's (EAAESS) approach to analyzing species requirements in relation to spring discharge rates and aquifer levels and developing withdrawal reduction levels and stages for managing the long-term survival of the aquatic communities of the Comal and San Marcos springs, in particular the federally listed and endangered species. I find no serious flaws or errors in their methodology or their findings.

Assumptions of the approach are well documented and are reasonable given today's less than complete understanding of aquatic ecosystems. The tools and methods of analysis employed, with respect to fish habitat, are appropriately used based on best available information. With regards to the "natural flow paradigm", this construct has been more than adequately addressed. As stated in the report, *"...minimum flows are a necessary part of a flow regime of a given aquatic ecosystem for the protection of its component species, but the maintenance of minimum flows alone is not considered sufficient to maintain a sound ecological environment."* They further quote from their previous work in 2008, *"...minimum springflows are required within the context of a system flow regime for the survival and recovery of each species...A system flow regime includes low flows which support the survival of individuals for limited periods of time, normal flows which support reproduction within the population, and higher flows that periodically rejuvenate the system."*

I specifically note the following with respect to the various components:

<u>Hydrology:</u>

The team focussed in on periods of time that were of significance to them, e.g., when species were extirpated, the period of time since the fountain darter was reintroduced. They then compared these smaller periods of time to a very long hydrological period of record, 1927 to 2009. Eighty-two years of hydrology should be a sufficient period of time to capture the variability in the flow regime in these systems. The process of following the concept of the natural flow paradigm, by taking the observed data for a period of interest and conduct an evaluation of the historical hydrology is to be commended.

Notwithstanding their rigorous approach to using the hydrology data, they propose further effort is needed to, *"(1) improve springflow measurement, (2) conduct sensitivity analyses, (3) run optimization models, (4) estimate the probability of recurrence of the 1950s drought, (5) evaluate the potential effects of climate variability on recharge, (6) conduct additional runs to refine withdrawal reductions, (7) update the model, (8) refine the calibration of the model, (9) enhance the management module, and (10) refine model calibration between San Marcos and Barton springs."* The team has more than thoroughly understood and importance of how important hydrology serves as the foundation for carrying out these type of studies.

Fish Habitat, Macroinvertebrates, Vegetation:

The approach of defining thresholds for loss of habitat using a number of metrics; a long-term average, minimum 6-month average, minimum 1-month average and an instantaneous flow threshold below which no water should be taken, is consistent with similar studies throughout North America.

Balancing the needs of a multitude of species specific requirements is a common issue in making one overall flow regime recommendation. The process undertaken by the team of taking the higher flow requirement for any particular species in each case, and then to ensure this requirement would not negatively impact the other species or overall ecosystem integrity is once again, a common approach used in many other studies. These two approaches are consistent with current thinking, understanding of flowing aquatic ecosystems and ecological theory.

Legal and Institutional Setting

The legal and institutional mandate of the Edwards Aquifer Authority is clearly articulated, "*...the Texas Legislature created the Edwards Aquifer Authority to regulate pumping in the aquifer and to ensure that, by December 31, 2012, endangered and threatened species dependent on springflow are protected to the extent required by federal law.*"

Managing Uncertainty

One of the most important tasks in carrying out these type of studies is to clearly articulate the uncertainty associated with data collection, modeling and data analysis. The team has done an excellent job in documenting uncertainty throughout the report, as noted when it is stated, "*...all commonly used models and methods for setting instream flow requirements have been criticized for their overly simplistic and reductionist treatment of complex ecosystem processes and interactions...they provide little insight into complex ecosystem dynamics...*" They further note, "*Management decisions based on...a limited number of species...may actually result in undesirable effects on the ecosystem...*" It is somewhat puzzling why, "*The subcommittee made a conscious decision not to add a margin of safety to the proposed recommendations.*" The team clearly evaluated the best available science in an objective fashion, yet decided to not factor in a margin of safety. While it is common to adopt "the precautionary principle", this team obviously discussed this issue at length, and agreed as a group not to factor in a margin of safety. It is not known to this reviewer if the legal and institutional setting will allow for changes to the water management plan, "*...if it is later revealed that significant impacts are not captured in the model results...*" Generally speaking, should information come forward in the future that the ecosystem is able to tolerate short periods of lower flow conditions or more frequent occurrences than is

recommended without significant consequence, then more water can be allocated for out of stream use. The opposite is not so easy. Ultimately, this is a decision about how the team wants to manage risk.

Overall Approach

The team clearly recognizes that understanding species requirements relative to flow is very complex and not one single method is without its pros and cons. The best possible overall approach is to use the most appropriate flow model(s) in conjunction with the target species life-history information, coupled with ecosystem based approaches, natural flow theory, and ultimately in the end, will rely on professional judgment to make a flow recommendation. The team is to be commended for using components of all of these assessment tools and for their in-depth analysis to understand the limitations and applicability of the tools, methods and approaches they used to complete their assigned tasks.

The following are specific comments, suggestions and questions. Overall, I believe the recommended flows and more specifically, the commitment to monitoring, is an acceptable approach to ensuring the long-term survival of the aquatic communities, including the federally listed and endangered species of the Comal and San Marcos springs.

Specific Comments:

1. On page 4, it is stated, *"For the aquifer-dwelling listed species such as the Texas blind salamander, Peck's cave amphipod, and Comal Springs dryopid beetle, maintaining the same amount of discharge needed for the protection of surface dwelling species would likely protect these species also; however, potential impacts on these*

species are considered." This is a reasonable assumption and one that is applied in many studies of this type.

2. On page 11 it is stated, *"In instances where natural flow variability can be maintained...benefits to the native communities can be substantial. However, this is an unrealistic scenario...and it is implausible in the Comal and San Marcos springs ecosystems. These two spring ecosystems have been altered by humankind for at least 150 years."* It is a reasonable assertion to suggest that a recommendation to restore the natural flow regime would be impractical. However, given the target species of interest evolved in the system since the last ice age, it may be worthwhile to at least use the natural flow regime as a benchmark against which the flow recommendations can be compared. These species have survived, to some degree for the last 150 years in altered flows, but the time since the last ice age is orders of magnitude longer. Will the long term survival of the target species be better ensured by *"maintaining a flow regime similar to the recorded hydrograph"*, or the one that existed for a much longer period of time? Examining the natural flow to better understand the frequency, duration and magnitude the recommended flow regime is changed from natural, could be revealing. To be clear, an examination of the natural flow regime is not the same as recommending the natural flow regime.

3. On pages 11 and12 it is stated, *"One assumption...[is]... there is consensus that any period of zero flow or flows below what was historically observed would greatly increase the risk for reduced survival of the surface dwelling species."* Given the information in the report, this is a very reasonable assumption.

4. On page 12 it is stated, *"...dedicated scientists...have spent much of their careers working with the threatened and endangered species in these springs' ecosystems...professional judgment is inherently embedded in our decisions. We have used the best available science for the determination of recommendations which in some cases is a direct result of professional judgment at this time."* This represents the state of the art / science for these type of studies. In the end, there isn't a model or process that guides you to the answer. The team is to be commended for clearly articulating the process and the very real fact that professional judgement must be used.

5. On page 12 it is stated, *"...conditions cannot go beyond thresholds that would not allow for the survival and recovery of any of these species in their natural environment."* Given the preceding discussion about the system not being natural for the past 150 years, and that "*natural flow variability...is an unrealistic scenario...*", perhaps this sentence could be clarified.

6. On pages 12 and13 the flow recommendation to meet the stated objectives is provided, *"Based on...best available science...professional judgment...underpinnings of instream flow science...natural flow theory, we selected the following components of the flow regime for evaluation:*
   - *long-term average flow,*
   - *minimum 6-month average flow, and*
   - *minimum 1-month average flow with an embedded minimum flow requirement."*

   The rationale for selecting these metrics is provided:

"The long-term average provides high quality habitat conditions throughout most of the spatial distribution of the species evaluated...The minimum 6-month average flow was incorporated into the flow regime to provide a safeguard from extremely low flow events...The minimum 1-month average flow was incorporated...to provide a threshold condition below which...the system should not fall...because it is widely acknowledged....that ecological systems are naturally defined by extreme events on both the high- and low-flow end of the spectrum."

Selecting a range of metrics that accounts for the long, medium and short term, including a threshold below which no water should be removed from the river, is consistent with many studies carried out in other areas of North America.

7. On page 13 it is stated, *"...the frequency and duration of these extreme events are of critical importance and, if extended beyond the natural tendency of the system, can be detrimental to the resident ecological community."* While this is a statement that is considered to be widely accepted by the ecology community, it is not clear how only looking at the last 150 years of altered flows achieves this.

8. On page 14 it is stated, *"...high flow pulses are very important... in both ...ecosystems to flush the system, remove vegetation mats, move sediment, and occasionally scour out vegetation...We evaluated high flow pulses within the context of each of the threatened and endangered species and made the determination that as these events are driven by precipitation, they would occur naturally."* The team is to be commended for not just focussing on the average to low flow range but including the higher flow ranges

as well. Many studies overlook this very important aspect of river ecology.

9. The process stated on page 14, *"...first started by...examining the overall condition of the system as we know it today...examining the available information to assess when impacts to a given species might first be evident...concluding with an evaluation of potential flow-related thresholds for the species [by starting]...with...monitoring data...[and]...modeling results...considered the historical hydrology, and finally confirmed or rejected based on professional judgment."*, represents the most common approach to developing a set of recommended flow values in North America today.

10. On page 17, it is stated, *"This, coupled with warm weather conditions present in the summer, leads to the development of extensive mats of green algae (this is not the filamentous algae previously described as high quality habitat)."* Perhaps it should be indicated whether the green algae is native or non-native.

11. On page 26 it is stated, *"To develop an ecologically protective flow regime, a balancing of species specific requirements was conducted where results did not align identically. In instances where there were competing species specific requirements, the higher flow requirement was conservatively chosen in each case following an analysis and understanding that this recommendation would not negatively impact the other species or overall ecosystem integrity."* It is noted this is a common and accepted practice to balance the needs of many species and life stages.

12. Pages 27 - 30 (Figure 5; Table 2): This is the heart of the report where they set the flow regime for the Comal Springs. I can see how the L-TA, M6-MA and M1-MA were determined. I do not see how they determined there should be "no flows below 5 cfs". I think the true test of their logic would be to see if others arrive at the same numbers.

13. On page 29 it is stated, *"The model assumes that the aquatic vegetation community will remain the same, which is certainly a false assumption to some unknown degree."* It is not clear what is being said here.

14. On page 30 it is stated, *"All the unknowns logically lead one to a conservative mindset in the setting of flow related requirements. However, we made a conscious decision not to incorporate a margin of safety into the proposed recommendations. It was our interpretation of the legislative charge that the subcommittee should evaluate the best available science objectively, clearly state the assumptions associated with the recommendations, and acknowledge the need for further study where appropriate. For instance, if it is later revealed that significant impacts are not captured in the model results or efforts to control the parasite or its host are not in place or successful in the future, then one needs to be cautious with strict implementation of the proposed flow recommendations. However, should information come forward that these species are able to aggregate in areas of suitable habitat more frequently or for longer durations than currently thought without significant consequence, or mitigation activities are in place that could be effective in providing additional levels of protection, then the proposed flow regime recommendations for the Comal Springs system would also need to be revisited. One thing is clear, long-term*

monitoring of this system is essential, and further study and research specifically during critical low flow periods (or simulated critical low-flows) are needed to accurately determine the potential impacts to the species at Comal Springs." As stated previously, it is interesting the team made the decision not to incorporate a margin of safety. I once again caution the team to ensure the legal and institutional setting allows for the changes that should occur in the future if it is determined the flows need to be more conservative.

15. I agree with the assessment of Figure 9 on pages 39 and 40 where it is stated, "*Figure 9 demonstrates that the measured channel changes between 1997 and 2001 resulted in a scaling of the predicted fountain darter habitat magnitude rather than a considerable change in the overall shape of the weighted usable area to discharge relationship...*" and *"the maximum amount of available habitat predicted for the fountain darter occurs at 65 cubic feet per second. As flow declines to 30 cubic feet per second, approximately 75 percent of the maximum available habitat remains."* It is suggested the team should refine the modeling efforts and use a finer scale of flow increments between 30 and 80 cfs to see if there is an obvious breakpoint in the slope of the curve.

16. On page 60 it is stated, *"The long-term average value flow of 140 cubic feet per second is supported by long-term monitoring data and modeling results. At these total discharge levels, populations of each of the threatened and endangered species are anticipated to maintain or increase their respective populations. The most important aspect of maintaining the long-term average component of the flow regime is that the system would not be able to have*

repeated 6- month or 1-month events also prescribed in the flow regime. As such, the lower flow criteria were developed with the understanding that if they should occur, they would rarely be experienced in the future." It is not clear what is meant by *"rarely be experienced"*. Perhaps the long term average flow target of 140 cfs could be presented graphically so that the frequency and duration for an appropriate time step, say monthly or what ever best suits the assemblage of flora and fauna, can be seen to better illustrate the point.

17. Pages 60 - 66 (Figure 19; Table 11) This is the heart of the report where they set the flow regime for the San Marcos Springs. I can see how the L-TA, M6-MA, M1-MA and low flow cut-off were determined. As above, I think the true test of their logic would be to see if others arrive at the same numbers. We should discuss this when we meet. I particularly like the statement, *"The minimum 6-month average flow of 75 cubic feet per second is supported by a combination of observed data, model results, and aspects of historical hydrology woven together with professional judgment."* P 63 - What is not clear to me is, " The historic minimum 6-month average was approximately 61 cubic feet per second during the 1950s drought." I can't find a clear explanation for this hydrological statistic, and why it was selected.

18. The text on page 63, *"There was considerable discussion amongst subcommittee members over the interpretation and integration of the observed data, model results, historical hydrology, changing conditions in the river, and potential frequency of occurrence of this flow component within the context of implementing the flow regime. As with the Comal Springs recommendations, we used best*

professional judgment to interpret and integrate these components and determined that 75 cubic feet per second for a minimum 6-month average would be protective with the associated assumption that the flow regime is implemented as designed, which would mean that this 6-month average would be experienced very infrequently in the future.", is a great example that clearly outlines the process of how the various data sources were used and ultimately it was the collective professional judgement of the team that ultimately set the recommended flows. It is an excellent summarization of the process.

19. On page 64 it is stated, *"A component of the historical hydrology we examined closely was the relative gaps between historical events (during periods of drought and falling spring discharge) as represented by the proposed flow regime. For instance, the gap between the historical minimum 6-month average and the historical 1-day minimum was approximately 16 to 23 cubic feet per second. We used this analysis to help describe the 1-day minimum (75 cubic feet per second [6-month average] - 23 cubic feet per second = 52 cubic feet per second (proposed 1-day minimum). Additionally, the gap between the historical minimum 1-month average and historical 1-day minimum was approximately 8 to 15 cubic feet per second. We included an 8 cubic feet per second gap from the proposed minimum 1-month average (60 cubic feet per second) to the 1-day minimum (52 cubic feet per second)."*

A more detailed description of the calculation,

hist 6 mon ave - hist 1 day min = proposed 1 day minimum

would be helpful to understand how the range of 16 - 23 cfs for the "gap" between the historical 6-month average and 1-day minimum was determined. As well, providing the rationale for why this calculation was used, as opposed to other methods to set the 1-day minimum would be helpful.

Tom / Ian / Clair: For me, this is a critical piece of the overall flow prescription since these cut off values tend to have the greatest impact on the water use licences.

20. On page 64 it is stated, *"As with the 6-month average recommendation for San Marcos, there was considerable discussion amongst subcommittee members over the interpretation and integration of the model results and embedded uncertainty, historical hydrology, changing conditions in the river, and potential frequency of occurrence of this flow component within the context of implementing the flow regime. We again used best professional judgment to interpret and integrate these components and determined that 60 cubic feet per second for a 1-month average with a minimum flow of 52 cubic feet per second would be protective with the associated assumption that the flow regime is implemented as designed resulting in a 1- month average that would be experienced very infrequently in the future."* Once again, it is clear there was considerable discussion by the team and that in the end, there was consensus on the process and the application of professional judgement. While not presented here in the text, it is the assumption of this reviewer the details of the conversations and the sequence of the logic for these discussions has been captured in minutes and are available to anyone who seeks to see them.

21. On pages 64 and 65 it is stated, *"... several questions remain: What frequency or duration of these events could be tolerated by these species without long-term consequences? How many individuals (or cover) can be lost before recovery is impeded or impossible? How long does recovery take, particularly in a population with diminished reproductive capacity? How much can the range be contracted before the probability of a stochastic event wiping out the species becomes significant? In the absence of those answers, we have chosen to exceed the historically observed flow statistics at San Marcos Springs because the condition of the threatened and endangered species populations following the 1950s drought is unknown."*

Tom / Ian / Clair: The team clearly states they made the best recommendation possible and acknowledge there are many unanswered questions. Based on that uncertainty, they appear to me to justify choosing to exceed historically observed flow statistics. I do not follow the logic here. I think it is more than likely the modeling and empirical data would not produce a flow recommendation that is identical to the historical flow record.

22. On pages 65 and 66 it is stated, *"All the unknowns logically lead one to a conservative mindset in the setting of flow related requirements. However, we made a conscious decision not to build in cushion to the proposed recommendations. It was our interpretation of the legislative charge to evaluate the best available science objectively, clearly state the assumptions associated with the recommendations, and acknowledge the need for further study where appropriate. For instance, if it is later revealed that significant impacts are not captured in the model results or efforts to control the*

parasite or its host, sedimentation, or recreation are not in place or successful in the future, then one needs to be cautious with strict implementation of the proposed flow recommendations. However, should information come forward that these species are able to tolerate short periods of lower flow conditions or more frequent occurrences without significant consequence, or mitigation activities are in place that could be effective in providing additional levels of protection, then the proposed flow regime recommendations for the San Marcos Springs System would also need to be revisited. One thing is clear, long-term monitoring is essential and further study and research specifically during critical low flow periods (or simulated critical low flows) are needed to accurately determine the potential impacts to the species at San Marcos Springs." As with my previous comments, it is clear the team thoroughly discussed this issue and it is clear they chose not to factor in a safety margin in view of the uncertainty. And to reiterate, it is not known to this reviewer if the legal and institutional setting will allow for changes to the water management plan if it is later revealed that impacts are occurring and the flow needs to be increased. Ultimately, this is a decision about how the team wants to manage risk. Perhaps the team should recommend an institutional analysis be carried out to determine the likelihood of such a change in the future being implemented.

23. On page 70 the following text, "*We used an existing numerical groundwater flow model of the Edwards Aquifer to develop withdrawal reductions and stages for critical period management. We used the model to consider different "scenarios", where a scenario included adjustments to critical period management, maximum pumping, or a model parameter such as an initial condition. After deciding on a scenario we wanted to investigate or*

consider, we filed a request with staff at the Edwards Aquifer Authority to run the model to simulate the scenario, what we refer to as a "model run request". Edwards Aquifer Authority staff used the model developed by Lindgren and others (2004) using MODFLOW-NR (Southwest Research Institute 2007). We used this model because it is (1) the best available tool at this time to evaluate the effects of pumping and recharge on water levels at J-17 and J-27 and springflows at Comal and San Marcos springs, (2) it is used by the Edwards Aquifer Authority for managing the aquifer, and (3) it is recognized by the Texas Water Development Board as a groundwater availability model for the San Antonio segment of the Edwards (Balcones Fault Zone) Aquifer. Where appropriate, the Edwards Aquifer Authority's management module was used to evaluate scenarios. The management module applies withdrawal reductions based on the triggers placed into the module. Edwards Aquifer Authority staff wrote a report of the results and, after internal review at the Edwards Aquifer Authority, delivered the report and output files to the chair of the subcommittee.", clearly outlines the approach that was used. Accounting for groundwater and surface water is a very complex undertaking and the team outlined very clearly how this was done in context of evaluating a number of flow alternatives. The team is to be commended for addressing this complexity in a comprehensive and reasonable fashion.

24. The text on page 71, *"...we used the model to look at meeting or exceeding three flow criteria for each of the two springs: a 1-month minimum, a 6-month minimum, and a long-term average for Comal Springs and a 1-month minimum, a 6-month minimum, and a long-term average for San Marcos Springs. Our requested model runs (simulations) fell into three broad categories: (1) runs at constant*

pumping, (2) runs to investigate the sensitivity of the model to various parameters and scenarios, and (3) runs to attempt to meet springflow requirements while maintaining the permitted pumping cap recognized in Senate Bill 3. We also requested a simulation to serve as a baseline application of current critical period management...to gain an understanding of springflow at different levels of pumping (that is, no critical period management reductions to investigate the sensitivity of different parameters and scenarios to gain an understanding of how springflows might respond to changes in these parameters the effects of limiting the non-critical period pumping at 437,000 acre-feet per year...Based on draft springflow requirements and what we learned from the constant pumping and sensitivity runs, we requested runs intended to meet or exceed the minimum springflow requirements for the endangered species of concern...", once again clearly outlines the process of selecting a broad range of alternatives and then from what was learned, focussed in on time-series analysis specific to the requirements of the species of concern. This is a very reasonable approach of casting the net wide, and then zeroing in on the matters of interest. While not stated in this report, it is assumed the total range of time-series analysis that were undertaken will meet the requests of all stakeholders involved in the process.

25. On pages 74 and75, it is stated, *"assumptions that may affect our results, which are ultimately related to predicting springflow. While some assumptions probably overestimate springflow, other assumptions probably underestimate springflow. With this task, we assumed that:*

550 • *all reductions and increases in pumping due to critical period*
551 *management were instantaneous,*
552 • *the maximum amount of groundwater that could be pumped*
553 *under any given scenario would be pumped,*
554 • *climate and drought in the future would look like climate and*
555 *drought in the past (specifically from 1947 through 2000),*
556 • *there was no movement in the location of pumping,*
557 • *the model accurately simulates springflows at Comal and*
558 *San Marcos springs and water levels at J-17 and J-27, and*
559 • *the subcommittee did not consider either the minimum*
560 *amount of pumping needed to maintain human health and*
561 *safety requirements or potential strategies to meet those*
562 *requirements."*
563
564 The team has worked on a very complex system and with studies of
565 this type, it is a simple fact there will be assumptions, uncertainty
566 and knowledge gaps. The team is to be commended for clearly
567 stating the assumptions in an objective and transparent fashion.
568
569 26. The text on page 75, *"The assumption that climate and drought in*
570 *the future will statistically resemble climate and drought in the past*
571 *probably leads to overestimated springflow. Global climate models*
572 *used by the International Panel on Climate Change suggest that*
573 *Texas will be warmer and most suggest that Texas will be drier*
574 *(Kundzewicz and others 2007). Warmer temperatures increase*
575 *evapotranspiration which decreases runoff (all other factors*
576 *remaining the same), an important factor for recharge to the*
577 *Edwards Aquifer. A recent study commissioned by the Lower*
578 *Colorado River Authority and the San Antonio Water System showed*
579 *that even with increased rainfall, runoff was expected to decrease in*

the contributing basins to the Highland Lakes (CH2M Hill 2008).", clearly shows the team attempted to address the very uncertain topic of climate change as best they could. If the climate models show the possibility of decreased flows in the future, the team could create an artificial flow set, for example the 1:100 and 1:200 year return low flow on a weekly basis and see how that would affect water use while trying to meet the flow recommendations for the species of concern.

27. On page 76 it is stated, *"The assumption that the model accurately simulates springflows at Comal and San Marcos springs and water levels at J-17 and J-27 probably leads to underestimates and overestimates in springflows."* It is good to point out that errors in model predictions are not in one direction.

28. The text on page 79, *"We evaluated the potential effectiveness of this critical period management approach by using the Edwards MODFLOW model with critical period management module to simulate several different management scenarios to determine which trigger approach gets us through the "drought of record"."*, once again shows a reasonable approach in using the accepted practice of sensitivity analysis.

29. On page 79 it is stated, *"The current critical period management plan in the Edwards Aquifer Authority Act (Table 12) does not achieve the springflow requirements in Task 1 (Table 13; figures 22 and 23). In fact, the groundwater model (Run 001) suggests that Comal Springs would stop flowing for 13 consecutive months and 29 months total. Under this scenario, pumping decreases from the*

610 *maximum permitted amount (572,000 acre-feet per year) to about*
611 *362,000 acre-feet per year (EAA 2009)."* This is an important piece
612 of information where the team shows how the current critical
613 management plan, (Table 12, page 80), *"...does not achieve the*
614 *springflow requirements in Task 1."*, the recommendations set forth
615 in this report by the EAAESS.
616
617 30. On pages 81 to 84, Table 13 and Figures 22 to 24 clearly show the
618 various pumping scenarios and how the scenarios do or do not
619 meet the biological criteria. Figure 24 is particularly good as it
620 shows the three criteria operating in concert for the model runs
621 presented. The figure clearly shows there isn't just one criterion
622 that is tripping. All criteria trip demonstrating there isn't just one
623 isolated instance of low flows in the entire period of record that is
624 the issue. And if only one of the criteria that was tripping, then
625 further work would be necessary to try to understand why that
626 was occurring.
627
628 31. On page 85 it is stated, *"We recognize that this final run that*
629 *reduces permitted pumping by 85 percent at Stage I does not take*
630 *advantage of the Edwards Aquifer Authority's current critical period*
631 *management approach... Given the legislatively mandated deadline*
632 *for the report, we did not have time to investigate multi-stage critical*
633 *period management with the final springflow requirements..."* And
634 again on p 92 it is further stated, *"...we did not have time to request*
635 *and consider model runs to potentially refine those reductions. For*
636 *example, given additional time, we would have requested model*
637 *runs to investigate different trigger levels and withdrawal*
638 *reductions."* It is unfortunate this line of reasoning could not be
639 further investigated. It appears obvious the plan to protect the

species of interest and the current use of water for humans will create serious discussion. Further exploring any possibility is warranted considering the circumstances. It is highly recommended the team be able to continue their suggested line of investigation. As with all these studies, there are time limits imposed and more often than not, further work should be carried out.

32. On page 89 it is stated, *"Managing the aquifer in this fluctuating manner may not be good for the species (rapid swings in springflows) or for associated infrastructure (turning wells on and off). Furthermore, these pumping reductions result in long-term flow averages much higher than historical values which may also be detrimental to the species. It is also probably not realistic to bring permit holders in and out of critical period management on a monthly basis. Although less of a cutback at a relatively continuous rate might stabilize springflows, it is not possible to simulate such a scenario with the current management module."* These "real time" operational issues should be addressed in the next phase. The work that has been undertaken to date can only answer so many questions. These operational issues however, are most valid and I agree with the team's assessment. It is the assumption of this reviewer they will be addressed as the plan moves forward.

33. On page 90 the team presents a list of tasks that in their opinion should be carried out, *"...(1) improve springflow measurement, (2) conduct sensitivity analyses, (3) run optimization models, (4) estimate the probability of recurrence of the 1950s drought, (5) evaluate the potential effects of climate variability on recharge, (6) conduct additional runs to refine withdrawal reductions, (7) update the model, (8) refine the calibration of the model, (9) enhance the*

management module, and (10) refine model calibration between San Marcos and Barton springs." These recommendations are reasonable given there will be intense debate when a plan to protect the endangered species means there needs to be an 80% reduction in pumping. Doing the very best possible science to address the largest areas of uncertainty is reasonable and prudent.

34. On page 91 it is stated, *"Given the proven utility and cost-effectiveness of simulation-optimization models used in studies of aquifers with hydrogeologic characteristics and problems similar to those of the Edwards Aquifer, it is recommended that efforts be undertaken to develop an optimization model of the Edwards Aquifer and apply it toward obtaining a better understanding of (and more-effective management strategies for) the Edwards Aquifer. For example, rather than relying on the laborious, drawn-out process (using minimum springflow constraints) to evaluate the effects of different critical-period trigger levels and percent pumping reductions, a properly designed and calibrated optimization model might have saved the subcommittee significant time and effort toward arriving at the optimum balance among the choices for triggers and cutbacks while maximizing pumping."* This recommendation is most reasonable. It's not certain from reading the report the team had to rely "...on the laborious, drawn-out process...", however, the team has clearly learned a great deal and suggesting to use more appropriate tools is reasonable.

35. On page 92 it is stated, *"The hydrologic modeling analyses done in support of these results for critical period management are based on the climate history from 1947 to 2000. This period of time includes the drought of the 1950s. It would be valuable to know the chance that any one year will experience rainfall deficits at least as severe*

as the worst part of the 1950s drought. Reconstructed climate history based on tree-ring data (Cleaveland 2006) might be used to estimate the frequency of annual rainfall deficits as severe as or worse than those that occurred during the worst part of the drought of the 1950s." Addressing climate change when making flow presents an enormous challenge. This is not unique to this basin, it applies to any basin in North America. A suggestion for the team is they could consider looking at a number of climate change models and once they agree to one that predicts less water in the future, they could calculated the return intervals for whatever time period is most appropriate, e.g., monthly. For example if it was agreed the 1:200 low flow event based on the historical flow regime best describes what climate change could be like then this 1:200 year artificial year can be inserted into the period of record and evaluated.

36. **Tom / Ian / Clair: On page 94 they discuss hydrology and modeling and the incredible complexity of the system (e.g., surface water, groundwater, pumping at various locations from both surface and groundwater). They provide recommendations that all seem reasonable. However, I am not a hydrologist and cannot provide an opinion. (Late Note: Good thing Tom Wesche was added to our group.)**

37. On page 94 it is stated, *"The critical period management module does not accurately model the Edwards Aquifer Authority's rules for reduction of pumping by water rights holders."* There appears to be a critical shortcoming between how the water consumption licences are administered and what it means to flows in the system. It is excellent to point this out to the administrators and legislative authorities. This disconnect between the administration

of water and the desire to respect thresholds is not uncommon and occurs in many basins. The recommendation that *"...the Edwards Aquifer Authority...consider modification of its rules to provide for more immediate responses to critical period management triggers."* is most reasonable.

A Review of

"Technical Assessments in Support of the Edwards Aquifer Science Committee "J Charge" Flow Regime Evaluation for the Comal and San Marcos River Systems"

for:

The Edwards Aquifer Recovery and Implementation Program

by:

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Prepared by:

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Summary

For the sections that I reviewed, I fully endorse the technical analysis and output of the flow dependent characteristics of physical habitat for target aquatic species within the Comal and San Marcos Rivers. The process of assembling a team of knowledgeable scientists with specific experience in the Comal and San Marcos rivers, as well as first hand knowledge on the primary target species, to review all available biological data including the updated modeling results based on refined habitat suitability information for the three target species, Texas wild rice, Comal Riffle beetle, and fountain darter, is to be commended. Using group

workshop settings to seek consensus is to be commended. Carrying out model validation to predict locations of animals against observed locations of animals is considered to be "best practice". Developing influence diagrams for the three target species provided a valuable tool to understand both intrinsic and extrinsic factors that affect the target species. Additionally, considering other factors such as non-native species of plants and animals, parasites, recreation, and anthropogenic impacts due to watershed development shows a depth of investigation that is not commonly seen in similar studies of this type.

The overall approach used in this study is exceptional and the team is to be commended for their efforts. Providing the historical information along with the updated modeling based on new information (temperature and dissolved oxygen) and physical habitat for Texas wild rice, Comal Springs riffle beetle, and fountain darters, demonstrates the improvement to the science.

Combining the physical habitat modeling with the temperature and dissolved oxygen modeling represents the state of the art / science of carrying out these type of studies. The modeling was improved by using empirical data, e.g., vegetation distribution using historical vegetation mapping results.

I find there are no serious flaws or errors in the team's methodology, findings, and recommendations. Assumptions of the approach are well documented and are most reasonable given today's understanding of aquatic ecosystems. The tools and methods of analysis employed, with respect to habitat modeling, are appropriately used based on best available information.

The following are some comments, suggestions and questions for specific issues.

Specific Comments by Section:

1. On page 4 it is stated, *"...a series of workshops involving a multidisciplinary team of biologists ... were held to develop influence diagrams...[to:]*

    - *Help identify where existing modeling efforts could inform key influence diagram linkages*
    - *Direct modifications and/or analysis of the existing modeling work on behalf of Science Subcommittee*
    - *Help identify the potential needs of existing and future biological modeling efforts to best support future Habitat Conservation Plan (HCP) analysis (to extent feasible)*
    - *To help conceptualize and illustrate how spatial, flow-dependent biological modeling inter-relates with other factors*
    - *Provide a framework for use by other EARIP teams in HCP development, and the U.S. Fish and Wildlife Service (FWS) in Endangered Species Act (ESA) analysis"*

    This clearly demonstrates the team identified the outstanding key issues and the creation of influence diagrams was a great means to visualize the complexity of all factors and how existing knowledge could help guide them in the modeling.

2. It is also noted on page 4, that *"Appendix A provides a listing of all comments and submitted influence diagram revisions."* The team is to be commended for keeping a meticulous record of the conversations.

One of the most overlooked tasks is carrying out these type of studies is to "document your logic".

3. On page 14 it is stated, *"It should be noted that continued channel topography changes associated with sedimentation has continued through the present...Movement of these sediments downstream has also altered channel topography and bed material composition...Additional alterations since the revised topography of 2001 was obtained include alterations to the channel structure...Some sensitivity analysis has been conducted on the impact of measured channel changes...and indicates that the primary effect has been scaling the magnitude of the habitat versus flow relationships rather than changing the underlying relationship between flow and available habitat."* It would be helpful to the reader if there were quantitative data provided to verify the channel changes falls within scientific standards to use the channel topography data as a representative site for the river reach.

4. On page 14 it is stated, *"The specific algorithms evaluated were linear krigging, inverse distance weighting, Clogh-Tocher and natural neighbor."*

Tom / Ian / Clair: Perhaps there could be a statement regarding the acceptability of the use of these algorithms versus other commonly used ones such as, the Petrov-Galerkin upwinding formulation, or the Newton-Raphson iterative or Generalized Minimal Residual methods, or the 'Jacobian' matrix, or the Newton-Raphson iteration, or the Gaussian elimination, or Venant and Sabaneev's Equations, and how about the Courant-Lewy-Freidrichs condition?

5. **Tom / Ian / Clair - Note: p 14 - 22 - hydraulic modeling and hydrology assumptions are beyond my ability to comment**

6. **Tom / Ian / Clair - Note: p 22 - 25 - Vegetation Mapping & Hydraulic Modeling - beyond my ability to comment.**

7. **Tom / Ian / Clair - Note: p 25 - 35 - Water Quality Modeling - beyond my ability to comment.**

8. On page 35 it is stated, *"The original work by Hardy et al. (1998), Bartsch et al. (2000) and INSE (2004) ...from collection data over a two year period ... and additional work by Saunders et al. (2001)... Long-term fisheries monitoring data collected by the Edwards Aquifer Authority over the past 8 years ... using the basic sampling protocol developed by Hardy et al. (1998) was utilized to develop updated habitat suitability curves for depth and velocity for fountain darters...the annual Texas wild rice monitoring data collected collaboratively by the Texas Parks and Wildlife Department and USFWS..."* This shows a very open, transparent and collaborative process was used to gather and agree to the development of the Habitat Suitability Criteria (HSC) curves. The team is to be commended for this since the HSC curves are the primary factors that form the habitat versus flow relationships upon which a flow recommendation is ultimate made.

9. On page 36 it is stated, *"The most common approach is to utilize Habitat Suitability Curves (HSC) which parameterize the relative suitability of a factor (e.g., depth) on a scale between 0.0 and 1.0 over the range of potentially useable values. These relationships, when combined with the hydraulic and water quality simulations produce relationships between flow and the quantity and quality of available*

habitat." Normalizing the HSC curves, and resultant habitat versus flow curves is a very common and accepted practice.

10. Pages 36 - 44: HSC Curve Discussion - The overall process of developing HSC curves is good and meets the common accepted practice of the state of the art / science. The amount of data considered is comprehensive relative to many similar type of studies. On page 38 it is stated, *"The technical team reviewed the existing wild rice habitat suitability curves for depth and velocity used in previous studies as well as the existing monitoring data collected over the past decade. This included and examination of the location of persistent wild rice stands within the San Marcos system that were overlaid on the hydraulic model solutions at different flow rates indicative of the long term flow characteristics during the last decade. Based on this review and discussions, habitat suitability curves were revised for use in modeling physical habitat in the San Marcos River."* The combination of modeling data with empirical data which is then thoroughly discussed with all stakeholders represents the best possible way to develop HSC curves.

11. On page 41 it is stated, *"It should be noted that the vegetation suitability curve utilized in all the simulations was based on the original curve developed by Bartsch et al. (2000) rather than the updated curve based on the analysis of the updated data sets. This was due to incompatibility of vegetation types delineated from the original vegetation mapping and different vegetation coding used in the EAS data sets. This will be reconciled during the revised modeling currently underway for both the Comal and San Marcos Rivers using the updated vegetation mapping for both systems."* It is not clear to the reader what the "revised modeling currently underway" is referring to. Will there be

further modeling that will be used by the EAAESS in their current report that is being reviewed?

12. Pages 44 -45 - Physical Habitat Modeling - The modeling approach undertaken by the team is similar to the accepted standard practices for this kind of modeling.

13. **Tom / Ian / Clair - Note: p 48 - 50 DO - no comment - will one of us make comments?**

14. On page 50 it is stated, *"The analysis of Comal Springs riffle beetle relied on a simple calculation of wetted surface area with depths greater than 0.02 feet. The analysis showed no change in total surface area at total Comal River flows between 300 and 150 cfs and then a linear reduction in available habitat below this flow magnitude. Additional simulations were run based on criteria developed from collection data on riffle beetles in the main spring runs as follows as an alternative to the surface area analysis."* There are two approaches discussed. One is a flow versus wetted surface area, the other is based on criteria developed from data in the main spring runs as an alternative to the surface area analysis. It is not clear to the reader if the intention was to demonstrate the second approach is superior to the first approach.

15. On page 59 it is stated, *"These results should be viewed with some caution however, given the known channel changes within the new channel not reflected in the current analysis that includes both topography and vegetation. These results are also cautionary in that the temperature simulations used a spring orifice temperature as the boundary conditions for flows entering the old channel rather than the simulated temperature at the node in Landa Lake where the culvert*

218 *orifice is located. This will be rectified in the updated modeling currently*
219 *underway."* It is not clear to the reader what the "revised modeling
220 currently underway" is referring to. Will there be further modeling
221 that will be used by the EAAESS in their current report that is being
222 reviewed?
223
224 16. On page 59 it is stated, *"Overall, the system wide temperature*
225 *simulations using both mean daily and maximum daily temperatures*
226 *strongly suggest that as total Comal River flow rates decrease, thermal*
227 *affects on darter life stages become limiting rather than the amount of*
228 *physical habitat in terms of suitable depth and velocities."* It is noted
229 this is consistent with similar systems where the upper lethal limit for
230 temperature for native cool water species is more limiting than
231 physical space.
232
233 17. On page 62 it is stated, *"Bartsch et al. (2000) did not include dissolved*
234 *oxygen simulations in their modeling evaluations, nor were they*
235 *included in subsequent modeling efforts within the San Marcos River.*
236 *As noted previously for the water quality simulations for the Comal,*
237 *there is concern for the potential of depressed dissolved oxygen values*
238 *during night time respiration at very low flows, especially in highly*
239 *vegetated areas such as Spring Lake and sections of the San Marcos*
240 *River upstream of Cape's Dam. If possible, this should be addressed in*
241 *the on-going modeling efforts in support of the HCP."* This is a very
242 reasonable recommendation given that systems that have abundant
243 vegetation experience large diel fluctuations in DO as the daytime
244 water temperature approaches that of the air temperature.
245
246 *18.* On page 66 it is stated, *"As part of the technical team evaluations, the*
247 *spatial distribution of predicted cell suitabilities were examined on a*

computational cell by cell basis and compared to actual wild rice distributions based on 1989 to 2008 monitoring data at each simulated discharge. Figure 46 shows the section of the San Marcos River in the Rio Vista to Cape's Dam section with the simulated suitabilities for Texas wild rice at each computational cell at a simulated discharge of 65 cfs. The known 1989 to 2008 distribution of plant locations are overlain for comparative purposes (red dots).

The results shown in Figure 47 for the 30 cfs simulation show Texas wild rice were associated with modeled cell suitabilities primarily below about 0.50 compared to results at 65 cfs, which show a proportional shift with modeled cell suitabilities above 0.50. This shift in proportionally more stands occupying modeled cells with suitabilities greater than 0.50 was observed at all higher flow rates modeled. Observed versus use frequency distributions at flow above 65 cfs are very similar to that reported for 65 cfs while the results for 30 cfs are indicative of the results at simulated flow lower than 30 cfs. This appears to be a systematic bias in the modeling results at lower flows that should be examined in more detail with the revised modeling currently underway. It should also be noted that in the simulations, the current calculations do not take into account if an existing plant species occupies the computational element. Modeling results were also examined for locations in which the simulations predicted suitabilities but were not occupied by Texas wild rice. Over 60 percent of these locations were occupied by native species." This appears to be a discussion on model validation, showing that the various species inhabit those areas the model predicts is of high habitat value and do not inhabit those areas the model predicts is of low habitat value. From the discussion it appears the argument is made that below 30 cfs, Texas wild rice is associated with modeled suitabilities below 0.5, and above 65 cfs, Texas wild rice occupied cells with suitabilities

greater than 0.50. It is stated, *" This appears to be a systematic bias in the modeling results at lower flows that should be examined in more detail..."* I agree, it would be highly recommended to undertake more effort to understand why this occurs.

Tom / Ian / Clair: I cannot follow this discussion very well. It seems like the discussion is about classic WUA model validation. What I cannot figure out, is how do you do it for a species that is non-mobile? Or is the flow in the different channels is so stable that is doesn't change at all over the period of record? How does the text on page 66 relate to Fig 47 - low suitability cells were occupied with plants at 30 cfs; at 65 cfs, similar occupancy for low to high suitability except 0.5 which had the most?

19. Page 68 - Fig 46 The scale of the figure is such that it is difficult to see if the red dot occupies a low or high suitability cell at this scale.

20. On page 70 it is stated, *"The simulation results indicate... Texas wild rice habitat begins to decline below approximately 100 cfs and rapidly declines below 65 cfs. Care should be taken not to treat these specific flow rates as an 'absolute' break point given the somewhat large intervals between simulated discharges... revised modeling efforts should utilize a finer scale of flow increments below the long term average to better define these habitat versus flow responses in physical habitat."* This is an excellent suggestion. I agree there should be more simulations to refine the curve in the lower flow range.

21. On page 74 it is stated, *"The average water temperature was always at the upper limit of useable temperatures for the fountain darter, and at a temperature which may impact fountain darter breeding. Field*

observations have shown the slough to become a vegetation-choked backwater area with extremely low flow and elevated temperatures, confirming the modeling result." It is most fortunate to have empirical data to confirm the predictive modeling output. The team is to be commended for bringing these two data sets together.

22. On pages 76 - 83, the sensitivity of simulation results for channel changes and suitability curves was presented. This is an excellent task to have undertaken. It goes above and beyond what is found in similar type of studies.

23. It is stated on page 77, *"It should be noted however, that maximum habitat may in fact occur at flow rates between 65 and 100 cfs and a more refined increment of flow simulations will be utilized in the updated modeling."* This is an excellent suggestion. There should be a finer resolution of flows modeled. I would recommend 5 cfs increments in the 35 to 100 cfs flow range. Given the historic out of stream use of water and the requirements to protect endangered species, the discussion could very well get down to the single digit cfs range.

24. On page 82 it is stated, *"As can be seen, the changes in habitat suitability curves for fountain darter not only changed the magnitude of simulated habitat versus discharge relationship (Figure 51) but also changed the underlying habitat versus flow relationship. As noted previously, this is primarily attributed to the differences in the velocity suitability curve (see Figure 29)."* Agree. The reason is the new velocity HSC curve in Figure 29 is shifted to the left. It shows the model is working.

25. On page 83 it is stated, *"It is cautioned however, that more simulated flows between the 65 and 30 cfs flow range are needed in the revised modeling currently underway to better define where this rapid decline in available habitat begins."* As above, this is an excellent suggestion. There should be a finer resolution of flows modeled. Once again, given the historic out of stream use of water and the requirements to protect endangered species, the discussion could very well get down to the single digit cfs range.

26. Pages 83 - 84 it is stated, *"Assuming that flow regimes are maintained in the Comal River such that spring discharges are maintained to protect the Comal Springs riffle beetle and fountain darters, adequate protection would be maintained...[for the Comal Springs dryopid beetle as for the Peck's cave amphipod, San Marcos Gambusia, San Marcos salamanders]"* This is a reasonable assumption. Given predictive models are unlikely to be developed for such species, the proposed monitoring should validate this assumption.

27. On page 84 it is stated, *"Maintaining adequate spring flow regimes for protection of Texas wild rice and fountain darters will likely contribute to suitable flow and water quality conditions in these downstream reaches."* It is not clear if it is meant the flows will maintain suitable water quality conditions for the Cable's map turtle, or the ecosystem in general.

28. On page 89, a set of recommendations are presented,

> " • *The current efforts to remodel by the Comal and San Marcos River systems should be undertaken with a single*

hydrodynamic model. This will allow for easier technology transfer and allow a consistent analysis framework.

- *It is also recommended that a single water quality model be applied in both river systems for these same reasons. The model should simulate maximum daily temperatures and be applied system-wide for both rivers.*
- *Water quality modeling should consider non-point and point source pollutants to the extent these inputs can be approximated from available data.*
- *Analysis of alternative species beyond the three target species focused on in this report should also be undertaken. The specific species to be included should be determined after an analysis of the existing long-term monitoring data available for both river systems.*
- *Consideration should be given the potential vegetation changes if possible since vegetation responses to flow regime changes are critical to evaluation of available fountain dater habitat.*
- *A quantitative assessment of potential impacts associated with recreation should be considered that includes not only Texas wild rice but other aquatic vegetation.*
- *Analysis of channel topography changes due to fine sediment input should also be considered if possible.*
- *A finer resolution on the number of simulated flows is also important, especially for flow ranges below the average annual flow to better inform decisions on critical flow management.*
- *Refinement in the total Comal River discharge versus specific spring flow rates and flow rates at which specific springs cease to flow should be undertaken.*

- *Texas wild rice habitat simulations should be modified to account for computational cells occupied by other species.*
- *If feasible, system wide substrate mapping in the San Marcos "under" existing vegetation stands should be considered to allow evaluation of non-native plan removal on providing suitable Texas wild rice habitat beyond a depth and velocity evaluation.*
- *Evaluate the potential of including anthropogenic induced turbidity on light attenuation as a function of the longitudinal profile of the river systems and its implication on vegetation."*

All of these recommendations seem reasonable and prudent. Assuming there will be intense debate by the stakeholders regarding water use and the protection of endangered species, further study will help to eliminate uncertainties and guide the decision makers.

"Analysis of Species Requirements in Relation to Spring Discharge Rates and Associated Withdrawal Reductions and Stages for Critical Period Management of the Edwards Aquifer"

Review by Clair Stalnaker

General comments on the report:

Senate Bill 3 charges the subcommittee to (1) evaluate designating a San Marcos Pool, (2) evaluate the necessity of maintaining minimum springflows, and (3) evaluate whether adjustments to drought triggers for San Marcos Springs should be made.

Senate Bill 3 also required the subcommittee to (1) analyze species requirements in relation to spring discharge rates and aquifer levels and (2) develop withdrawal reduction levels and stages for critical period management associated with the species requirements. Given the charge from the Senate Bill 3 the subcommittee did indeed focus efforts on possible adjustments to the withdrawals and stages commensurate with the Edwards Aquifer Management Authority's ongoing critical period management process.

The subcommittee makes a point of stating that this report "can be considered as the beginning of a conversation among scientists, stakeholders, and various agencies on the ultimate management of the Edwards Aquifer to protect the endangered species that rely on the springflow for survival". They further state "One thing is clear, long-term monitoring is essential and further study and research specifically during critical low-flow periods (or simulated critical low flows) are needed to accurately determine the potential impacts to the species".

The subcommittee addressed the charge within the context of a protective flow regime. They interpreted a protective flow regime as one "that will ensure the 'survival and recovery of the species in the wild'". The recommendations did not take the form of recommended flow regimes for maintaining intra- and inter- annual hydrologic variability as is common practice and supported by the Instream Flow Council. Rather the subcommittee was constrained by the legislation to focusing recommendations to triggers for setting withdrawal reductions and pool levels in the San Marcos and Uvalde Pools for use during critical period management.

A subcommittee report submitted in November 2008 concluded; (1) there is not sufficient data to support the designation of a separate San Marcos Pool, (2) minimum springflows are required within the context of a system flow regime for the survival and recovery of each species, and (3) trigger levels for San Marcos Springs should not be adjusted at this time. The 2008 report further concluded that "minimum flows are a necessary part of a flow regime of a given aquatic ecosystem for the protection of its component species, but the maintenance of minimum flows alone is not considered sufficient to maintain a sound ecological environment".

Therefore the reader can conclude that the recommendation presented in this report are intended as interim triggers and levels as a beginning management effort ultimately expected to evolve as more understanding in gained from ongoing monitoring and improved modeling. This appears to be an excellent candidate program primed for adaptive management. The ongoing communications among and involvement of scientists, stakeholders, agencies and the management authority has set the stage and an Adaptive Management Program for the Edwards Aquifer should be considered.

The subcommittee has indeed used the best available science in support of a very narrowly constrained charge. Consequently the report is focused on minimum springflows, specifically identified as two tasks.
Task 1: Analyze species requirements for springflow and aquifer levels as a function of recharge and withdrawal levels, and
Task 2: Develop withdrawal reductions for critical period management associated with the species requirements.

The foundation assumptions adopted by the subcommittee in support of minimum flows within the context of a system flow regime were: "A system flow regime includes low flows which support the survival of individuals for limited periods of time, normal flows which support reproduction within the population, and higher flows that periodically rejuvenate the system".

Task 1 led to recommended long-term, 6-month, and 1-month average flow targets as triggers for determining a 85% reduction in pumping withdrawals. From the discussion presented in the report the subcommittee seems to assume that if the triggers as proposed were used in actual practice for critical period management the resulting flow regimes would maintain hydrological variability and "sustain an overall trend of maintaining or increasing the populations of the threatened and endangered species". This also assumes that "conditions cannot go beyond thresholds necessary for survival of any listed species". This seems hopefull and is not likely to result in increased populations but is a good first step in preventing further degradation of the listed species.

The subcommittee relied heavily on historical flow records to identify long-term, 6-month, and 1-month minimum flow statistics as a basis for maintaining hydrological variability and recommended minimum flow triggers similar these statistics but adjusted (usually to higher levels) based on the available science. The evidence used to further adjust the triggers primarily came from monitoring studies and modeling studies of water temperatures and physical habitat. This supporting biological and modeling evidence was summarized for the subcommittee and presented in the Hardy December 2009 report .The focus was on surface-dwelling species that were known to rely on spring discharge necessary for survival. The other aquifer-dwelling listed species were assumed to be protected if the needs of the surface-dwelling species were met. This assumption appears valid.

Task 2 was assumed by the subcommittee to be "limited to adjusting withdrawal (pumping) reduction levels and stages for critical period management". To meet this

objective the subcommittee used an existing numerical groundwater flow model to develop withdrawal reductions and stages by considering different "scenarios" or adjustments. The model used was MODFLOW-NR presently used by the Edwards Aquifer Authority for managing the aquifer. This is a state-of-the-art model and with the recommended improvements to the model and data bases suggested by the subcommittee should become the vehicle for continual reevaluation of the flow triggers and species responses.

.Model runs (simulations) fell into three broad categories: (1) runs at constant pumping, (2) runs to investigate the sensitivity of the model to various parameters and scenarios, and (3) runs to attempt to meet springflow requirements while maintaining the permitted pumping cap recognized in Senate Bill 3. Over 40 different runs were made. After examining numerous model runs the subcommittee developed withdrawal reductions and stages that met or exceeded the flow requirement set for Task 1.

This is a reasonable approach representing common practice for water planning and management. As in all such modeling studies based on historical records the underlying assumption is "that climate and drought in the future will statistically resemble climate and drought in the past". While this is standard practice and provides the basis for time series analyses the committee recognized that evidence from global climate modeling indicates that for the southwestern U.S. the future is likely to become drier. This reinforces the fact that the flow recommendations presented represent the initial steps in maintaining the threatened and endangered species. Undoubtedly these levels and stages will need to be modified in the future supported by ongoing monitoring and updated modeling.

The subcommittee recommended flow and pool stage triggers would reduce pumping during stage I only, for the San Marcos Pool from the present 20% reduction level to 85% reduction and for the Uvalde Pool from the existing 0% reductions to 85% reduction. The model runs evaluated assumed instantaneous cessation of pumping when stage level I triggers were reached.
This was recognized as unrealistic for actual critical period management as pumping could not be stopped instantaneously for several reasons including existing policy that allows farmers to continue pumping after a crop is planted. None the less the subcommittee concluded "that pumping reduction will need to exceed 80 percent to achieve springflow goals during a repeat of the drought of record".

From the discussion presented in the report it is obvious that the subcommittee believes that their interim recommended flow and stage triggers would provide for some improvement in system conditions for the listed species, particularly during period of drought thus assuring survival. This appears to be a reasonable expectation given the background information. However, their stated goal of enhancing the system to allow the listed species populations to increase (recover) is not likely.

The Edwards Aquifer Authority should take these recommendations as initial system management steps and attempt to reduce stage I pumping levels by 80-85% during

critical management periods and fund the recommended studies, research and model improvements. Under such a program the listed species should survive. With the kind of cooperation illustrated in these reports andwith interim guidelines set in motion a viable Adaptive Management Program should ultimately lead to sustainable populations for listed species and perhaps recovery toward historical levels. However, full restoration can never expect to be achieved due to the nearly two centuries of human activity and resulting degradation of the system.

Specific comments:

P 26-27- Figure 5 summarizes the rational for the long-term, 6-month, and 1-month average flow minimum recommended levels. These seem reasonable and support the recommendations. It was noted that the darter was extripated from Comal Springs during the drought of 1956 but has survived under favorable conditions since 1975. The historical flow record post 1975 represents the time period since the fountain darter was reintroduced to Comal Springs. In 1984 flows went below 60 cfs for 100 days and below 40cfs for over 40 days (down to 25cfs). This would support the recommended 1-year average of 30cfs but no biological rational is given for allowing the absolute minimum to go down to 5cfs. I do not accept the 5cfs level as supporting the goal for survival and increasing populations of the fountain darter in 'Comal Springs. If maintaining or increasing the populations is the goal then the absolute lowest level should be more like 25cfs rather than 5cfs.

P 29- Next to last paragraph. "...we have elected to recommend flows higher than the historically observed low flow statistics at Comal Springs because of the extirpation of the fountain darter following the 1950' drought..." This is direct contrast to the selected absolute minimum of 5cfs discussed above.

P 30- The subcommittee report makes reference to the flow regime setting as reflecting a conservative mindset. Given the scientific evidence presented these recommendations are somewhat higher than historical statistics (other than the lowest minimum of 5cfs). The very fact that the species are listed indicates that present conditions are unfavorable to survival of viable populations and some improvements are necessary for maintenance. Significant improvements may be necessary for increased populations (recovery). A conservative approach is justified. I feel that the subcommittee's recommendations are not very conservative but should prevent the listed species from becoming extinct during the interim. The subcommittee acknowledges that additional study is needed and the proposed flow regime be revisited as more accurate information on species becomes available.

P 48-50- It is obvious that recreation use of the river is having an impact on wild rice and other aquatic vegetation. Some control measures will need to be developed.

P 61-Figure 19 summarizes the rational for the long-term, 6-month, and 1-month average minimum flow recommendations. The rational seems to be well supported. The subcommittee chose to exceed the historically observed flow statistics at San Marcos

because of uncertainty associated with stochastic events wiping out species. Of particular note is the 1-month average minimum of 60cfs with an absolute minimum of 52 cfs. This contrasts with the low flow recommendation for the Comal Springs where the lowest flow reached since reintroduction of the darter has been 26cfs.

P 66-68- The subcommittee's recommendations for future study are certainly on the mark for better understanding of the system and should be pursued. Increased sedimentation and recreational pressure are confounding issues that need to be specifically addressed during future study of the San Marcos Springs.

P 69- The subcommittee assumed that Task 2 was "limited to adjusting withdrawal (pumping) reduction levels and stages for critical period management". The subcommittee used an existing numerical groundwater flow model to develop withdrawal reductions and stages by considering different "scenarios" or adjustments. After examining numerous model runs they developed withdrawal reductions and stages that met or exceeded the flow requires set for Task 1. The model was MODFLOW-NR that is presently used by the Edwards Aquifer Authority represents the state-of-the-art and is appropriate for evaluating Task 1 minimum flows and stages.

P 71- Model runs (simulations) fell into three broad categories. Over 40 different runs were evaluated with various assumptions and sensitivity analyses. This was a most useful exercise that illustrates how the present management the model can be is used for listed species protection.

P 85- The recommendations would reduce pumping only during stage I. Changes in other stages were not evaluated due to lack of time. Further such evaluations were recommended in the future and are needed.

P 90-95- The subcommittee has identified further studies needed to (1) improve springflow measurement, (2) conduct sensitivity analyses, (3) run optimization models, (4) estimate the probability of recurrence of the 1950s drought, (5) evaluate the potential effects of climate variability on discharge, (6) conduct additional runs to refine withdrawal reductions, (7) update the model, (8) refine the calibration of the model, (9) enhance the management module, and (10) refine model calibration between San Marcos and Barton Springs. These recommendations are well thought out and appear to be consistent with modern scientific thought regarding the use of modeling in water planning and management as is discussed by the National Research Council (2008).

Specific recommendations for the next generation of waster quality and physical habitat modeling and guidance for addressing seasonal and interannual variability through improvements in modeling and time series analyses are outlined in my review of the Hardy 2009 report. The continued integration of these modeling efforts as improved by ongoing and future monitoring should provide a firm foundation for a viable Edwards Aquifer Adaptive Management Program capable of producing conservation plans in support of the Endangered Species Act.

"Technical Assessments in Support of the Edwards Aquifer Science Committee "J Charge" Flow Regime Evaluation for the Comal ad San Marcos River Systems"

Review by Clair Stalnaker

General comments on the report:

The gathering of experts and development of conceptual models as illustrated via influence diagrams for each of the species of concern is to be commended. This represents excellent communication among the stake holders and led to an agreed upon focus for analyses. Appendix A provides a permanent documentation of the deliberations and influence diagrams developed by the group. One important biological feature that should have more focus as the system planning and management advances is the timing of life stage events for the important surface dwelling species. This should focus both the monitoring and modeling efforts as species respond in time and space to flow and resulting physical habitat and water quality.

The report emphasizes that it is to provide support to the Science Subcommittee and does not make specific flow recommendations. That however this does not preclude providing guidance to the committee through illustrative analyses as was done. I would suggest that future guidance emphasize the timing and duration of hydrology driven events and associated species life stage development and population response.

More attention should be focused to the spatial distribution of suitable conditions including the timing and duration of these conditions in the system. This includes all aspect of the hydrology, water quality, physical habitat and species life histories.

It appears that the hydrology analyses driving the Physical Habitat and Water Quality modeling as well as the Hydrology analyses central to the Expert Science Subcommitee for the Edwards Aquifer Recovery Implementation Program were separately developed. For continuity all analyses should be based on the same underlying description of the system hydrology. How the flow is partitioned among the different springs and routed through the system is not only critical for obtaining realistic representations of the hydrology but is also the primary driver of the water quality and physical habitat models. Because each discipline tends to work independently the notion of being forced to agree on a common description and model representation of the system hydrology **before** the different analytical analyses are conducted remains a central issue for more holistic views of river systems. I have become convinced after reviewing many similar programs that the lack of a common description of the hydrology through time and space is the **primary** excuse for not conducting time series analyses of water quality and physical habitat followed by the identification of potential bottlenecks to species life stage development and population viability. The illustration of these types of analyses of spatial distribution and timing can provide a basis for identifying critical limiting events as bottlenecks to healthy life stage development for aquatic species. Such analyses in support of the Scientific Subcommittee should be pursued.

A positive indication from the reports is that the Edwards Aquifer Program appears to be philosophically open to continued monitoring, data collection and modeling to advance understanding for planning and management of the system. This suggests possible movement toward "Adaptive Management".

The report goes to considerable detail for calibration and verification of the water quality model. This is laudable and represents standard practice in this discipline. However similar verification for the hydrodynamic modeling is not given. This is essential as the velocity distribution predictions are critical input to the physical habitat simulations. Proper calibration and verification must become standard practice for stream physical habitat analyses. Controversy continues over the use of such models for biological analyses. See National Research Council (2008) for a through discussion of formulating and applying models in ecosystem management.

Specific comments:

P 14- It is noted that a flood in 1998 altered the channel geometry and greatly affected the vegetation of the San Marcos River. Analysis of subsequent cross sectional data was judged that "the channel changes could potentially impact modeling results enough to warrant remapping of channel topographies". Later in the report analyses illustrate a scale change in the flow/physical habitat relations but little change in the overall shape of the relation. However, the scale is very import when conducting time series analyses. As the program progresses it would be important to periodically update the data base by resurveying the topography when significant change is evident from episodic driven but less intensive sampling. Likewise is the need for remapping the distribution of vegetation over time. As the time series is put together the different channel topographies and vegetation distributions would be entered into the data base at appropriate intervals to represent the channel for specific time periods in the series.

P 18- How does the partitioning among springs from Brune (1981) compare with the hydrology analyses discussed in the "J Change" report. It is very important that the same description of the system hydrology, including partitioning among spring flows and routing water through the system, be used for all water quality and physical habitat analyses.

P 29- The last paragraph refers to assumptions made to adjust flows. Such assumptions must be common for all flow based modeling input to obtain consistent understanding across disciplines of the system response.

P 30-31- The presentation of calibration and verification data for the water quality modeling as illustrated in Fig.23 represents the long established practice among water quality experts. This must also be included for the hydrodynamic (hydraulics) models. Also noted here is reference to modeling DO. Later in the report emphasis is placed on needing to know if DO depletions may occur during the night time. These water quality models are useful for such analyses of diel predictions by season and climatic condition and should be used for such examination.

P 35- Here and other places in the report identify the importance of aquatic vegetation as habitat features for darters. Habitat suitability criteria for these vegetation types should also be developed and included for future modeling exercises.

P 38-39- The differences between USFWS/USU and TPW HSC would obviously yield significantly different physical habitat simulations used in time series analyses. Improvement in HSC based on professional judgment should be verified with presence/absence analyses as illustrated later in Figure 46. Future modeling efforts should compare model output with field observations of wild rice distribution and the models "calibrated" to attain agreement with field observations. See further discussion of this issue below for pages 67-68. F

P 44- Not clear throughout the report just where velocity was simulated. Here for "fountain darters, the velocity at six inches (15cm) above the bottom was also evaluated…" For each figure it would be helpful to designate where in the water column the velocity is computed.

P 50- Comal Springs riffle beetle analysis relied on a simple calculation of wetted surface area with depths greater than 0.02 feet. However, the equation on page 45 indicates a suitability value of 1.0 for depths <0.02 feet.

P 52- 59- It is obvious that temperatures are limiting to darters in Comal River. Dramatic reduction is seen in darter physical habitat suitability by flow reduction from 40 cfs to 10 cfs. Suitability is even very low at 40 cfs. Presented data and figures indicate that as flow rate decreases, thermal effects on darter life stages becomes more limiting rather than the amount of suitable physical hydraulic based habitat. One statement indicates that this thermal effect results in potentially reduced larval survival. Here is one of the few times the report emphasizes life stage events. As the program matures such attention to the timing and duration of potentially limiting life stage events on species of interest should become routine practice. Time series of maximum daily water temperature distributions through the system by season (under simulated ambient air conditions representing hot, normal, and cool years) would be most informative.

P 62- Here the need for modeling DO is stressed and should be included in future modeling.

P 67-68- Figures 45 and 46 are useful to illustrate the value of physical habitat modeling through time and space. Such analyses start with the need for converting hydrologic time series data to habitat time series and the presentation of habitat duration plots representing the total system as well as specific reaches. In Figure 45 the flow/habitat relation is curvilinear. Typical for this kind of relation any time series analyses and duration plots for system hydrology and physical habitat would be quite different. In these cases (really all cases) it is important to translate the hydrology time series into physical habitat time series and subsequent summations and duration plots. When searching for potentially limiting habitat events this conversion is necessary. Figure 46 is

an excellent way of presenting model results with actual field observations and should become standard practice in complex systems with high water use and where maintenance or even recovery of aquatic species is the goal. With system wide analyses driven by time series illustrations of the distribution of highly suitable physical habitats by season and year can be produced. With this information the biologist can start teasing out potential limiting events (and duration) that influence species life stage development and population response. Once these life stages and the timing and duration of limiting events become obvious management schemes can focus on control of water diversions and pumping to maintain areas and timing of highly suitable physical habitat conditions at appropriate seasons and places (even improving the extent and duration of suitable conditions if recovery or restoration is the goal). Excellent first step are presented in this report illustrating model use. Following suitable physical habitat time series study and identification of potential limiting events the most appropriate comparison of field observations on species distribution would be with those simulated conditions and areas shown to be most favorable during critical life stage events. For wild rice study good correlations with actual field observed distributions would be very unlikely at the discharge and quality conditions found at the time of field observation. Rather it is most likely that past events and duration have greater influence on the observed distribution. One would expect a much greater correspondence with areas experiencing repeated and sustained highly suitable conditions This can only be illustrated via time series simulations. Incidentally, these types of analyses are equally important when applied to the fish populations.

P 82- Figure 55 differences between "old HSC" and "new HSC" are quite dramatic and illustrate the significant changes in suitable physical habitat area that may occur between 40 cfs and 150 cfs. To maintain or enhance conditions for the darter populations through time series analyses of past habitat conditions the analyst determine **when** (seasons and years) and **where** (reaches having highly suitable as well as stable conditions with longer duration at critical times) physical habitat conditions occurred that had the potential for supporting healthy populations. From a management perspective the important question often becomes: can those conditions be maintained or even improved with similar timing and distributions in the future? The converse is equally true for identifying conditions of most unsuitable physical habitat conditions. Can the timing and duration of unsuitable events be reduced? Fine tuning HSC to these species distribution plots is the preferred way for calibrating and verifying suitable physical habitat mode output.

P 88- Impacts of recreation on sediments, turbidity and aquatic vegetation obviously need additional research leading to possible control.

P 89- These recommendations are all most pertinent and if followed should lead to improved understanding of system limitations and species distributions and trends over time. The statements recommending using the same water quality model in both systems is right on. Of equal if not even greater importance is the use of the same model for describing the hydrology of the systems for all analyses within each system. This description of the system hydrology and distribution over time and space should be the common input to the water quality and the physical habitat modeling. Finer resolution of

simulated flows is best brought about through calibration and verification of all modeling efforts (hydraulic, water quality physical habitat). Verified models are more believable by stake holders when simulated conditions diverge from the sampled input conditions. This is critical for time series analyses of past conditions.

When accompanied by improved (through additional data collection, calibration, and verification) modeling efforts for flow distribution through time and space and coupled with water quality (temperature and DO at the least) and physical habitat future system modeling efforts can provide valuable support for an "adaptive management approach' undertaken by the Edwards Aquifer Program. Important first steps toward a viable Adaptive Management Program are presented in this and the "J Charges" report. As long as the stakeholders and management agree to periodic (2-5 year) updates of the data bases along with repeated model runs the program should reach a common understanding of limiting conditions and consensus on what would be necessary to protect or even enhance system conditions allowing recovery of the T & E species. However agreeing on actual implementation measures to achieve protection or recovery may be difficult or even not physically possible and/or politically unacceptable.

It is important to remember that good science can lead to common understanding and agreement on the conditions that are controlling the biological response of species and populations of concern. Disagreements may well arise over management measures and the political will to implement control over water use. An adaptive management program should move away from disagreements over the science and help focus discussion toward understanding potentials for protection by preventing further degradation (or even enhancing) by addressing the limiting system conditions found to be critical for maintaining viable species populations.

This report represents a good beginning for building a collaborative understanding of the ecology of the system.

References;

National Research Council. 2008 Hydrology, Ecology, and Fishes of the Klamath River Basin. The National Academies Press. Washington, DC

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23 April 2010

TO: Tom Annear
FROM: Tom Wesche
SUBJECT: Comments on Hardy report entitled, ATechnical assessments in suport of the Edwards Aquifer Science Committee AJ Charge@ flow regime evaluation for the Comal and San Marcos River systems@.
COPIES: Ian Chisholm, Claire Stalnaker, Allan Locke

As you requested, I have reviewed the Hardy report and offer the following comments:

General Comments:

1. Overall, I found this report to be a valid, defensible, science-based presentation of what is known regarding the physical habitat-flow relationships of the target species (fountain darter, Texas wild rice, Comal Springs riffle beetle) in the San Marcos and Comal Rivers. As such, the report presents a solid basis for describing these aquatic ecosystems and a valuable contribution to the Science Subcommittee for developing spring flow recommendations for these streams.

2. Strengths of the study are many and include 1) the updating and revision of habitat suitability curves (HSC) for the target species where new data were available, 2) the use of workshops with recognized species and river experts to generate influence diagrams for each target species and assist with HSC revisions, 3) the use of 2-dimensional hydraulic modeling, including development of water velocity adjustments based upon species-specific vegetation roughness, 4) the inclusion of water temperature and dissolved oxygen concentrations in the development of flow-habitat relations, where applicable, and 5) the identification of important research needs and management issues that need to be addressed in the future.

3. I recommend that future study of these flow-habitat relations include consideration of additional species life functions and stages (e.g. fountain darter spawning/incubation), seasonal variation in flow regimes and habitat availability, and time series analyses to compare habitat provided by different flow regimes and assist in identifying flow-related habitat bottlenecks.

Specific Comments:

1. On p. 11, Figure 10 (and others), are channelization and urban encroachment also influencing factors?

2. On p. 18, is it satisfactory to assume the flow splits of Brune (1981) are still valid just because no response was received from reviewers? Is there field evidence to suggest these should be validated almost 30 years after they were first reported?

3. On p. 24, how does Manning's n vary by season with changing vegetation size and condition?

4. On p. 25, 1st paragraph, the resultant velocities from the 2-D model are still modeled values, not actual values, whether they are adjusted by the velocity ratio or not.

5. On p. 25, the modeling exercise using maximum dissolved oxygen values would likely have been more meaningful had minimum or daily average values been used. Also, since an optimum temperature range was defined for fountain darters, it would appear that modeling minimum temperature values might also be insightful, especially if seasonal analysis were to be undertaken.

6. On p. 37, top 2 paragraphs, if flowing water is important for survival of beetles, why was just the depth criterion (<0.02 ft) used for habitat modeling? In 4th paragraph, has sufficient information been gathered over the years to develop a relationship between wild rice presence or abundance and turbidity? If so, could this be incorporated into the habitat modeling analysis for wild rice? Also, has nutrient loading been investigated?

7. On p. 39, Figure 27, the extension of optimum water velocity (SI = 1.0) leftward to 0.25 ft/s does not seem to be supported by the 1996 and 1933 observations discussed in the text. Further explanation for this curve modification is needed.

8. On p. 42, Figure 29, is this HSC curve for mean velocity or velocity near stream bed?

9. On p. 45, 1st paragraph, the equation for riffle beetle should be A1.0 for depths > 0.02 ft@ based on the discussion in the text.

10. On p. 46, how does water temperature vary seasonally, and if such variations exist, how do they influence physical habitat quality and availability?

11. On p. 48, the discussion of DO limitations in the last paragraph emphasizes the need to include minimum DO levels in the habitat modeling exercise.

12. On p. 50, 4th paragraph, the use of a limiting factor approach for DO is good, but ignoring

APPENDIX F:

EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM RECHARGE FACILITIES FEASIBILITY SUBCOMMITTEE, "FINDINGS, DETERMINATIONS AND RECOMMENDATIONS REGARDING FIVE CHARGES IN SUBSECTION (N) OF SECTION 1.26A OF THE EDWARDS AQUIFER AUTHORITY ACT," NOVEMBER 23, 2009

Findings, Determinations and Recommendations Regarding Five Charges in Subsection (n) of Section 1.26A of the Edwards Aquifer Authority Act

Report to the Steering Committee and Stakeholders
of the
Edwards Aquifer Recovery Implementation Program

By the
Recharge Facility Feasibility Subcommittee
For the Edwards Aquifer Recovery Implementation Program

November 23, 2009

November 23, 2009

To: The Steering Committee and Stakeholders of the Edwards Aquifer Recovery Implementation Program

From: The Recharge Facility Feasibility Subcommittee
For the Edwards Aquifer Recovery Implementation Program

Attached please find a final report titled *Findings, Determinations and Recommendations Regarding Five Charges in Subsection (n) of Section1.26A of the Edwards Aquifer Authority Act*. This report meets the requirements of Article 12, Senate Bill 3, Regular Session, 80th Texas Legislature, Section 1.26A(n), and the requirements of your charges to us. On November 23, 2009, the Recharge Facility Feasibility Subcommittee met to consider the final report. A quorum of the voting membership was present. The Subcommittee adopted this report by consensus.

If you have any questions regarding this report, please contact Mr. Steven J. Raabe, P.E, with the San Antonio River Authority and Chair of the Recharge Facility Feasibility Subcommittee.

INTRODUCTION

A. Compliance with Senate Bill 3. This Report of the Recharge Facility Feasibility Subcommittee (Subcommittee) of the Edwards Aquifer Recovery Implementation Program (EARIP) has been prepared in compliance with the requirements of Article 12 of Senate Bill 3, 80th Texas Legislature (2007). Article 12 amends the Edwards Aquifer Authority Act by adding new Section 1.26A (hereafter referred to as Sec. 1.26A or the Act.) Section 1.26A requires Edwards Aquifer stakeholders to participate in an EARIP, overseen by a Steering Committee and managed by a Program Director, for the purpose of developing recommendations to the Edwards Aquifer Authority (Authority) for the protection of Aquifer-related endangered species. Subsection (n) of Section 1.26A requires the EARIP stakeholders to establish a Recharge Facilities Feasibility Subcommittee to review the feasibility of aquifer recharge facilities, and to prepare and submit to the RIP Steering Committee and other RIP stakeholders a report of its findings, determinations, and recommendations not later than December 31, 2009, responding to the five charges stated in paragraph B.

B. Charges. Section 1.26A directs the Subcommittee to address the following five charges:

1. assess the need for the Authority or any other entity to own, finance, design, construct, operate, or maintain recharge facilities;

2. formulate plans to allow the Authority or any other entity to own, finance, design, construct, operate, or maintain recharge facilities;

3. make recommendations to the Steering Committee as to how to calculate the amount of additional water that is made available for use from a recharge project including during times of critical period reductions;

4. maximize available federal funding for the Authority or any other entity to own, finance, design, construct, operate, or maintain recharge facilities;

5. evaluate the financing of recharge facilities, including the use of management fees or special fees to be used for purchasing or operating the facilities.

C. Subcommittee Chair, Vice-Chair, and Members. The Steering Committee appointed 18 EARIP participants as voting members of the Subcommittee. The members include representatives of environmental groups, land stewardship organizations, river authorities, water purveyors, general stakeholders, business interests, state agencies, and stakeholders from the Edwards Aquifer recharge and contributing zones. The Subcommittee also includes six non-voting members representing state and federal agencies. The Subcommittee elected Steve Raabe, a representative of the San Antonio River Authority and member of the Steering Committee, as Chair of the

Subcommittee and Kirk Patterson, a representative of Regional Clean Air and Water and also a member of the Steering Committee, as Vice-Chair. The names of the persons who served on the Subcommittee are listed on the membership roster attached to this Report as ***Appendix 1.***

D. Subcommittee Meetings. The Subcommittee held regular monthly meetings from August 2008 through November 2009. The Subcommittee received informational presentations at the meetings held from September 2008 through February 2009. The Subcommittee considered and made findings and recommendations relating to the five statutory charges during the meetings held from March 2009 through November 2009.

The Subcommittee limited its initial work to responding to the five statutory charges. Subcommittee members recognize and acknowledge that there are other important issues related to the subject of aquifer recharge facilities feasibility that is not addressed in this report.

Copies of the Subcommittee meeting agenda, the Subcommittee reports to Steering Committee, and handouts to Subcommittee members are included in ***Appendix 2***.

E. Initial Report. This initial report sets forth the findings and recommendations of the Subcommittee. The findings and recommendations are intended to be supplemented as aquifer stakeholders continue to study the feasibility of recharge facilities.

SUBCOMMITTEE'S RESPONSES TO STATUTORY CHARGES

1. Charge 1 – Assess the need for the Authority or any other entity to own, finance, design, construct, operate, or maintain recharge facilities.

The Subcommittee's Response.

1.1. The climate of the Edwards Aquifer region alternates between periods of drought and heavy rainfall causing flooding. The Texas Legislature, in 1993, adopted comprehensive aquifer management legislation (Edwards Aquifer Authority Act or Act), which was implemented in 1996. The Act changed the recognition of groundwater withdrawal rights in the region from the common law "rule of capture" to a system of permits issued by the Authority in amounts based on the historic usage of permit holders. The Act guaranteed permits to qualified historic users and capped the total amount of permits that could be issued. The 450,000 acre-foot cap set in the 1993 legislation was raised by the Legislature in 2007 to 572,000 acre feet, provided in Article 12 of Senate Bill 3, to correspond to the total of guaranteed permits that the Authority was required to issue. The Authority manages the aquifer by monitoring compliance with the withdrawal permits and enforcing pumping reductions when aquifer index wells or springflows are below

certain levels under the statutory demand management critical period management (DM/CPM) limitations.

The Authority's multiple statutory objectives, which include aquifer "optimization" and springflow protections for endangered species, create a need for increasing aquifer recharge to increase the amount of available water and the need for facilities to cause or permit the increase. The Subcommittee acknowledges, and this Report recognizes, that facilities which can increase recharge to the aquifer include not only structures that facilitate recharge but also land management practices that facilitate recharge.

1.2. Recognizing both the challenges and opportunities of the climate of the Edwards region, the Subcommittee has identified needs for and benefits from recharge enhancement. They include:

(a) Increased springflow for the benefit of endangered species;

(b) Increased water available for withdrawal permits;

(c) Increased reliability for withdrawal permits. (Edwards Aquifer groundwater withdrawal permits are subject to Drought Management/Critical Period Management (DM/CPM) restrictions. One incentive to the development of enhanced recharge might be the improvement in regional index well levels and springflows that trigger the DM/CPM restrictions. If the index well levels and springflows can be improved, permit holders would receive a benefit of reduced DM/CPM.) ;

(d) Increased Edwards Aquifer water levels.

1.3. The entities and interest groups who have a need to own, finance, design, construct, operate, or maintain recharge facilities include:

(a) the Authority

(b) aquifer permitholders

(c) land stewardship interests

(d) private interests

(e) governmental interests

(f) springflow interests

2. Charge 2 – Formulate plans to allow the Authority or any other entity to own, finance, design, construct, operate, or maintain recharge facilities.

The Subcommittee's Response.

2.1. The issues to be addressed in a plan to allow the Authority or other entities to own, finance, design, construct, operate, or maintain recharge facilities include:

(a) identify interested parties;

(b) determine purpose of recharge facility – purpose purely intended to support springflow, water supply, or mixed purpose (an example of which could be a recharge facility coupled with other purposes such as flood control);

(c) evaluate legal authority;

(d) develop project partnerships;

(e) determine feasibility;

(f) determine and Allocate benefits and costs;

(g) acquire applicable federal, state and local permits and authorizations;

(h) evaluate financing alternatives – heavily predicated on success of implementing advice from Charges 4 and 5.

2.2. The Subcommittee recognizes that planning for any proposed recharge facility will include additional factors related to the type of facility.

3. Charge 3 – Make recommendations to the Steering Committee as to how to calculate the amount of additional water that is made available for use from a recharge project including during times of critical period reductions.

The Subcommittee's Response.

3.1. There are four techniques by which recharge to the Edwards Aquifer might be enhanced. They are: (1) direct injection, 2) recharge structures, (3) land stewardship and (4) recharge and recirculation. The subcommittee recognized that determining the amount of additional water that is made available for use from a recharge facility has to be accomplished in two steps.

The first step is to calculate the enhanced recharge to the aquifer for the particular recharge enhancement technique employed. The second step is to determine or

allocate the amount of enhanced recharge that is available for a particular purpose.

3.2. Step One – Calculating Enhanced Recharge

3.2.1. Enhanced Recharge by means of Direct injection – (a technique per the Texas Water **Code**) implies an "injection well," which is an excavation or artificial opening. The Code recognizes five classes of injections wells, designated (I-V). All classifications are regulated either by Texas Commission on Environmental Quality (TCEQ) or the Railroad Commission of Texas (RRC). The Subcommittee understands, based on the information in the TCEQ guidance texts that "direct injection" wells for recharge purposes would most likely be assigned a Class V designation, which would be regulated by TCEQ. Class V wells include those releasing a liquid or liquids into or above a drinking water source.

The **calculation** of recharge by means of an injection well requires devices and strategies, including the following:

(a) Flow meter – device for measuring fluid movement. Variations of mechanical, pressure, electromagnetic/ultrasonic devices exist and an appropriate device installed to manufacturer's specifications would measure flow contribution within a prescribed accuracy. A flow meter in the case of direct injection would be installed to measure amount of recharge.

(b) Location and timing – currently a product of the conceptual understanding of the aquifer and its modeling. All direct injection is predicated on a conceptual understanding of the aquifer system based on conceptual geologic information and modeling based on coarse observations. More detailed site-specific observations would be required to validate or refine this limited understanding.

(c) Confirmation that water is reaching aquifer (well log) – a properly constructed well for injection to the aquifer would provide the most direct route to deliver volumes of water for recharge to a target zone. A well log and construction records would substantiate the confirmation.

(d) Water quality limitations (dependent on proximity to springs for species requirements, TCEQ standards for direct injection) – The unique application of direct injection in the context of any recharge contemplated by the EARIP program may require matching the ambient conditions of natural surface waters recharging the targeted injection zone. A bracketed range may be biologically sufficient for the sentinel endangered species of focus, depending on the water quality parameter(s) of most concern.

(e) Source water and injection permit – Having regulatory rights and access to both the water and approval to implement the technology.

(f) Environmental review.

3.2.2. Enhanced recharge by means of recharge structures

Major Recharge dams are major structures or dams located on the larger streams that traverse the Edwards Aquifer recharge zone and contributing zone. These structures have historically been studied and classified as 1) Type 1 – projects located on the Edwards Aquifer contributing zone that collect and store runoff for long periods of time and release it at a rate so that the flow enters the Edwards Aquifer as it flows across the recharge zone; 2) Type 2 – projects located on the Edwards Aquifer recharge zone on streams that are often dry. These structures impound water for only a few days or weeks following storm events and recharge water very quickly to the aquifer.

Minor recharge dams are small structures or dams on ephemeral waterways to capture runoff and hold it for seepage into the aquifer. This strategy can be implemented by individual landowners, but would probably need cost sharing by organized groups who depend upon the aquifer or through federal, state and local programs that provide technical and financial assistance.

The measurement of enhanced **recharge by recharge structures requires:**

(a) direct measurement (such as stream gauges, synoptic flow measurements, groundwater monitoring wells);

(b) indirect estimation (surface water-groundwater models, analytical calculations);

(c) confirmation that water is reaching aquifer (geologic assessment of recharge feature, recharge capacity);

(d) location and timing;

(e) water quality limitations (recharge meets ambient source stream water quality);

(f) O&M to preserve recharge rate;

(g) source water appropriation permit; and

(h) environmental review.

Permitting of any recharge facility will be subject to all federal, state, and local laws and restrictions. The Subcommittee recognizes the following section of the Edwards Aquifer Authority's Act that reads as follows:

Section 1.45 Recharge Dams

(a) The authority may own, finance, design, construct, operate, and maintain recharge dams and associated facilities, structures, or works in the contributing or recharge area of the aquifer if the recharge is made to increase the yield of the aquifer, the recharge project does not impair senior water rights or vested riparian rights, and the recharge project is not designed to recirculate water at Comal or San Marcos Springs.

(b) The commission shall determine the historic yield of the floodwater to the Nueces River basin. The historic yield is equal to the lesser of:

(1) the average annual yield for the period from 1950 to 1987; or
(2) the annual yield for 1987.

(c) Only the amount of floodwater in excess of the historic yield as determined by the commission may be impounded by a recharge dam built or operated under this section (emphasis added).

The Subcommittee suggests that this Section is vague and complicates the process of developing recharge facilities over the Edwards Aquifer so long as "the historic yield of the floodwater to the Nueces basin" remains undefined and the "amount of floodwater in excess of the historic yield" remains undetermined.

3.2.3. Enhanced recharge by means of Land Stewardship. Private ranches and rangelands comprise the bulk of lands over the Edwards Aquifer, and keeping watersheds (or more appropriately, water catchments) in open space is critical for water infiltration and recharge in the recharge and contributing zones of the Edwards Aquifer. The precipitation that falls on Texas rangelands is the major source of surface flow and aquifer recharge, and the condition and management of these rangelands has major impacts on the water available for recharge and river flows. Healthy rangelands provide clean, high quality drinking water, promote recharge, conserve soil, filter and slow overland flow of water, provide forage for livestock, and provide wildlife habitat (Hays *et al* 1998). Over the last century, encroachment of woody species (particularly Ashe juniper – commonly known as cedar) across much of Texas' open rangelands has degraded many of these services, and research demonstrates juniper has affected recharge and streamflow. Rangeland restoration programs reverse this trend through the use of sound management practices to control woody species, and with proper follow-up management practices healthy rangelands can be restored. Such restoration may benefit spring dependent species affected by the Edwards Aquifer as well as downstream organisms and communities dependent on reliable stream flows.

Research indicates rangeland restoration and management increases water quantity, as well as quality, for surface water run-off and aquifer recharge. The proper site and geology are critical specific to aquifer recharge, but most central Texas areas within the recharge zone and contributing zone can be enhanced for increased spring, seep and surface water flow. Woody plant invasion can be reversed through rangeland restoration. Initial costs, however, are generally more than a landowner can justify when considering livestock production alone. Costs are more for established, mature stands of unwanted brush and lower for younger aged, non-resprouting species. Under certain circumstances, additional water yield results from rangeland restoration. As is suggested by several studies, there may be opportunities for creating incentive-based programs that lead to additional water yield through rangeland restoration. An additional acre-foot can be gained for every 5 to 8 acres of brush converted to native rangeland in the Edwards Plateau.

Assuming rangeland restoration practices are effective for at least 10 years, the cost to produce an additional acre-foot of water in the Edwards Plateau would be $40 to $180 depending on the method. (Connor *et al* 2008) These surface waters flows are also slowed and cleaned with good range management, releasing water more slowly over time rather than in a singular muddy rush in a huge flood event, allowing for these waters to slowly percolate and released over time and/or to flow over increased periods of time into aquifer recharge structures. There is still uncertainty as to exactly how much additional water actually enters the aquifer. Additional research is underway and reporting is expected soon.

Vegetation management (brush management, prescribed burning, grassland restoration, grazing management, riparian management) is used to capture rainfall, increase soil infiltration, reduce runoff, and enhance water quality and quantity. The goal of vegetation management is to reduce Ashe juniper canopies in appropriate areas while enhancing and then maintaining healthy mid and tall grasses with vigorous root systems that can reduce erosion from rainfall impact on bare ground, increase infiltration into the root zone and beyond, and reduce rapid runoff that prevents the slow, continuous natural recharge in creeks and riparian areas.

Other conservation practices (such as terracing, soil aeration) can also be used to increase soil infiltration and slow or reduce runoff

3.2.4. The measurement of enhanced recharge by rangeland management requires:

(a) Several studies measuring evapo-transpiration have calculated an average increase in water yield (streamflow and recharge) of approximately 1.75 inches/year (45mm/year) under average or above average annual precipitation. (Wright 1996, Dugas *et al* 1998, and Huang *et al* 2006) However, there is still some uncertainty as to what fraction of additional water goes toward recharge. Interception losses to the canopy and litter are significant depending upon

species of woody plant and species composition of woody/herbaceous cover. (Thurow and Hester, 1997)

(b) Direct measurement (such as stream gauges, synoptic flow measurements, groundwater monitoring wells, synoptic water level measurements, lysimeters, evapo-transpiration monitoring). Two separate demonstrations in the Seco Creek project point to water quantity increases to the Edwards Aquifer through selective woody plant management that increases water yield from rangeland watersheds. The two demonstrations show an increase of 35,000 to 55,000 gallons of water per acre per year following the selective removal of certain woody species. (http://wmc.ar.nrcs.usda.gov/news/secocreek.html)

(c) Indirect estimation (surface water-groundwater models, analytical calculations) Keese *et al* 2005 modeled recharge dynamics for the entire state of Texas taking into account the influence of climate, soils, and vegetation. For the Edwards Plateau region, their simulations suggest that recharge would be approximately 0.1-0.4 inches/ year (5-10 mm/year).

(d) Confirmation that water is reaching aquifer (geologic assessment of recharge zone, recharge capacity). There is still uncertainty as to exactly how much additional water actually enters the aquifer. There are several studies proposed that would research this but none have been funded at this point.

(e) Location and timing of vegetation management is important to achieve the desired vegetative state in areas identified to contribute to aquifer recharge particularly as they impact watersheds (water catchments) above critical spring areas and increased flows in rivers related to downstream species of interest.

(f) Enhancement and maintenance management practices to preserve desired vegetative state in targeted areas include planned/managed grazing (including deferment), prescribed fire, brush management, reseeding grasses and forbs with native plants as necessary, wildlife and habitat management planning, riparian management and restoration, erosion management and springs and creek-banks protection strategies, conserving and maintaining specific recharge features, increasing native biodiversity, conservation of rare species, managing exotics (flora and fauna) as necessary, appropriate estate planning (to limit fragmentation), conservation easements, local community and neighbor efforts to prioritize abilities of landowners to maintain open space broadly conserving spring sites, aquifer recharge areas and upstream contributing areas through conservation programs including federal, state and local community efforts such as PDRs, 2008 Farm Bill programs (such as CRP, CTA, CPGL, GRP, EQIP, WRP, CStP, FRPP) state programs (such as Landowner Incentive Program), local programs (Proposition 4) See Appendix 4.

(g) Environmental review for compliance with federal and state laws

3.2.5. Enhanced recharge by means of Recharge and Recirculation - Recharge and Recirculation is a combination of strategies for adding water to the aquifer by a number of methods that are inclusive of enhanced recharge structures, surface water sources (including both available stream flows and water from surface storage units) and groundwater sources (including pumping both regular permits and recharge withdrawal permits from the Edwards Aquifer). The purposes of a Recharge and Recirculation strategy is to provide springflow and/or additional firm yield water supply through aquifer management techniques, when compared to baseline conditions such as maximum allowed pumping under the regime established under S.B. 3, Article 12 .

Recharge and Recirculation source waters can include:

(i) unused regular withdrawal permits (Edwards);
(ii) unused recharge withdrawal permits (Edwards);
(iii) enhanced recharge structures over Recharge Zone (Type 2s);
(iv) enhanced recharge structures over Contributing Zone (Type 1s);
(v) diversions from rivers and lakes (surface water);
(vi) diversions from groundwater projects such as ASR projects;
(vii) diversions from additional surface water storage (quarries);
(viii) enhanced recharge from land stewardship projects.

Recirculation is a source of enhanced recharge that using previously created recharge withdrawal rights or regular rights to add water to the Aquifer at locations and times that can increase the amount and duration of stored waters in the Aquifer

3.2.6. Methods of measuring the amount of enhanced recharge to the aquifer include both direct and indirect measurements:

(a) "Direct measurements," which include gauges above and below contributing streams or recharge structures, and flow meters on pipelines and water wells diversion facilities from storage units to recharge structures or injection wells.

(b) "Indirect measurements,"which include use of groundwater models and surface water models, and analytical calculations such as those used by TCEQ in Surface Water Availability Models (WAMs), Region L, Trans-Texas, HDR Engineering, and Todd Engineers.

3.2.7. Methods of calculating the amount of recharge that may be withdrawn from enhanced recharge projects include:

(a) Use of groundwater models such as the GAM models (Groundwater Availability Models) (MODFLOW or GWSIMIV) to calculate the duration of aquifer storage from a recharge project, adjusting over time for increased understanding of site specific characteristics and hydrologic behavior through adaptive management.

(b) Groundwater models may also be used to provide "safety factors" and to calculate "optimizations" required in calculating withdrawals, including these conditions on recharge withdrawals required by the EAA Statute and EAA Rules. The optimizations and safety factors are described as follows:

(i) *Optimization:* The recharge project is sited and designed to "optimize" the beneficial use of groundwater available for withdrawal from the Aquifer. EAA Rules, Sec. 711.264(15)

(ii) *Safety Factor***:** The proposed withdrawal of groundwater under the recharge recovery permit would not unreasonably negatively affect other permittees, including permitees holding initial regular permits. EAA Rules, Sec. 711.264(11), Sec. 711.264(14)

(iii) *Safety Factor:* Continuous minimum springflows of the Comal Springs and San Marcos Springs necessary to protect endangered and threatened species to the extent required by federal law, will not be negatively impacted when compared to springflow conditions if the project did not exist. EAA Rules, Sec. 711.264(16).

(iv) *Safety Factors:* Only the enhanced recharge with the project over base conditions of recharge without the project can be included in water available for withdrawal, less:

- additional waters discharged through springs due to the stored water;
- artificial recharge attributable and permitted to another Aquifer recharge storage and recovery project;
- loss of stored water; and
- an amount of groundwater not to be recovered to compensate the EAA in lieu of aquifer management fees as may be determined by the EAA Board.

Withdrawals may be reduced by an additional safety factor to account for uncertainties in the above calculations.

[EAA Statute, Sec. 1.44(b); EAA Rules, Sec. 711.261]

(c) Withdrawals of enhanced recharge, after being subjected to optimization and safety factors, are not subject to the maximum total permitted withdrawals provided by Sec. 1.14 of the EAA Act [Sec. 1.44(d) EAA Act]; and recharge

withdrawal rights are not subject to EAA Critical Period Reductions under the present rules of the EAA [Sec. 711.255 (f) and (g), EAA Rules].

(d) Water remaining in Aquifer storage must be considered. In order to assess how much water remains in the Edwards Aquifer for pumping or recirculation or to assess how much of the enhanced recharge has gone to increase springflows or has otherwise left Edwards Aquifer storage, groundwater models such as the accepted Groundwater Availability Models used in state water planning can be used for evaluation purposes, given the location and timing and quantity of both the enhanced recharge and the location and timing and quantity of the enhanced pumping from enhanced recharge withdrawal permits.

(e) In order to confirm that water is reaching the Edwards Aquifer, local assessments of geological features at recharge sites may be made and any losses due to pipeline losses carrying water to the recharge site can be estimated or metering can occur as the water enters the recharge feature.

(f) Water quality limitations on recharge entering the aquifer in natural recharge features from surface water sources are identified in the EAA Rules, both for artificial injection into the Aquifer and for natural infiltration. [EAA Rules, Sec. 711.254 (b)(1) & (2)].

(g) The EAA may not approve an application for an aquifer recharge and storage permit unless protection of the water quality of the Aquifer is demonstrated in the application.

(h) Operation and Maintenance (O&M) Costs: There are varying amounts of O&M costs involved in preserving recharge rates for Recharge and Recirculation projects, depending on whether the project uses dam structures that need to be maintained, pipelines and diversion facilities that need to be maintained or well fields that need to be maintained.

(i) Source water appropriation permits include the surface water and groundwater permits for withdrawing or diverting water from surface water streams and groundwater sources. These include both state and federal permits, as well as permits from the Edwards Aquifer Authority.

(j) The projects for Recharge and Recirculation are subject to environmental review under both state and federal laws and regulations, as well as the reviews provided for under the rules of the Edwards Aquifer Authority.

3.3 Step Two – Allocate Enhanced Recharge

The Subcommittee identified several purposes for water recharged to the Aquifer as well as techniques that may be used to evaluate the effectiveness of a recharge

project. These techniques may be used to design a project and to predict project performance, or they may be used to evaluate performance after a project is operating.

3.3.1. Purpose: Increased spring flow for benefit of endangered species

Evaluation techniques include:

(a) GAM Numerical models of Edwards Aquifer (such as MODFLOW[1], GWSIMIV[2]);

(b) biological studies to determine effects on the aquatic species;

(c) analytical tools (such as Darcy equation); and

(d) field measurements (such as synoptic[3] water level measurements, tracer studies).

3.3.2. Purpose: Increased water available for permits

Evaluation techniques include:

(a) GAM Numerical models of Edwards Aquifer (MODFLOW, GWSIMIV);

(b) consideration of the biological need to contribute to the recovery of species which are the focus of the EARIP;

(c) analytical tools (such as Darcy equation); and

(d) field measurements (such as synoptic water level measurements, tracer studies).

3.3.3. Purpose: Increased reliability for permits

Evaluation techniques include:

(a) GAM Numerical models of Edwards Aquifer (such as MODFLOW, GWSIMIV);

(b) consideration of the biological need to contribute to the recovery of species which are the focus of the EARIP;

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[1] U.S. Geological Survey Modular Finite-Difference Ground-Water Flow Model, see USGS 1996.
[2] Texas Water Development Board Edwards Aquifer model, see TWDB 1999.
[3] Synoptic water level measurements are measurements that are taken at approximately the same time (over a period of several days).

(c) analytical tools (such as Darcy equation); and

(d) field measurements (such as synoptic water level measurements, tracer studies).

3.3.4. Purpose: Increased water levels

Evaluation techniques will rely on a number of tools, including:

(a) GAM Numerical models of Edwards Aquifer (such as MODFLOW, GWSIMIV);

(b) biological studies to determine effects on the aquatic species;

(c) analytical tools (such as Darcy equation); and

(d) field measurements (such as synoptic water level measurements, tracer studies)

3.4. Technical evaluations.

Technical evaluations will be required for all recharge projects. The level of detail and specificity required in the technical evaluation will depend on the project's purpose. Highly detailed evaluations will be required if the purpose of the project is to increase the amount of water that may be pumped from the Aquifer (i.e., projects seeking recharge credits), whether for water supply or springflow. Less detail may be required if the sole purpose of a project is to increase springflow, and recharge credits are not being sought.

The permitting agency may develop default evaluation procedures for small projects that will not necessitate the expense associated with a detailed evaluation.

Technical evaluations should answer fundamental questions regarding the fate of recharged water, and the evaluations should show how the fate would change over time. All technical evaluations should answer the following questions.

(a) How much water would be recharged by the project?

(b) How much recharge would occur in the absence of the project?

(c) How much of the recharged water would discharge to springs?

(d) How much of the recharged water would be pumped from the Aquifer?

(e) What are the impacts to the downstream water rights and environmental flows?

(f) If there is evidence that the downstream water rights and/or environmental flows are adversely impacted, how would they be mitigated?

3.5. Additional questions.

Depending on the nature of the project, additional questions may have to be answered. One such question concerns the amount of the recharged water would discharge to streams and adjacent aquifers.

(a) "Safety factors" and "Optimization factors" may be applied to enhanced recharge projects to ensure that the water pumped by the operators of a recharge project does not exceed the amount of recharged water remaining in the Aquifer, to protect regular permit holders and minimum springflows required for endangered species by federal law, and to "optimize the benefits" of waters withdrawn from the Aquifer for recharge projects.

(b) In an application for a recharge withdrawal permit for a recharge project that adds enhanced recharge to Aquifer storage, the amount of the enhanced recharge that may be withdrawn over time may be determined by an application of the GAM models to the particular recharge project (MODFLOW model of the EAA; GWSIM4 model of the TWDB).

(c) To ensure that the permittee does not withdraw water that is not remaining in Aquifer storage, the Authority may require Monthly Reporting by the permittee [EAA Rules, Sec. 711.270], Operations Report by the permittee [EAA Rules, Sec. 711.271] and may consider the application of a safety factor to account for uncertainties, and shall review the permit every five years or on a more frequent schedule established by the Authority [EAA Rules, Sec. 711.272], which may result in an increase, decrease or no change in the calculation of water remaining in Aquifer storage that is subject to withdrawal over time.

4. Charge 4 - Maximize available federal funding for the authority or any other entity to own, finance, design, construct, operate, or maintain recharge facilities.

The Subcommittee's Response.

The Subcommittee has identified federal agencies and programs within federal agencies which are potential sources of federal funding. The Subcommittee recognizes that potential sources are subject to change as programs are modified and additional programs are made available. Budget considerations will affect whether funds are available and the amounts of available funds.

The federal agencies currently identified are listed below in this Section 4.

4.1. United States Department of Agriculture (USDA)

a) all USDA programs require cost share between landowner/USDA; and

b) additional assistance/partners to help fund landowner share of costs could increase participation in these programs.

4.1.1. The Conservation Reserve Program (CRP) provides technical and financial assistance to eligible farmers and ranchers to address soil, water, and related natural resource concerns on their lands in an environmentally beneficial and cost-effective manner. The program provides assistance to farmers and ranchers in complying with Federal, State, and tribal environmental laws, and encourages environmental enhancement. The program is funded through the Commodity Credit Corporation (CCC). CRP is administered by the Farm Service Agency, with NRCS providing technical land eligibility determinations, conservation planning and practice implementation. The Conservation Reserve Program reduces soil erosion, protects the Nation's ability to produce food and fiber, reduces sedimentation in streams and lakes, improves water quality, establishes wildlife habitat, and enhances forest and wetland resources. It encourages farmers to convert highly erodible cropland or other environmentally sensitive acreage to vegetative cover, such as tame or native grasses, wildlife plantings, trees, filter strips, or riparian buffers. Farmers receive an annual rental payment for the term of the multi-year contract. Cost sharing is provided to establish the vegetative cover practices.

4.1.2. The Environmental Quality Incentives Program (EQIP) is a voluntary conservation program that promotes agricultural production and environmental quality as compatible National goals. Through EQIP, farmers and ranchers may receive financial and technical help to install or implement structural and management conservation practices on eligible agricultural land. EQIP was reauthorized in the Food, Energy and Conservation Act of 2008 (Farm Bill). The Natural Resources Conservation Service (NRCS) administers EQIP. Funding for EQIP comes from the Commodity Credit Corporation.

4.1.3. The Agricultural Water Enhancement Program (AWEP) is a voluntary conservation initiative that provides financial and technical assistance to farmers and ranchers to improve water conditions on their agricultural land.

4.1.4. The Conservation Innovation Grant program (CIG) is a voluntary program intended to stimulate the development and adoption of innovative conservation approaches and technologies while leveraging Federal investment in environmental enhancement and protection, in conjunction with agricultural production. Under CIG, Environmental Quality Incentives Program (EQIP) funds are used to award competitive grants to non-Federal governmental or non-governmental organizations, Tribes, or individuals. CIG enables NRCS to work

with other public and private entities to accelerate technology transfer and adoption of promising technologies and approaches to address some of the Nation's most pressing natural resource concerns. CIG will benefit agricultural producers by providing more options for environmental enhancement and compliance with Federal, State, and local regulations. The Natural Resources Conservation Service (NRCS) administers CIG. The CIG requires a 50-50 match between the agency and the applicant. The CIG has two funding components - national and state.

4.1.5. The Cooperative Conservation Partnership Initiative (CCPI) is a voluntary conservation initiative that enables the use of certain conservation programs with resources of eligible partners to provide financial and technical assistance to owners and operators of agricultural and nonindustrial private forest lands.

4.1.6. The Wildlife Habitat Incentives Program (WHIP) provides financial incentives to develop habitat for fish and wildlife on private lands. Participants agree to implement a wildlife habitat development plan and NRCS agrees to provide cost-share assistance for the initial implementation of wildlife habitat development practices. NRCS and program participants enter into a cost-share agreement for wildlife habitat development. Cost-sharing is available for 50 percent of the average cost of practice establishment. The cost-share agreement typically is for a minimum of 5 years from the date that the contract is signed.

4.1.7. The Wetlands Reserve Program (WRP) is a voluntary program offering landowners the opportunity to protect, restore, and enhance wetlands on their property. The USDA Natural Resources Conservation Service (NRCS) provides technical and financial support to help landowners with their wetland restoration efforts.

4.1.8. The Grassland Reserve Program (GRP) is a voluntary program that helps landowners and operators restore and protect grassland, including rangeland and pastureland, and certain other lands, while maintaining the areas as grazing lands. Emphasis for enrollment into the program is on support for grazing operations, plant and animal biodiversity, and grasslands under the greatest threat of conversion.

4.1.9. The Farm and Ranch Lands Protection Program (FRPP), formerly the Farmland Protection Program, is a voluntary conservation program that helps farmers and ranchers keep their land in agriculture. This program provides funds to help purchase development rights to keep productive farmland in agricultural uses. Working through existing programs, the USDA Natural Resources Conservation Service (NRCS) joins state, tribal, or local governments and non-governmental organizations to acquire conservation easements. The NRCS provides up to 50 percent of the appraised fair market easement value.

4.1.10 The Conservation Stewardship Program (CSP) is a voluntary conservation program that encourages producers to address resource concerns in a comprehensive manner by undertaking additional conservation activities and improving, maintaining, and managing existing conservation activities. CSP is available on tribal and private agricultural lands and non-industrial private forest land in all 50 States and the Caribbean and Pacific Islands Areas. The program provides equitable access to all producers, regardless of operation size, crops produced, or geographic location. The resource concerns that have overarching priority in Texas are water quantity**,** soil erosion and plant health and condition**.**

4.1.11 Texas Watershed Program - In the mid-1930s, Congress began looking at ways to complement the downstream flood control program of the Corps of Engineers. It passed flood control acts in 1936, 1944, and 1954 and assigned responsibility of the Watershed Protection and Flood Prevention Program to the USDA Soil Conservation Service, now the Natural Resources Conservation Service (NRCS).

Since that time, NRCS has assisted watershed sponsors in construction of nearly 2,000 floodwater retarding structures in 145 watershed projects across Texas. In addition, NRCS has assisted watershed sponsors in installation of land treatment practices, channel improvements, and dikes for watershed protection.

(a) Conservation Technical Assistance – planning and implementation assistance provided to landowners by NRCS staff

4.1.12 Conservation Technical Assistance Program – Conservation technical assistance is the help NRCS and its partners provide to land users to address opportunities, concerns, and problems related to the use of natural resources and to help land users make sound natural resource management decisions on private, tribal, and other non-federal lands.

The technical assistance can help land users:

(a) maintain and improve private lands and their management;

(b) implement better land management technologies;

(c) protect and improve water quality and quantity;

(d) maintain and improve wildlife and fish habitat;

(e) enhance recreational opportunities on their land;

(f) maintain and improve the aesthetic character of private land;

(g) explore opportunities to diversify agricultural operations; and

(h) develop and apply sustainable agricultural systems.

The assistance may be in the form of resource assessment, practice design, resource monitoring, or follow-up of installed practices.

Although the CTA program does not include financial or cost-share assistance, clients may develop conservation plans, which may serve as a springboard for those interested in participating in USDA financial assistance programs. CTA planning can also serve as a door to financial assistance and easement conservation programs provided by other Federal, State, and local programs.

4.1.13 Conservation of Private Grazinglands Program - The NRCS Conservation of Private Grazing Land (CPGL) initiative will ensure that technical, educational, and related assistance is provided to those who own private grazing lands. It is not a cost share program. This technical assistance will offer opportunities for: better grazing land management; protecting soil from erosive wind and water; using more energy-efficient ways to produce food and fiber; conserving water; providing habitat for wildlife; sustaining forage and grazing plants; using plants to sequester greenhouse gases and increase soil organic matter; and using grazing lands as a source of biomass energy and raw materials for industrial products.

Conservation of Private Grazing Land Program was authorized by the conservation provisions of the Federal Agricultural Improvement and Reform Act (1996 Farm Bill). The intent of this provision is to provide accelerated technical assistance to owners and managers of grazing land. The purpose is to provide a coordinated technical program to conserve and enhance grazing land resources and provide related benefits to all citizens of the United States. Currently, funds have not been appropriated for this program.

4.2 United States Fish and Wildlife Service (USFWS)

4.2.1. Partners for Fish and Wildlife

(a) Partners for Fish and Wildlife is a voluntary program that provides technical and financial assistance to private landowners to restore or enhance fish and wildlife habitats for Federal trust species (e.g. migratory birds, threatened, endangered, and candidates species and other declining species).

(b) A fact sheet about the Partners for Fish and Wildlife program is included in Appendix 6.

4.2.2 Endangered Species Habitat (Section 6)

(a) Section 6 of the Endangered Species Act, also called the "Cooperative Endangered Species Conservation Fund," establishes a grant program to the

States that provides funds for voluntary conservation projects for candidate, proposed and listed species.

(b) Section 6 grants are available in two categories: Traditional and Nontraditional grants.

Traditional grants are provided for conservation actions for candidate, proposed and listed species. Funds for this program are provided to the states based on a formula and grants are selected by Texas Parks and Wildlife Department (TPWD) in cooperation with the Service. It's called "Traditional" because this part of the program has been around since the 1980s.

Nontraditional (or "Competitive") grants fund only one of three specific activities: Recovery Land Acquisition, Habitat Conservation Planning Assistance, and Habitat Conservation Plan (HCP) Land Acquisition. Proposed projects are submitted by TPWD for competition and awarded by the Service. The grants are called "Nontraditional" because this part of the program began around 2001.

(c) A fact sheet about the Section 6 grant program is included in Appendix 6.

4.2.3. Federal Aid in Wildlife Restoration

(a) Since 1937, the Federal Aid in Wildlife Restoration Program has provided funds to state fish and wildlife agencies for the restoration, conservation, management, and enhancement of wild birds and mammals, and the provision for public use of and benefits from these natural resources. Federal Aid is a major funding source for Texas Parks and Wildlife Department, including habitat restoration and management and assistance to private landowners.

(b) Funds are also used for the education of hunters and archers in the skills, knowledge, and attitudes necessary to be responsible, competent sportsmen and women.

(c) A federal excise tax is collected from manufacturers of firearms, ammunition, and archery equipment. This tax is passed on to the hunter and shooter, who benefit from the recreational and educational opportunities created with the funds; users pay, and users benefit.

4.3. Environmental Protection Agency (EPA)

(a) 319(h) funding;

(b) Project must be water quality based.

4.4. United States Army Corps of Engineers (USACE)

(a) The USACE can participate in projects in conjunction with local sponsoring governments. Projects are initiated and funded through one of three mechanisms: 1) traditional feasibility study, design and construction process, 2) Continuing Authorities Program, or 3) non-traditional process.

(b) Regardless of which mechanism is employed to initiate a project, the project must progress through four main phases:

(i) Reconnaissance Phase
(ii) Feasibility Phase
(iii) Preconstruction, Engineering and Design Phase
(iv) Construction Phase

(c) Traditional Feasibility Study, Design and Construction Process

(i) Reconnaissance Phase does not need project specific authorization and is 100 percent funded by the USACE up to $100,000.
(ii) A project has to be authorized by an act of Congress and funds appropriated by Congress in order for USACE to participate in a feasibility study. The costs for the feasibility study are shared equally between the USACE and local sponsor.
(iii) The costs for the preconstruction, engineering, design phase and construction phase are typically shared 65 percent federal and 35 percent local sponsor; however, with certain projects the federal cost share can be as high as 75 percent. These phases require a separate appropriation of funds by Congress in order to proceed.
(iv) Office of Management and Budget (OMB) applies its decision criteria, which can be different from the USACE criteria, to projects that have a federal interest determination and are vying for construction funding. Projects need OMB support in order to get into the President's budget. Otherwise congressional delegation has to insert funding for the project in budget committee negotiations.

(d) Continuing Authorities Program

(i) Projects follow the same phases as in the traditional process
(ii) The Continuing Authorities Program is pre-authorized and appropriated so projects do not need individual authorizations and appropriations directly from Congress
(iii) Total federal participation in projects initiated through this program is limited to $5 million.
(iv) New project starts are subject to the availability of federal funds.

(e) Nontraditional Project Processes include:

(i) Local sponsor conducts reconnaissance and feasibility studies in conformance with USACE requirements and standards.

(ii) Local sponsor works with its congressional delegation to write authorization and appropriation language in a bill to direct the USACE to build project plan developed by the local sponsor.

(iii) Must conform to the National Environmental Policy Act (NEPA).

(iv) Projects are subject to "earmark" scrutiny and prohibitions.

A Nontraditional Project must be consistent with one of the USACE authorized purposes. The two USACE authorized purposes that are most applicable to recharge are:

(i) Flood control; and

(ii) Ecosystem restoration (recharge supports spring flow that supports endangered species or bay and estuary inflow)

(f) As of November 2009 there are five currently authorized USACE projects that have the potential to enhance recharge to the Edwards Aquifer:

(i) *Nueces Watershed study:* Project includes multi-purpose flood risk management; ecosystem restoration; recharge; and recreation;

(ii) Guadalupe-San Antonio Basin Study;

(iii) *Cibolo Creek Feasibility Project*: Project includes multi-purpose flood risk management; ecosystem restoration; recharge; recreation;

(iv) *Leon Creek Feasibility Study:* Project includes primarily flood risk management; ecosystem restoration can be added and if there is detention, the project has recharge potential; and

(v) *Lower San Antonio Feasibility Study:* Project will not affect Edwards recharge zone

(g) Annual appropriations, or lack thereof, typically restrict or lengthen the amount of time needed to complete any study.

(h) Requires executing a cost share agreement between local sponsors and USACE.

(i) Studies can be modified or terminated at any time by local sponsor.

(j) USACE can only fund projects that meet the requirements of a federal interest (favorable cost/benefit ratio, for a federal authorized purpose).

(k) The USACE cannot fund mitigation projects but can fund recovery projects

4.5 Other Federal Agencies –to explore opportunities of additional federal funding.

4.5.1. United States Geological Survey (USGS)

4.5.2. Department of Defense (DOD)

4.5.3. United States Bureau of Reclamation (USBR)

4.6. Other state and local funding sources – to be used as match for federal funds or to be used independently of federal funds

4.7 Landowner Associations

4.7.1 Wildlife **Management** Associations

(a) Wildlife management associations are landowner-driven organizations formed by groups of neighboring landowners for the purpose of improving wildlife habitat and associated wildlife populations and to achieve shared wildlife management goals.

(b) These associations are often 501(c) 3 not for profit organizations with the ability to receive and administer funding for habitat and watershed improvement practices on lands operated by the members.

4.7.2 Prescribed Burn Associations

(a) Prescribed burn associations facilitate prescribed burns among members by providing equipment, training and manpower. They don't receive any funding other than some grants to purchase equipment.

(b) The presence of a local prescribed burn association would facilitate prescribed burning as a land stewardship tool and might provide a opportunity for equipment to be obtained through grants.

4.8 Conservation Easements and Land Trusts

4.9 Local tax revenue funding programs

(a) City of San Antonio Propositions 1 and 3; and

(b) City of Austin Proposition 2.

5. Charge 5 - Evaluate the financing of recharge facilities, including the use of management fees or special fees to be used for purchasing or operating the facilities

The Subcommittee's Response:

This Report lists below the options for financing recharge facilities and describes the main potential sources of funding. Funding sources are subject to change from time to time, and thus the list is not all-inclusive . Further, each agency's budget is subject to appropriation. The Subcommittee will provide more detail and evaluation of the available alternatives for financing of recharge facilities upon receiving guidance from the Steering Committee.

5.1. Evaluation of other financing options:

(a) General Obligation bonds issued by cities, counties;

(b) General tax revenues issued by cities, counties;

(c) Revenue bonds/contracts issued by cities, utilities, river authorities, water districts, private entities, port authorities;

(d) Voluntary contributions by private entities, individuals, NGOs; and

(e) Dedicated revenues from special marketing items (*E.g.*, License plate fees, use fees, bottled water).

5.2. Evaluation of the use of management fees or special fees to be used for purchasing or operating facilities:

(a) EAA, TCEQ (surface water permit holders): A Special fee for recharge programs would be applied all permit holders so all aquifer beneficiaries participate in funding.

(b) Impact/development fees assessed by a regulatory authority

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APPENDIX 1

MEMBERSHIP

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Roster

Voting Members

Environmental Groups
- George Rice, AGUA
- Tyson Broad, Sierra Club

Land Stewardship Groups
- Kirby Brown, Texas Wildlife Association
- Mike McMurry, Texas Department of Agriculture
- Gene Richardson, Texas Farm Bureau
- Linda Campbell, Texas Parks and Wildlife

Regional/River Authorities
- Steve Raabe, San Antonio River Authority
- Con Mims, Nueces River Authority

Water Purveyors
- Humberto Ramos, Bexar Met
- Jerry James, City of Victoria
- Darren Thompson, replaced by Patrick Shriver, SAWS
- Gus Gonzales, City of Corpus Christi

General Stakeholders
- Dan Laroe, Guadalupe Basin Coalition
- Kirk Patterson, Regional Clean Air and Water

Contributing Zone
- Ronald Fieseler, GMA 9

Recharge Zone
- Vic Hilderbran, Uvalde County Underground Water Conservation District
- Robert Rothe, Medina County Groundwater Conservation District

Business Interests
- Mary Kelly, Greater San Antonio Chamber of Commerce

Non-Voting Members
- Cary Betz, Texas Commission on Environmental Quality
- George Ozuna, US Geological Survey
- Mark Mosely, Natural Resources Conservation Service
- Will Amy, replaced by Kevin Connally, US Fish and Wildlife Service
- Marcia Hackett, US Army Corps of Engineers
- Roberto Anaya, Texas Water Development Board

APPENDIX 2

Meeting Agenda and Reports to Steering Committee

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Subcommittee Report
Of
August 14, 2008 meeting

The subcommittee elected Steve Raabe, San Antonio River Authority, chair.

Reviewed the five (n) charges for the subcommittee.

Discussed completing the subcommittee's work by January 2010 with a report to the Science Subcommittee in July 2009.

Recommended adding the following agencies as non-voting members of the subcommittee:

Texas Commission on Environmental Quality
Texas Water Development Board
Edwards Aquifer Authority
United States Geological Survey
United States Army Corps of Engineers
United States Fish and Wildlife Service
Natural Resources Conservation Service

The subcommittee agreed to meet at 8:30 am the morning of the monthly Steering Committee meetings.

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Agenda

September 25, 2008
9:00 am
Edwards Aquifer Authority Boardroom

1. Call to Order
2. Election of Vice-Chair
3. Review and Prioritization of Subcommittee Charges
4. Schedule/Timelines
5. Alternates/Committee Rules
6. Subcommittee Webpage Content
7. Bibliography on Recharge/Land Stewardship
8. Status of Research
9. Subcommittee Reporting
10. Agenda Items for Next Meeting

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Subcommittee Report
Of
September 25, 2008 meeting
Held at the Edwards Aquifer Authority

The meeting was called to order at 9:15 am, however a quorum was not present.

Discussion was held on the organization and content of the subcommittee webpage and regarding a bibliography on land stewardship prepared by Tyson Broad.

At the completion of those discussions a quorum was achieved.

The subcommittee elected Kirk Patterson, Regional Clean Air and Water, Vice-chair.

Steve Raabe laid out a proposed process by which the subcommittee would review, prioritize and address the five subcommittee charges including a schedule. After some adjustments to the schedule, Humberto Ramos moved and Cary Dupuy seconded to adopt the process as presented and the schedule as modified. The motion passed unanimously. The adopted process and schedule are attached.

The subcommittee discussed the need for alternates and modifications to the quorum requirements. There are 18 voting members on the subcommittee of which 16 members (85%) constitute a quorum for meetings at which the subcommittee will make a decision on a recommendation to the Steering Committee. The subcommittee recommended changing the quorum requirement to 50% for meetings where no recommendation decisions are made. The subcommittee noted that the appointments to the subcommittee were on an entity or organization basis. Con Mims moved and Robert Rothe seconded to have subcommittee members designate an alternate if they will be absent provided they notify the chair of their designation of an alternate prior to the meeting. The motion passed unanimously.

The meeting adjourned at 10:30 am.

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Process

Review Subcommittee Charges

- The five charges direct the subcommittee to make recommendations on who should do recharge projects, how to calculate and allocate enhanced recharge and how should recharge projects be funded.
- The charges do not direct the subcommittee to recommend specific recharge projects for implementation.
- Recommend that selection of specific recharge projects for implementation be done by the Steering Committee starting January 2010 as part of "Task 5 – Develop Water Management Plan" of EARIP implementation schedule prepared by Dr. Gulley.

Prioritize Subcommittee Charges

- Charge #3 directs the subcommittee to make a recommendation to the Steering Committee on how to calculate the amount of enhanced recharge due to recharge projects and how that water could be made available for support of springflow and for Edwards permit holders.
- Charges #1, #2, # 4 and #5 deal with which entity should do recharge projects and how could they be funded.
- Charges #1, #2, # 4 and #5 are not particularly relevant unless recharge can be calculated and allocated which is the focus of Charge #3.
- Work on Charge #3 first followed by Charges #1, #2, # 4 and #5.

Subcommittee Schedule

- Have presentations on the various recharge projects and land stewardship to get subcommittee familiar with the various ways recharge can be enhanced. (October 2008 through January 2009)
- Next work on Charge #3. Complete this work by July 1, 2009 so subcommittee recommendation is available to Science Subcommittee to consider in their recommendation. (February 2009 through June 2009)
- Next work on Charges #1, #2, # 4 and #5 and have subcommittee recommendation to Steering Committee by January 2010 (July 2009 through December 2009)

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Schedule/Timeline

September 25, 2008	-	Agree on Charges, Activities and Schedule
October 16, 2008	-	Presentation on Previous Recharge Project Studies
November 13, 2008	-	Presentation on Barton Springs Recharge project
Nov./early Dec.	-	Workshop on Cibolo/Nueces Corps of Engineers Studies and Land Stewardship
December 11, 2008	-	Topic to be determined
January 8, 2009	-	Presentation on EAA Recharge Rules
January 27 or 28, 2009	-	Presentation on Recharge and Recirculation
February 2009 – June 2009	-	Work on Charge # 3. Meet 2 times per month if needed.
July 2009 – December 2009	-	Work on Charges #1,2,4,5
January 2010	-	Report to Steering Committee

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Agenda

October 16, 2008
8:30 am
Dunbar Recreation Center
San Marcos, Texas

1. Call to Order

2. Presentation on Previous Recharge Studies for the Edwards Underground Water District, Trans-Texas Water Program and Region L Planning Group – Sam Vaugh, HDR Engineering, Inc.

3. Subcommittee Reporting

4. Agenda Items for Next Meeting

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Subcommittee Report
Of
October 16, 2008 meeting
Held at the Dunbar Recreation Center, San Marcos, Texas

The meeting was called to order at 8:30 am, however a quorum was not present at the beginning of the meeting but was achieved during the presentation.

Sam Vaugh/HDR Engineering made a presentation on previous recharge studies conducted by the Edwards Underground Water District, Trans-Texas Water program, Region L and the US Geological Survey.

Chair Steve Raabe reminded the subcommittee that the next meeting is to be November 13, 2008 at Trinity University. There will be a presentation on the Antioch Cave Recharge project by Ron Fieseler/Blanco-Perdenales Groundwater District and Brian Smith/Barton Springs Edwards Groundwater District.

The meeting adjourned at 9:45 am.

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Agenda

November 13, 2008
8:30 am
Trinity University
San Antonio, Texas

1. Call to Order

2. History and Operation of the Antioch Cave Recharge Facility on Onion Creek, Hays County, Texas – Ron Fieseler, Blanco-Perdernales Groundwater District and Brian Smith, Barton Springs Edwards Aquifer Conservation District

3. Report on Workshop

4. Discussion regarding comments to the Program Operating Rules Work Group

5. Subcommittee Reporting

6. Agenda Items for Next Meeting

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Subcommittee Report
Of
November 13, 2008 meeting
Held at the Fiesta Room, Trinity University, San Antonio, Texas

The meeting was called to order at 8:30 am, however a quorum was not present.

Ron Fieseler/Blanco-Perdenales Groundwater District and Brian Smith/Barton Springs Edwards Groundwater District made a presentation on the Antioch Cave Recharge project.

Chair Steve Raabe reminded the subcommittee that the Recharge Facility Feasibility Subcommittee Workshop will be held on December 4 from 9:00 to 3:00 at the EAA boardroom.

Discussed comments regarding the Program Operating Rules.

The meeting adjourned at 9:45 am.

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Agenda

December 4, 2008
9:00 am to 3:00 pm
Edwards Aquifer Authority Boardroom
San Antonio, Texas

1. Call to Order

2. Corps of Engineers Nueces and Cibolo Studies – Marcia Hackett, USACOE

3. Rangeland Restoration to Enhance Recharge to the Edwards Aquifer – Summary of Research/Region L Study – Brad Wilcox/Todd Snelgrove, TAMU

4. Recovery Credit System – Concept and Case Study - Fort Hood – Susan Baggett, NRCS

5. Rangeland Restoration for Enhancing Recharge to the Edwards Aquifer – Implementation Scenario – Neil Wilkins, TAMU IRNR

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Subcommittee Report
Of
December 4 2008 meeting
Held at the Edwards Aquifer Authority Boardroom, San Antonio, Texas

The meeting was called to order at 9:00 am, however a quorum was not present.

Marcia Hackett/US Army Corps of Engineers made a presentation on the Nueces Feasibility Study and Rob Newman/US Army Corps of Engineers presented on the Cibolo Creek Feasibility Study. Both of these studies are evaluating enhancing recharge to the Edwards Aquifer for ecosystem restoration benefits.

Dr. Brad Wilcox/Ecosystem Science and Management Department, Texas A&M University presented on the state of research regarding water yield from rangeland restoration using brush management.

Todd Snelgrove/Institute for Renewable Natural Resources, Texas A&M University presented on geospatial techniques available to identify and evaluate candidate areas suitable for rangeland restoration using brush management to enhance recharge.

Susan Baggett/USDA Natural Resources Conservation Service presented on recovery credits as a method to value endangered species habitat in a recovery program.

Dr. Neal Wilkins/ Institute for Renewable Natural Resources, Texas A&M University presented a conceptual implementation scenario using recovery credits for enhancing recharge to the Edwards Aquifer.

Chair Steve Raabe announced that the Recharge Facility Feasibility Subcommittee meeting on December 11, 2008 was cancelled since the EARIP Steering committee meeting was cancelled. The next meeting of the Recharge Facility Feasibility Subcommittee will be held on January 8, 2009 from 8:30 to 10:00.

Steve Raabe also stated that the Recharge and Recirculation presentation to the Recharge Facility Feasibility Subcommittee will have to be moved to early February. It was agreed to schedule that presentation for February 11, 2009 pending confirmation from the Edwards Aquifer Authority.

The meeting adjourned at 2:50 pm.

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Agenda

January 8, 2009
8:30 am
San Antonio Water System
San Antonio, Texas

1. Call to Order

2. Presentation on Edwards Aquifer Authority Recharge Rules

3. Subcommittee Reporting

4. Schedule and Agenda Items for Next Meeting

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Subcommittee Report
Of
January 8, 2009 meeting
Held at the San Antonio Water System, San Antonio, Texas

The meeting was called to order at 8:35 am, however a quorum was not present. A quorum was achieved during the next agenda item.

Darcy Frownfelter with Kemp Smith, LLP, Edwards Aquifer Authority legal counsel, made a presentation on the Edwards Aquifer authority recharge rules.

Chair Steve Raabe reminded the subcommittee that the next meeting of the subcommittee will be held on February 11, 2009 to hear a presentation on the Edwards Aquifer Authority's study regarding recharge and recirculation. The location and time will be announced when they are determined.

The meeting adjourned at 9:45 am.

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Subcommittee Report
Of
February 11, 2009 meeting
Held at the Great Hall in the Chapman Center at Trinity University in San Antonio, Texas

The meeting was called to order at 1:00 pm, however a quorum was not present.

Phyllis Stanin, Todd Engineers, made a presentation of the results of the Phase III/IV Report on Recharge and Recirculation. The study was funded by the Edwards Aquifer Authority and the San Antonio Water System. Also present were the remaining members of the consultant team, Dr. Bob Brandes with TRC/Brandes, and Bill Norris and Mike Irlbeck with NRS Engineering.

Chair Steve Raabe stated that this meeting concluded the informational phase of the Subcommittee's work. The agenda for the next meeting will include a discussion of the process to develop the committee's recommendations and consideration of changing the meeting day and times for the subcommittee.

Chairman Raabe reminded the subcommittee that the next meeting of the Subcommittee will be held on March 12, 2009 at 8:30 am at GBRA.

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Agenda

March 12, 2009
8:30 am
Guadalupe-Blanco River Authority
River Annex
Seguin, Texas

1. Call to Order

2. Discuss Process for Development of Subcommittee Work Products
    a. Short Term Objectives
    b. Long Term Role

3. Consider Changing Meeting Times and Location

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Subcommittee Report
Of
March 12, 2009 meeting
Held at the Guadalupe-Blanco River Authority River Annex in Seguin, Texas

The meeting was called to order at 8:30 am, however a quorum was not present.

The subcommittee discussed the process for development of the subcommittee's work products. It was noted that the subcommittee was not given a statutory deadline to complete its work on the five (n) charges. A two step process was discussed to get more direction from the Steering Committee and to allow the EARIP process to mature. The process is listed below:

- Short Term Objectives to be completed by December 31, 2009
    - Layout key concepts and information relating to Charges 1-5
    - Work on information that is most useful to the EARIP Steering committee at this point in the process
    - Prepare a "Fact Book" that includes the information developed above
- Long Term Role for the Subcommittee after December 31, 2009
    - Activity of subcommittee will have better focus as the Steering Committee and stakeholders layout objectives for the Edwards Aquifer and species
    - Subcommittee will flesh out Charges 1-5 as the Steering Committee discussions/negotiations progress

The subcommittee changed its regular meeting time to the fourth Monday of the month at 1:00 pm. The next meeting will be held on March 23, 2009 at 1:00 pm at the San Antonio River Authority boardroom.

Chair Steve Raabe asked for volunteers for the Steering Committee to consider for appointment of a working group to visit with the US Army Corps of Engineers regarding the Corps role in implementation of strategies developed by the EARIP. Steve Raabe, Kirk Patterson, Patrick Schriver, Dan Laroe and Rick Illgner volunteered.

The meeting was adjourned at 9:35 am.

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Agenda

March 23, 2009
1:00 – 4:00 pm
San Antonio River Authority
Boardroom
San Antonio, Texas

1. Call to Order

2. Review Process for Development of Subcommittee Work Products
    a. Short Term Objectives
    b. Long Term Role

3. General Discussion Regarding Charges 1-5

4. Detailed Discussion Regarding Charge 3
    a. Methods of recharge enhancement to specifically accommodate
    b. Identify types of benefit of recharge enhancement
    c. Identify required parameters for each method of recharge enhancement

5. Set Location and Agenda for next meeting

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Subcommittee Report
Of
March 23, 2009 meeting
Held at the San Antonio River Authority River Boardroom in San Antonio, Texas

The meeting was called to order at 1:05 pm, however a quorum was not present.

The subcommittee reviewed the short term objectives and long term role of the Recharge Facility Subcommittee. The subcommittee also reviewed the (n) charges 1-5.

There was an extended discussion on the draft outline and contents of the Subcommittee Report (Fact Book). The subcommittee identified key points in each charge that should be addressed.

The agenda for the April 27th meeting would address Charges 1 and 2. Charge 3 would be discussed if time allows.

The next meeting will be held on April 27, 2009 at 1:00 pm at the San Antonio River Authority boardroom. The May 25th meeting was moved to June 1st because of Memorial Day falling on May 25th.

The meeting was adjourned at 4:00 pm.

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Agenda

April 27, 2009
1:00 – 4:00 pm
San Antonio River Authority
Boardroom
San Antonio, Texas

1. Call to Order

2. Discussion Regarding Charges 1-2

3. Discussion Regarding Charge 3

4. Set Location and Agenda for next meeting
    a. June 1, 2009, 1:00 pm
    b. Location

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Subcommittee Report
Of
April 27, 2009 meeting
Held at the San Antonio River Authority River Boardroom in San Antonio, Texas

The meeting was called to order at 1:00 pm, however a quorum was not present.

The subcommittee worked on developing the contents of the Subcommittee Report (Fact Book). The subcommittee addressed Charges 1 and 2. Charge 3 was not discussed and will be the topic of the June 1, 2009 meeting.

The next meeting will be held on April 27, 2009 at 1:00 pm at the San Antonio River Authority boardroom. The May 25th meeting was moved to June 1st because of Memorial Day falling on May 25th.

The meeting was adjourned at 4:00 pm.

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Agenda

June 1, 2009
1:00 – 4:00 pm
San Antonio River Authority
Boardroom
San Antonio, Texas

1. Call to Order

2. Discussion Regarding Charge 3

3. Set Agenda for next meeting
    a. June 22, 2009, 1:00 pm

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Subcommittee Report
Of
June 1, 2009 meeting
Held at the San Antonio River Authority River Boardroom in San Antonio, Texas

The meeting was called to order at 1:05 pm. A quorum was not present at the start of the meeting but a quorum was established during Agenda Item No 2.

George Rice explained the draft document he developed regarding availability of recharged water which included a simplified water balance. Future refinements would include revising the water balance as a time series and adding an example of how the water balance equation could be applied.

The subcommittee had an extended discussion regarding how to calculate enhanced recharge for each type of recharge technique and how to allocate enhanced recharge for each purpose or use of recharge.

Charge 3 was not discussed in any great detail and will be the topic of the June 22, 2009 meeting.

The next meeting will be held on June 22, 2009 at 1:00 pm at the San Antonio River Authority boardroom.

The meeting was adjourned at 3:20 pm.

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Agenda

June 22, 2009
1:00 – 4:00 pm
San Antonio River Authority
Boardroom
San Antonio, Texas

1. Call to Order

2. Discussion Regarding Charge 3

3. Set Agenda for next meeting
    a. July 27, 2009, 1:00 pm

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Subcommittee Report
Of
June 22, 2009 meeting
Held at the San Antonio River Authority River Boardroom in San Antonio, Texas

The meeting was called to order at 1:05 pm. A quorum was not present at the meeting.

The subcommittee identified potential parameters and methods to calculate enhanced recharge for direct injection, recharge structures, land stewardship and recharge and recirculation.

Discussed the schedule and topics for the remaining subcommittee meetings in 2009 as follows:

July 27 – Complete Charge 3, discuss water balance
August 24 – Work on Charges 4 and 5
September – November – complete subcommittee report

The next meeting will be held on July 27, 2009 at 1:00 pm at the San Antonio River Authority boardroom.

The meeting was adjourned at 3:40 pm.

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Agenda

July 27, 2009
1:00 – 4:00 pm
San Antonio River Authority
Boardroom
San Antonio, Texas

1. Call to Order

2. Discussion Regarding Charge 3
    a. Review purposes of recharge
    b. Develop remaining Charge 3 items

3. Review Water Balance

4. Set Agenda for next meeting
    a. August 24, 2009, 1:00 pm

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Subcommittee Report
Of
July 27, 2009 meeting
Held at the San Antonio River Authority River Boardroom in San Antonio, Texas

The meeting was called to order at 1:05 pm. A 51 percent quorum was present. An 85 percent quorum was not present at the meeting.

Robert Gulley asked Calvin Finch/SAWS to brief the subcommittee on a potential study being considered by the Additional Studies Workgroup. The potential study would evaluate recharge to 1) support springflow, 2) reduce the frequency of Stages 3 & 4 Critical Period pumping reductions, 3) prepare preliminary cost-benefit analyses and 4) consider all potential sources of recharge water, components and methods used to increase recharge. The preliminary budget is approximately $150,000. The scope of the study will be developed by the Additional Studies Workgroup for potential action by the EARIP Steering Committee at the September 10th meeting. The Recharge Facilitiy Feasibiltiy Subcommittee members offered comments on the study and were requested to submit any remaining comments to Dr. Finch or Dr. Gulley.

The subcommittee identified potential parameters and methods to allocate enhanced recharge for 1) increased spring flow for benefit of endangered species, 2) increased water available for permits, 3) increased reliability for permits and 4) increased aquifer water levels.

The subcommittee also reviewed the water balance prepared by George Rice.

The next meeting will be held on August 24, 2009 at 1:00 pm at the San Antonio River Authority boardroom.

The meeting was adjourned at 3:50 pm.

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Agenda

August 24, 2009
1:00 – 4:00 pm
San Antonio River Authority
Boardroom
San Antonio, Texas

1. Call to Order

2. Discussion Regarding Charge 4

3. Discussion Regarding Charge 5

4. Review Charge 3

5. Set Agenda for next meeting
    a. September 28, 2009, 1:00 pm

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Subcommittee Report
Of
August 24, 2009 meeting
Held at the San Antonio River Authority River Boardroom in San Antonio, Texas

The meeting was called to order at 1:05 pm. A 51 percent quorum was present. An 85 percent quorum was not present at the meeting.

The subcommittee discussed Charge 4 – How to maximize federal funding for recharge facilities. Mark Moseley – USDA NRCS, Marcia Hackett – USACOE and Linda Campbell – TPWD provided information on relevant federal funding opportunities.

The subcommittee discussed Charge 5 – Evaluate the financing of recharge facilities including the use of management or special fees to be used for the purchasing or operating recharge facilities.

Chair Steve Raabe asked for volunteers to start writing text for the subcommittee report. The following volunteered: Steve Raabe, George Rice, Patrick Schriver, Kirk Patterson, Linda Campbell and Kirby Brown.

The next meeting will be held on September 28, 2009 at 1:00 pm at the San Antonio River Authority boardroom.

The meeting was adjourned at 4:00 pm.

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Agenda

September 28, 2009
1:00 – 4:00 pm
San Antonio River Authority
Boardroom
San Antonio, Texas

1. Call to Order

2. Review Draft Report

3. Set Agenda for next meeting
    a. October 26, 2009, 1:00 pm

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Subcommittee Report
Of
September 28, 2009 meeting
Held at the San Antonio River Authority River Boardroom in San Antonio, Texas

The meeting was called to order at 1:05 pm. A 51 percent quorum was present. An 85 percent quorum was not present at the meeting.

The subcommittee discussed the draft committee report. The subcommittee established the following schedule to complete the report:

- October 9 - RFS comments, additions and modifications to text submitted to Steve Raabe
- October 19 – revised text emailed out to RFS
- October 26, 1:00 – Review meeting report and make final drafting assignments
- November 6 – final comments submitted to Steve Raabe
- November 16 – final report draft emailed out to RFS
- November 23, 1:00 – final RFS meeting to consider adoption of report. **Need 85% quorum at this meeting (16 out of 18 members)**

The next meeting will be held on October 26, 2009 at 1:00 pm at the San Antonio River Authority boardroom.

The meeting was adjourned at 3:00 pm.

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Agenda

October 26, 2009
1:00 – 4:00 pm
San Antonio River Authority
Boardroom
San Antonio, Texas

11. Call to Order

12. Review Draft Report

13. Set Agenda for next meeting
    a. November 23, 2009, 1:00 pm

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Subcommittee Report
Of
October 26, 2009 meeting
Held at the San Antonio River Authority River Boardroom in San Antonio, Texas

The meeting was called to order at 1:05 pm. A 51 percent quorum was present. An 85 percent quorum was not present at the meeting.

The subcommittee discussed the draft committee report. Several drafting assignments were made. It was requested that the formatting of the report be improved to increase the visual and content clarity. Mary Kelly, although not at the meeting, had previously volunteered to accomplish the reteve formatting. The subcommittee established the following schedule to complete the report:s

- October 30 – final drafting work submitted to Steve Raabe
- November 2 – revised draft emailed to RFS
- November 6 – final comments submitted to Steve Raabe
- November 16 – final report draft emailed out to RFS
- November 23, 1:00 – final RFS meeting to consider adoption of report. **Need 85% quorum at this meeting (16 out of 18 members)**

The next meeting will be held on November 23, 2009 at 1:00 pm at the San Antonio River Authority boardroom.

The meeting was adjourned at 3:30 pm.

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Agenda

November 23, 2009
1:00 – 4:00 pm
San Antonio River Authority
Boardroom
San Antonio, Texas

14. Call to Order

15. Review Draft Report

16. Consideration of Adoption of Report

Edwards Aquifer Recovery Implementation Program

Recharge Facility Feasibility Subcommittee

Subcommittee Report
Of
November 23, 2009 meeting
Held at the San Antonio River Authority River Boardroom in San Antonio, Texas

The meeting was called to order at 1:10 pm. An 85 percent quorum was present at the meeting.

The Subcommittee discussed the draft committee report and made several minor revisions. The Subcommittee directed the Chair to make several final formatting changes subsequent to the meeting. Kirk Patterson moved to adopt the report substantially in the form as presented and revised at the meeting. Kirby Brown seconded the motion. The motion passed by consensus.

Dr. Robert Gulley briefed the Subcommittee on a potential study regarding the feasibility of certain recharge options to protect springflow at the Comal and San Marcos Springs. If approved by the EARIP Steering Committee, the consultant would make several presentations regarding the progress of the study to the Subcommittee to receive comments.

The meeting was adjourned at 2:45 pm.

APPENDIX 3

Land Stewardship Publications

LAND-BASED WATER CONSERVATION & WATER YIELD PRACTICES IN REGION L: MONITORING STRATEGIES

SUBMITTED TO
REGION L
SOUTH CENTRAL TEXAS REGIONAL WATER PLANNING GROUP
BY

TEXAS A&M | Institute of Renewable Natural Resources

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GRAZINGLAND MANAGEMENT SYSTEMS, INC.

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ABSTRACT

The goal of the monitoring program is to determine the amount, if any, of additional recharge and/or streamflow results from managing woody plants. An effective monitoring program would need to include multiple measurements at several different scales. Monitoring approaches include remote sensing, watershed comparisons, small catchment studies, micrometeorological towers and soil moisture measurements. For the Region L area we recommend the following: (1) incorporate and apply the large scale remote sensing technology across the Region L area; (2) in each of the target areas have a network of evaptranspiration (ET) towers in treated and untreated locations; (3) in the Carrizo-Wilcox area, complement ET tower measurements with detailed monitoring of soil moisture in treated and untreated areas: and (4) in the Guadalupe Watershed monitor spring flow in as many locations in treated and untreated areas (ET towers would be in the same areas).

LAND-BASED WATER CONSERVATION & WATER YIELD PRACTICES IN REGION L: MONITORING STRATEGIES

We have determined that there are three distinct areas within Region L that offer the most potential for increased streamflow through management of woody plants. These include (1) the Carrizo-Wilcox aquifer recharge zone with special emphasis in Dimmit and Zavala Counties (2) the Edwards aquifer recharge zone in Uvalde, Medina, Bexar, Comal and Hays Counties, and (3) the Guadalupe River watershed above Canyon Lake including Comal and Kendall counties. Each of the areas are different and have a distinct regional hydrology that must be taken into account in developing monitoring protocols that are aimed at evaluating the hydrological effect of brush control.

There are two major recharge zones within the Region L Area—the Carrizo-Wilcox and the Edwards Aquifer. As noted above the recharge zones and the aquifers that they supply are very different in character. The Edwards Aquifer is a karst system and as such is very dynamic and capable of very rapid recharge as well as discharge. It is a renewable groundwater resource meaning that recharge is roughly equivalent to discharge, including groundwater pumping. Recharge occurs largely within stream channels that traverse the recharge zone. There is likely some distributed recharge outside of the stream channels but as of yet there have been no reliable estimates of how important distributed recharge may be.

The Carrizo-Wilcox aquifer, by contrast, is not a renewable aquifer and recharge is lower than ground water pumping, with the result being that groundwater levels are declining. Recharge occurs where the Carrizo Sands and Wilcox formation are exposed at the surface. Soils are quite sandy and infiltration rates are high (little runoff). Water that moves beyond the rooting zone is available for recharge.

The third area that we have identified as having a potential for augmenting water supply through brush control is the area of the Guadalupe Watershed above Canyon Lake. The presence of Canyon Lake affords the opportunity for storing any additional water that may result from land management activities.

The goal of this report to lay out some potential strategies and techniques that may be employed for determining the extent to which, if any, water supply is augmented through brush management. Because each area is so distinct, a different suite of monitoring protocols will be required for each.

POTENTIAL MONITORING STRATEGIES

The fundamental challenge posed is that of determining how much, if any, additional water has resulted from particular land management practices. This requires determining both how much recharge (or streamflow) occurs AND whether or not it is higher than would have been in the absence of the land management practice. The variability of climate often makes this a difficult and time consuming proposition. In addition, in order

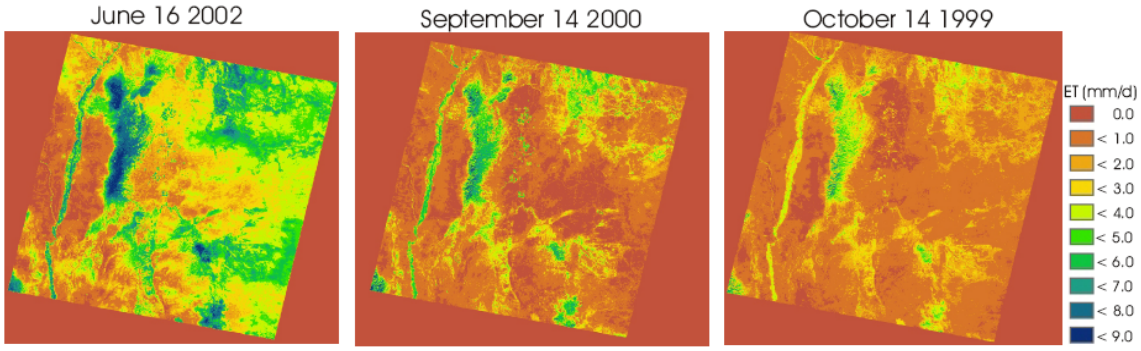
to determine if there is a difference we have to be able to make a comparison of different treatments either in time or space.

Regional scale

Remote sensing

Emerging technology now exits for estimating evapotranspiration using remote sensing imagery. This is relatively new technology but there is the potential to map evapotranspiration across very large areas within Region L and relating evapotranspiration rates to vegetation cover (the presence or absence of woody plant cover). This approach could potentially allow for a comprehensive evaluation of the potential for releasing more groundwater recharge through shrub control. Specifically, tracking evapotranspiration rates across several years could answer specific questions such as (1) can shrub clearing lead to enhanced recharge (2) where would shrub clearing be most effective (3) would the effect be the same or different for wet and dry years.

The technique has been successfully applied in New Mexico. An example from the Rio Grande Valley in New Mexico is presented below (Hong and Hendrickx, 2006). This example provides a nice illustration of the spatial and temporal resolution that is possible.



Challenge: This technique is still experimental and would require implementation and evaluation by remote sensing experts

Application Area: This technique could be effectively applied in each of the three target areas

Intermediate scale (100-10000 km^2)

Large Watershed Studies

Watershed experiments in which streamflow is continuously monitored in one or more watersheds offer the potential of assessing land management practices. These kinds of experiments have been conducted in many settings, with considerable success(Bosch and Hewlett, 1982; Stednick, 1996). However, there are significant challenges in successfully completing such experiments. A typical approach is using a pair of watersheds where one is treated and the other is not. For these kinds of experiments to

work, considerable time is required (years), both to insure that the watersheds are comparable and also having sufficient time after implementation of the treatment. Another approach is that of using a single watershed and implementing the treatment after several years of monitoring. The effectiveness of the North Concho shrub control project has recently been evaluated using this kind of approach (Wilcox et al. 2008). Similarly, Trimble et al. (1987) used long term streamflow records to demonstrate that streamflows in Tennessee have been diminished because of expanding forests.

Challenge: Time and expense. Large watershed studies require significant time and resources to be successfully implemented

Application Area: Guadalupe River above Canyon Lake.

Field Scale

At smaller scales more detailed measurements of water fluxes can be measured and several approaches are available, both of which have advantages and disadvantages

Evapotranspiration Micrometeorology Towers

The technology is now available to directly measure evapotranspiration over areas the size of a football field using instrumentation that is mounted on towers. The most common approach for doing this relies on the Eddy Covariance technique. Similarly, the Bowen Ratio approach has been applied with some success. Direct measurements of evapotranspiration at the field scale can provide estimates of water savings resulting from vegetation management. These techniques have been used with good success for assessing the effects of vegetation on the water cycle (Dugas *et al.*, 1998; Dugas and Mayeux, 1991; Scott *et al.*, 2003) and for best results these measurements should be complemented by field measurements of surface runoff.

Challenge: Operation of evapotranspiration towers require skilled technicians and good data management systems.

Application Area: All areas

Small catchments experiments

Monitoring runoff and springflow at the scale of a few acres can provide insight as to the effects of vegetation manipulation. The same logic ideas and constraints apply as for the very large watershed scale studies discussed above. Small catchment studies have been done with some success in the Edwards Plateau in evaluating the effect of vegetation management (Huang *et al.*, 2006; Wilcox *et al.*, 2005).

Challenge: As with the large watershed studies, catchment experiments required many years of observation. In addition, it can be very difficult to find suitable catchments for paired experiments.

Application Area: Guadalupe River above Canyon Lake.

Plot Scale

Monitoring water in the vadose zone

One of the best ways of determining the influence of plants on recharge is that of making detailed measurements soil water both within and below the plant root zone. Ideally measurements would be made repeatedly in both time and space. The technology is available for continuous monitoring of soils moisture and a variety of techniques and approaches are available. This approach has been used with great success including several studies in South Texas (Weltz and Blackburn, 1995; Moore *et al.*, 2008)

Challenge: Soil monitoring is difficult if not impossible in the Edwards Plateau region because of shallow, rocky soils.

Application Area: Carrizo-Wilcox recharge zone.

Plant level measurements of transpiration and interception

Woody plants affect the water cycle because they transpire water and they also intercept rainwater—both of which are very important. Transpiration and interception by shrubs can be directly measured and there are examples of this kind of work in the Edwards Plateau and south Texas (Owens *et al.*, 2006; Owens, 1996; Owens and Schreibe, 1992).

Challenge: Tree level measurements can be made but it is often difficult to determine what they mean on a landscape scale

Application Area: all areas

RECOMMENDATIONS

Each of the target areas are different and each pose opportunities and challenges in terms of monitoring.

Recommendation 1: Incorporate and apply the large scale remote sensing technology across the Region L area. In addition to addressing the effectiveness of the brush management program, it will provide very useful regional information related to water resources

Recommendation 2: In each of the target areas have at a network of ET towers in treated and untreated locations. These measurements should be complemented by monitoring of surface runoff so that recharge could be estimated by difference.

Recommendation 3: In the Carrizo-Wilcox area, complement ET tower measurements with detailed monitoring of soil moisture in treated and untreated areas

Recommendation 4: In the Guadalupe Watershed monitor spring flow as many locations in treated and untreated areas (ET towers would be in the same areas).

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LAND-BASED WATER CONSERVATION & WATER YIELD PRACTICES IN REGION L: INFLUENCE OF LAND BASED CONSERVATION PRACTICES ON WATER YIELD

SUBMITTED TO
REGION L
SOUTH CENTRAL TEXAS REGIONAL WATER PLANNING GROUP
BY

TEXAS A&M | Institute of Renewable Natural Resources

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GRAZINGLAND MANAGEMENT SYSTEMS, INC.

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Abstract

In this report we examine the potential for increasing water yield within region Region L though land management. Our assessment is based on the available literature and our own experience. The major land management practice which has the potential for affecting water yield would be that of reducing woody plant cover through brush control. Region L encompasses a large region in south-central Texas and includes several distinct vegetation and physiographic zones including the Edwards Plateau, South Texas Plains, Gulf Coast Prairies, Post Oak Savanna and Blackland Praire. The areas with the most potential for increasing water yield through brush control would be the Edwards Plateau overlying the Edwards Aquifer and the South Texas Plains that overly the Carrizo-Wilcox aquifer. The most current research indicates that within the Edwards Plateau, reducing ashe-juniper cover could result on average 40-60 mm of additional water yield per year. This translates into roughly an additional acre-ft of water for every 5-8 acres cleared. Within the South Texas plains, water yield (groundwater recharge) could be augmented up to10 - 20 mm/yr or about 1 acre-ft of water for every 15-30 acres cleared. Depending on the method and expense of brush clearing these estimates would translate into a cost of between $40 and $180 per acre-ft of water for the Edwards Plateau and $100 and $300 per acre-ft in regions of the South Texas Plains that overlie the Carrizo-Wilcox Aquifer

Executive Summary

Vegetation and Vegetation Management in the MLRA of Region L

Edwards Plateau

The northern parts of Uvalde, Medina, Bexar, Comal and Hays Counties of Region L are in the Edwards Plateau Major Land Resource Area (81C) immediately above the Balcones Escarpment. For the purpose of this report, soil series typical of the area are represented by a Low Stony Hill ecological site, an upland site with slope gradients mainly 1 to 8 percent but that can range up to 12 percent. The plant communities of a Low Stony Hill site are dynamic and vary in relation to grazing, fire and drought. Presettlement conditions were strikingly different than those found today. Large areas that were once open grasslands are now infested with heavy woody cover consisting of species such as Ashe juniper, liveoak, post oak, honey mesquite, agarito, Texas persimmon, elbowbush and lotebush.

Brush management treatment alternatives commonly used in the Edwards Plateau MLRA include mechanical and chemical practices, as well as prescribed fire and biological control associated with the use of goats. Ashe juniper is the primary target species for brush management a very high percentage of the time. Mechanical brush management treatments can be either broadcast when densities of plants are greater than 300 plants per acre or large enough to respond to treatments such as chaining or cabling, or individual plant treatments (IPT) when densities are low enough and/or plants are small enough to justify treating individual plants. Ashe juniper is non-sprouting species; that is, it will suffer mortality if all the above ground green material is removed. This allows top removal practices to be effective for brush management and the most popular of these methods currently is the use of a "skid-steer loader" equipped with a front-end attachment of hydraulically operated shears. The shears are placed with the skid steer at the base of a target plant species and the shears are then closed hydraulically so that they cut entirely through the trunk of the tree.

South Texas Plains

The South Texas Plains MLRA includes the largest portion of Region L. All or part of the following Region L Counties are in the MLRA; Uvalde, Zavala, Dimmitt, Medina, Frio, La Salle, Bexar, Atascosa, Wilson, Karnes, Goliad, DeWitt, and Gonzales. Upland soils are of three groups: dark, clayey soils over firm clayey subsoils; grayish to reddish brown, loamy to sandy soils; and brown loamy soils. Gray, clayey, saline, and sodic soils are extensive on the coastal fringe, along with Galveston deep sands. Bottomlands are typically brown to gray, calcareous silt loams to clayey alluvial soils. The original vegetation was an open grassland or savannah-type along the coastal areas and brushy chaparral-grassland in the uplands. The plant communities that can be found on this site range from a mid-grass dominant to a brush covered site with bare ground. This diversity in plant communities is in direct response to grazing management, fire, and drought. At this point the area is represented as a Shrubland with a canopy of brush greater than 20

percent and often reaching between 60 percent to total closure. In the heavy brush cover, understory vegetation will range from a cover of short and mid grasses to bare ground. Woody species include guajillo, blackbrush, condalia, wolfberry, pricklypear, Texas persimmon, paloverde , ceniza and coma.

The South Texas Plains are the heart of the Texas "Brush Country", sharing that designation with the western part of the Gulf Coast Prairie MLRA. Brush stands in the area are often aggregates of 15 or more species, most characterized by thorns or spines and existing in three strata – overstory of trees, mid-story of shrubs and an understory of subshrubs and cacti. Chaining and rootplowing where the most popular of the early mechanical practices utilized in the area and have been applied on hundreds of thousand of acres in the MLRA. The MLRA also has a long history of the use of broadcast chemical brush management treatments.

Other MLRAs in Region L

Other MLRAs in Region L include the Gulf Coast Prairies and Marshes consisting of all or part of Refugio, Calhoun, Victoria and Goliad Counties. The Post Oak Savannah and Blackland Prairies are two additional MLRA that include portions of Counties within Region L. Compared to the Edwards Plateau, Gulf Coast Prairies and Marshes and South Texas Plains, the land areas of the Post Oak Savannah and Blackland Prairies within Region L are small.

Potential to Augment Recharge and Streamflow Within Region L Through Shrub Control

In this section, we examine the scientific basis for using shrub control as a means of increasing groundwater recharge with an explicit focus on two of the landcover types within the Region L Planning area: (1) juniper woodlands within the Edwards Plateau Major Land Resource Area (MLAR) and (2) South Texas shrublands within the South Texas Plains MLRA—in particular those shrublands overlying the Carizzo-Wilcox recharge zone within Zavala and Dimmitt counties.

Rangeland areas with the most potential for increasing recharge through shrub control are those areas where deep drainage (water movement beyond the herbaceous rooting zone) can occur (Seyfried et al. 2005, Wilcox et al. 2006). This characteristic is found, for example, where soils are shallow and overlie relatively permeable bedrock (such as karst limestones). An example in Texas is the Edwards Plateau area, which supports large tracts of juniper woodlands and has considerably more "flowing water" than would be expected for a semiarid or subhumid climate (ca. 700 mm/yr). The explanation lies in the karst geology—a substrate of fractured limestone that allows rapid flow of water to the subsurface. Other soil types that may enable deep drainage are sandy soils. Shrublands in region L that exhibit these characteristics are the juniper shrublands within the Edwards Plateau and the South Texas shrublands overlying the recharge zone of the Carrizo-Wilcox Aquifer.

Edwards Plateau

On the basis of the literature available, our current best estimate is that conversion of Ashe Juniper woodlands into open savannas would result in an average increase in water yield (streamflow and recharge) of around 50 mm/year. The influence of Ashe juniper on the water budget has been the subject of some confusion and disagreement, in part because the implications of the scale at which measurements were made have not been fully considered. For example, at the tree scale, the most common measurement is some index of evapotranspiration by trees. After removal of trees, these numbers have often been extrapolated up without taking into account the compensatory effects of regrowth of trees or replacement by other vegetation. These measurements do not take into account water use by replacement vegetation, as the larger-scale studies do. For example, at the tree scale, for an area with an average annual precipitation of 750 mm/yr, an individual tree will intercept and transpire virtually all of the available water. At the stand scale, however, as estimated by Dugas *et al.* (1998), the difference in water consumption between a woodland and a grassland is between 40-50 mm/yr. Newer work suggests differences as high as 90 mm/year however. Water balance studies at the small-catchment scale (where springs exist) indicate water savings of around 50 mm/yr. (Huang et al. 2006).

South Texas Shrublands

Our estimate that for the South Texas shrublands, average recharge on sandy soils could be increased by shrub control anywhere from 10 -20 mm/year. All of the available data strongly suggest that in the presence of dense shrub cover, there will be little if any recharge. However, both the modeling and field work suggest that in the absence of shrubs, recharge will be appreciably higher—especially for sandy soils. For example, Weltz et al (1995) found that when rainfall was slightly above average, recharge was around 20 mm/year for grass covered areas. The implications of this then are that shrub control over the recharge area would in the long term increase distributed recharge.

Assessing the Cost Effectiveness of Brush Control to Enhance Off-site Water Yield

Estimates of added groundwater recharge cost reported herein are based only on the highly variable costs of the brush control practices and/or programs. Factors that influence brush control cost and contribute to the high variability include the type, size and density of the target brush species; the type, rock content and slope of soil in which the target species is growing; whether the target species sprouts re-growth from root buds; whether cost effective herbicides are available for controlling the target species; etc.

In addition, there are many other factors which would impact the ultimate costs; ie., program implementation and management, percent of costs born by landowners, extent of landowner participation, etc.

Edwards Plateau

In a previous section, it was reported that there are several different mechanical practices appropriate for use in the control of Ashe juniper. The costs of these various mechanical practices may vary from less than $100 to as much as $400 per acre (Pestman, 2007). Also in a previous section of this report the added ground water recharge estimated to result from control of Ashe juniper was reported to be 50mm/year. The inch equivalent of 50mm/yr. is 2 in. which is also equal to 0.167 ft. Therefore, control of Ashe juniper on an acre of land is estimated to result in 0.167 added ac.ft. of groundwater recharge per year.

The cost estimates are obtained by taking the per acre cost of the brush control practice, or cost of a program consisting of an initial plus follow-up practices, and dividing it by 0.167. This results in the estimated cost per acre foot of added groundwater recharge resulting from brush control if the practice, or program, is effective for only one year. If brush control programs were implemented and if provisions of the programs require participating landowners to reduce brush canopies to 5 percent and maintain them at this level or less for 10 years, then the costs per acre foot of added ground water recharge would be expected to range between $40 and $180 per acre foot in the Edwards Plateau.

South Texas Shrublands

In a previous section, it was stated that several herbicides and several different mechanical practices were appropriate for use in the control of mixed brush in South Texas. The costs of these various chemical practices are less variable and generally less costly than the mechanical practices in the Edwards Plateau as discussed above. In addition, the mechanical practices applicable to the control of mixed brush in South Texas would generally be less costly than when used in the Edwards plateau because the soils tend to be less rocky and the terrain is generally flatter in South Texas. Therefore, costs for mixed brush management in South Texas may vary from less than $50 to more than $100 per acre (Pestman, 2007). Also in a previous section of this report the added groundwater recharge estimated to result from control of mixed brush was reported to be between 10 and 20mm/year. To be conservative, we will use 10mm/year in the following analysis. The inch equivalent of 10mm/yr. is 0.4 in. which is also equal to 0.033 ft. Therefore, control of Ashe juniper on an acre of land is estimated to result in 0.033 added ac.ft. of groundwater recharge per year.

Using the same methods described for the Edwards Plateau, costs per acre foot of added ground water recharge would be expected to range between $100 and $300 per acre foot in The Carrizo – Wilcox Aquifer recharge area.

LAND-BASED WATER CONSERVATION & WATER YIELD PRACTICES IN REGION L: INFLUENCE OF LAND BASED CONSERVATION PRACTICES ON WATER YIELD

Vegetation and Vegetation Management in the MLRA of Region L

Edwards Plateau

General

General descriptions of soil, climate and vegetation resources for all Region L MLRA in this paper are from Hatch et al. (1990), Checklist of the vascular plants of Texas and adapted from the Natural Resources Conservation Service (NRCS) Ecological Site Descriptions (2007), web site: http://esis.sc.egov.usda.gov/ or were furnished upon request by NRCS as a proposed site description (Gray Sandy Loam for South Texas Plains 83B).

The northern parts of Uvalde, Medina, Bexar, Comal and Hays Counties of Region L are in the Edwards Plateau Major Land Resource Area (81C) immediately above the Balcones Escarpment. The Balcones Escarpment forms the distinct boundary of the Edwards Plateau on its eastern and southern borders. The area is a deeply dissected, rapidly drained stony plain having broad, flat to undulating divides.

Soil series typical of the area are included in a Low Stony Hill ecological site, an upland site with slope gradients mainly 1 to 8 percent but that can range up to 12 percent. The very shallow to shallow, well drained, moderately slow permeable soils of this site were formed in residuum over interbedded limestone, marls, and chalk. Soil thickness and depth to limestone ranges from 4 to 20 inches. Subrounded to angular pebbles, cobbles, and stones of limestone comprise 35 to 80 percent by volume of the soil. The soil is a clay soil and is alkaline to neutral. The depth of soil is one of the main factors affecting water holding capacity.

The climate is humid subtropical and is characterized by hot summers and relatively mild winters. The average first frost should occur around November 15 and the last freeze of the season should occur around March 19. The average relative humidity in mid-afternoon is about 50 percent. Humidity is higher at night, and the average at dawn is about 80 percent. The sun shines 70 percent of the time possible during the summer and 50 percent in winter. The prevailing wind direction is southeast. Approximately two-thirds of annual rainfall occurs during the April to September period. Rainfall during this period generally falls during thunderstorms, and fairly large amount of rain may fall in a short time. Mean annual precipitation ranges from over 30 inches in the eastern portion of the MLRA (Hays County) to about 24 inches in the western portion Uvalde County).

The plant communities of a Low Stony Hill site are dynamic and vary in relation to grazing, fire and drought. Presettlement conditions were strikingly different than those found today. One major vegetative difference was the presence of open prairies of tall grasses which were common throughout much of Texas. The historic climax plant community (HCPC) was greatly influenced by large herbivore grazing and fires. It is hypothesized that buffalo would come into an area, graze it down and then leave, not to come back for many months or even years, usually following a fire. This long deferment period allowed the better quality grasses and forbs to recover from heavy grazing. Fire was probably a very important factor in maintaining the original prairie vegetation and also had a major impact on the plant community structure. Species, such as Ashe juniper (*Juniperus ashei*), would invade the site, but not at the level we see today. Periodic fires, set either by Native Americans or by lightning, suppressed the range and density of Ashe juniper and other woody species. Woody plant control would vary in accordance to the intensity and severity of the fire encountered, which resulted in a mosaic of vegetation types within the same site.

While grazing was a natural component of this ecosystem, long-term overstocking and thus overgrazing by domestic animals had a tremendous impact on the site (Taylor 2004). Heavy grazing eliminates the possibility of fire and promotes the rapid encroachment of Ashe juniper. Continued overgrazing will lead to the demise of the higher quality grasses and forb species that are part of the HCPC. When site degradation is extreme, range planting may be the only means by which these species can be re-established on the site.

The HCPC, which was an open grassland with scattered oak (*Quercus* spp.) motts, included little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), Indiangrass (*Sorghastrum nutans*), and Eastern gamagrass (*Tripsacum dactyloides*). Continued overuse brought about the removal of these and many other species from a large portion of the site. Low successional, unpalatable grasses, forbs and shrubs have taken the place of the more desirable plant species. The loss of topsoil and soil organic matter makes it unlikely that these abused areas will return to the HCPC in a reasonable period of time. The diversity of native forbs and grasses has been reduced, while the presence of introduced and non-native species appears to be increasing. However, little bluestem and other native species will slowly return to the site with a sound range management program mimicking the historic management.

Ashe juniper, because of its dense low growing foliage, has the ability to retard grass and forb growth. Grass and forb growth can become almost nonexistent under dense juniper canopies. Many times there can be a resurgence of the better grasses, such as little bluestem and Indiangrass, when Ashe juniper is controlled and followed by proper grazing management.

The tallgrasses of the HCPC and similar community composition aided in increasing the infiltration of rainfall into the slowly permeable soil. The loss of soil organic matter due to overgrazing has a negative effect on infiltration. More rainfall is directed to overland flow, which causes increased soil erosion and flooding. Soils are also more prone to drought stress since organic matter acts like a sponge and aids in moisture retention for

plant growth. Mulch buildup under the Ashe juniper canopy, following brush management and incorporation into the soil, can have a positive effect on increasing infiltration.

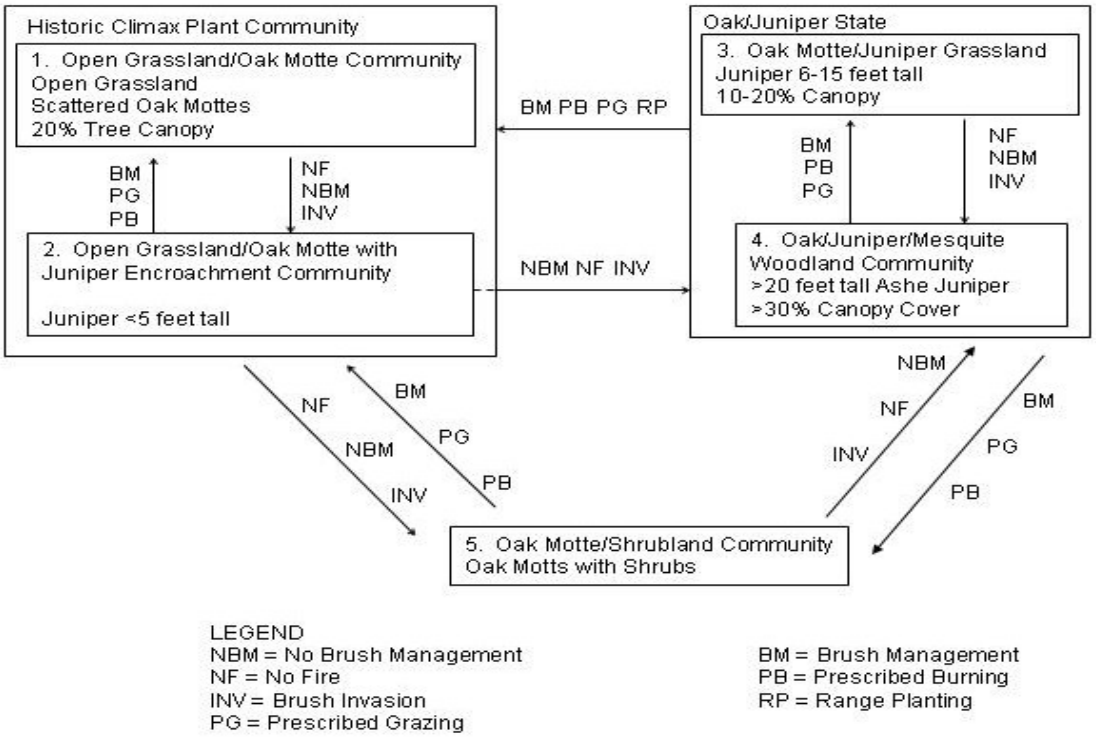
The Edwards Plateau is 98 percent rangeland; arable lands are found only along narrow streams and some divides. The rangeland is used primarily for mixed livestock (combinations of cattle, sheep, and goats) and wildlife production. The area is known as the major wool-and mohair-producing region in the United States, however in recent years there has been a move to greater meat goat production and a reduction in angora goats. The area also supports the largest deer population in North America. Most ranches in the area maintain livestock production, but wildlife has become increasingly important and may equal or exceed livestock in management emphasis and income on many ranch operations. Exotic big-game ranching is also important, and axis, sika, and fallow deer and blackbuck antelope have increased in numbers. Management for all resources, livestock, wildlife, and recreation, provides the best use of the rangeland, although other products such as cedar oil and wood products have local importance. Forage, food, and fiber crops such as sorghum, peanuts, plums, and peaches are well adapted to arable land.

The increasing concern for wildlife habitat, especially white-tailed deer, over the past four decades has dictated a change in the approach to rangeland vegetation manipulation with brush control practices from wide-scale broadcast treatments, such as chaining, to a more limited "sculpted" approach. However, brush management for increased forage production for domestic livestock is still an important practice in the area.

Specific Reference to a Dominant Ecological Site

Ecological Site Descriptions (ESD) developed by the Natural Resources Conservation Service provide a detailed means to view landscapes in the MLRA. For the purpose of this paper, a dominant ecological site in the Edwards Plateau will be used to show the vegetation steady states and transitions that occur from the HCPC through the process of retrogression to those communities more commonly existing today. A Low Stony Hill ecological site is one of the most commonly occurring sites in the MLRA.The ESD for a Low Stony Hill site includes the state and transition model shown in Figure 1.

Figure 1. State and Transition model for a Low Stony Hill Site, Edwards Plateau MLRA



The HCPC for the site is shown as plant community 1. In its pristine (HCPC) condition, this site is a fire-climax, open grassland with scattered oak mottes with about 20 percent tree canopy. The liveoaks (*Quercus virginiana*) are most abundant along water courses, where elm (*Ulmus* spp.) and hackberry (*Celti*s spp.) trees also grow. The herbaceous plant community is dominated by little bluestem. Indiangrass and big bluestem are subdominants, and may even dominate locally. Also native to the site, but occurring less frequently or in lesser amounts are the wildryes (*Elymus* spp.), sideoats grama (*Bouteloua curtipendula*), tall dropseed (*Sporobolus compositus*), feathery bluestems (*Bothriochloa* spp.), green sprangletop (*Leptochloa dubia*), vine mesquite (*Panicum obtusum*), Texas wintergrass (*Nassella leucotricha*) and Texas cupgrass (*Eriochloa sericea*). The site also grows an abundance of climax forbs, shrubs and woody vines.

Retrogression from the HCPC to plant community 2 is indicated by reduction in the occurrence of fire on the site, no brush management and the invasion of woody plants, primarily Ashe juniper. The model indicates that communities 1 and 2 are contained within the same steady state (large box) and that community 1 can be restored from community 2 by brush management, prescribed burning and prescribed grazing. However, as retrogression continues to occur, a new steady state, an oak/juniper state, develops that includes plant communities 3 and 4. Alternatively, steady state 5 can establish as an oak motte/shrubland community from either of the other steady states.

Brush management, prescribed burning and prescribed grazing can be used to restore the site to more closely resemble the HCPC, but as the size of juniper increases beyond that effectively controlled with prescribed fire, so does the cost of brush management. For example, in the oak/juniper steady state costly practices, such as mechanical removal of juniper must be employed, as well as range planting in areas where the native seed source is judged to be depleted. Representative composition by different plant types and total annual production of the HCPC are provided in Table 1.

Table 1. Annual Production by Plant Type (HCPC)

	Annual Production (lbs/AC)		
Plant Type	Low	Representative Value	High
Forb	65	110	135
Grass/Grasslike	1950	3250	3900
Shrub/Vine	45	75	90
Tree	180	300	360
Total:	2240	3735	4485

As a contrast and to show the influence of heavy invasion on the site from Ashe juniper and other woody species, Table 2 provides plant types and production from plant community 4, the Oak/Juniper Woodland community. Community 4 has developed as a result of a severe vegetation shift from an original plant community which was a grassland with scattered oak mottes to a plant community which is predominately tall woody plants and limited tallgrass vegetation. This community will exhibit Ashe juniper 20 feet tall and taller, with canopies in excess of 30%. Grass and grasslike vegetation is significantly reduced due to the severe competition that Ashe juniper and other woody species present regarding sunlight and moisture.

Large areas that were once open grasslands are now infested with heavy woody cover consisting of species such as Ashe juniper, liveoak, post oak (*Quercus stellata*), honey mesquite (*Prosopis glandulosa*), agarito (*Mahonia trifoliata*), Texas persimmon (*Diospryos texana*), elbowbush (*Forestiera pubescens*) and lotebush (*Ziziphus obtusifolia*)

.

Table 2. Annual Production by Plant Type (Community 4)

	Annual Production (lbs/ac)		
Plant Type	Low	Representative Value	High
Forb	30	50	70
Grass/Grasslike	400	650	800
Shrub/Vine	100	150	200
Tree	720	1200	1450
Total:	1250	2050	2520

Management alone will not allow this community to shift back towards the climax community. Implementation of brush management programs involving heavy equipment and very high treatment cost is the only option if decision-makers desire to transition this site back towards the historic plant community. By implementing other conservation measures, such as prescribed burning and prescribed grazing, land managers can maintain the community as a grassland community following initial brush management practices.

As the plant community degenerates to community 4, big and little bluestem, Indiangrass and the wildryes decrease and Sideoats grama, tall dropseed, silver bluestem, Texas wintergrass and buffalograss (*Bouteloua dactyloides*) are initial increasers on the site. Prolonged overuse of these plants usually results in a community of Texas wintergrass, curlymesquite *(Hilaria belangeri*), buffalograss and woody species. The following grasses and forbs are commonly found on this site in a deteriorated condition: western ragweed (*Ambrosia psilostachya*), broomweed (*Amphiachyris* spp.), prairie coneflower (*Ratibida columnifera*), snow-on-the-Mountain (Euphorbia marginata), silverleaf nightshade (*Solanum elaeagnifolium*), milkweeds (*Asclepias* spp.), Leavenworth eryngo (*Eryngium leavenworthii*), two-leaf senna (*Cassia roemariana*), gray goldaster (*Heterotheca canescens*), horehound (*Marrabium vulgare*), evax (*Evax* spp.), buffalograss, *curlymesquite, Texas grama (Bouteloua rigidiseta), hairy tridens (Erioneuron* pilosum), red grama (*Bouteloua trifida*), tumblegrass (*Schedonnardus panniculatus*), windmillgrasses (*Chloris* spp.) and annual bromegrasses (*Bromus* spp.).

Woody species dominate the site in this community with Ashe juniper being the dominant. Shade tolerant species such as cedar sedge (*Carex planostachys*) and uniola species (*Uniol*a spp.) dominate the understory that is void of sunlight. The majority of the soil surface on this densely canopied site will have a thick mat of cedar leaves and other woody tree and shrub leaf material. The open areas between canopies will produce a grass cover of primarily low successional species such as gramas (*Bouteloua* spp.), three-awns (*Aristida* spp.), tridens (*Tridens* spp.), and dropseeds (*Sporobolus* spp.). The total grasslike production potential for this community is severely restricted.

A key difference between plant community 1 and 4 is herbaceous forage production. Plant community 1 can produce up to 3900 lbs./acre of grass/grasslike plants in an above average year versus only 800 lbs./acre in plant community 4. It is significant that these same plants, the grass and grasslike species, are also the fine fuel that can potentially carry effective fires contributing to control of Ashe juniper.

Brush Management Practices

Brush management treatment alternatives commonly used in the Edwards Plateau MLRA include mechanical and chemical practices, as well as biological control associated with the use of goats. Selection of these treatments depends on the size and density of the woody plant species, primarily Ashe juniper. Some ranchers will remove oak species with brush management practices, but these are more likely shinoak species or oaks that are thinned within mottes, rather than mature oaks. Live oaks, Spanish oaks, post oaks, or other oak species are generally not considered in brush management scenarios, meaning that Ashe juniper is the target woody plant species a very high percentage of the time. Mechanical brush management treatments can be either broadcast when densities of plants are greater than 300 plants per acre or large enough to respond to treatments such as chaining or cabling, or individual plant treatments (IPT) when densities are low enough and/or plants are small enough to justify treating individual plants.

Chaining is usually accomplished by pulling a ships anchor chain between two crawler tractors, commonly D7 size or greater, depending on the size and density of the target species. The tractors are arranged in a "J" configuration, with one tractor moving slightly ahead of the other and the chain or cable being pulled in-between the tractors to make a swath width that is roughly equal to one-half the length of the chain. Commonly used chain lengths vary from 150-300 ft., giving a swath width of about 75-150 ft. Again, the length of chain and swath width would depend on the density and size of the juniper and the power of the tractors (Scifres 1980). Keeping the swath width at one-half the chain length allows the chain to be pulled from directly behind the tractor and reduces pull from the side that causes maintenance problems. Chaining or cabling work best when trees are large enough to provide significant resistance to the pull of the chain so that they can be uprooted rather than broken off or simply bent over and allowed to remain connected to the subterranean root structure. Mortality of the target species associated with chaining or cabling is usually in direct proportion to the stature of the trees and the degree of uprooting that is accomplished. Two-way chaining, covering the area twice in opposite directions, usually gives better control than one-way chaining (Welch 1985). Raking and stacking may be necessary to remove woody debris after chaining of heavy brush cover to allow maximum development and utilization of range forages and to minimize livestock handling problems. The degree of slope on the land must be considered as a hazard to use of equipment in the area, with slopes of 15% or greater limiting the application of these practices.

In areas of the MLRA where soils are deep, rootplowing is an option for removal of woody vegetation. Rootplowing is a nonselective treatment used to sever woody plants below ground. This practice is very energy intensive and costly, but results in a high

degree of mortality of the target plant species. A rootplow is pulled behind a crawler tractor, normally of D7 or D8 size. The rootplow is a heavy steel V-shaped blade that is attached to shanks carried on a toolbar behind the tractor. The rootplow blade travels under and parallel to the soil surface cutting through all the subterranean root material of plants. Depth of the blade beneath the soil surface will vary, but in deep soils it may be 12-16 inches, depending on the density and size of the trees, soil texture, soil moisture and power of the tractor. Rootplowing causes a high level of soil disturbance and can destroy most perennial grasses. Thus, seeding is often necessary as a follow-up treatment. If rootplowed areas are not seeded, the majority of forage production for the first year or two may be from annuals and other plants low on the successional scale. The flush of forbs on rootplowed areas may dramatically improve wildlife forage until perennial grasses become dominant (Welch 1985).

Bulldozing has been used many years for clearing Edwards Plateau rangeland of unwanted woody plant species. When Ashe juniper is the target species, all plants attacked by bulldozing will suffer mortality if they are either uprooted or sheared off from their roots below the lowermost above ground green growth. Conversely, resprouting species, such as honey mesquite, will produce multiple new sprouts from buds in the stem base and root crown area of the plant (Welch 1991).The bulldozer can place the cleared trees in piles or windrows.

Since Ashe juniper is a non-sprouting species, this allows top removal practices to be effective for brush management and the most popular of these methods currently is the use of a “skid-steer loader” equipped with a front-end attachment of hydraulically operated sheers. The sheers are placed with the skid steer at the base of a target plant species and the shears are then closed hydraulically so that they cut entirely through the trunk of the tree. The hydraulic system on the skid steer can be used to place cut trees in piles or in windrows, or they can be left in place on the soil surface. Both bulldozing and sheering of Ashe juniper have been shown to produce enough soil disturbance to provide an adequate seedbed for seeding Mannel (2007.)

Another broadcast brush management practice that is infrequently used in the MLRA is roller chopping. Roller chopping is accomplished with a heavy drum-type roller with blades mounted on the surface of the drum parallel to the axis. The blades cut through woody plants as the roller chopper is pulled over them by a crawler tractor, commonly D6 to D8 size. The drums can be filled with water to increase their overall weight and the weight per unit of blade surface area contact with woody stems that results in greater cutting performance. Roller chopping has limited capability to cause mortality on woody species, since it is a simple top removal practice that leaves a high percentage of plant subterranean material in place and often does not remove all of the above ground plant material necessary to result in mortality of Ashe juniper. Roller chopper blades may penetrate the soil several inches deep, depending on soil texture and moisture and the size and weight of the chopper. Thus, soil disturbance may be significant, resulting in improved water infiltration. Seeded grass stands have been established on seedbeds prepared by offset, tandem roller choppers.

Hydraulic shredders, such as the "Hydro Axe" are also used for woody plant control and are effective on Ashe juniper if the cut by the shredder is below the lowermost green plant material. A Hydro-Axe shredder is mounted on the front of a large rubber-tired tractor and is powered by a hydraulic motor. The entire shredding unit can be raised and lowered to shred down large trees. While the shredders can take down larger trees, they are probably most economically efficient in brush with 3-6 inch stem diameters. With the exception of Ashe juniper as stated above, most undesirable plants will resprout vigorously following shredding. Like roller chopping, shredding may increase browse availability and quality by increasing the number of young, succulent sprouts. Prescribed fire can be used as a follow-up to roller chopping or shredding to suppress woody regrowth.

Individual plant treatment (IPT) mechanical practices include "lopping" with manual sheers that cut Ashe juniper plants near ground level and result in a high level of control. In recent years the use of "track hoes" or "excavators", large self-propelled backhoes on tracks that have a reach of about 25 feet in 180 degrees, has become popular, especially in the western Edwards Plateau where redberry juniper, a sprouting species, requires extirpation below the bud zone (Wiedemann 2004). These large grubbers cover a 50 ft. Swath when moving in a straight line and can be used for other resprouting species, as well as for Ashe juniper if desired, particularly in areas where the size of trees or soils (primarily rockiness) may limit the use of smaller grubbing equipment. The bucket, equipped with rock-digging teeth, is very effective for removing junipers from rocky soil and stacking them. A U-shaped grubbing blade can be used in place of the bucket (Wiedemann 2004). Low-energy grubbing can also be used in some soils for juniper control. "Low–energy" grubbers are those that use hydraulic power in the grubbing unit to offset the need for tractor horsepower (Wiedemann 2004). Rotating cutter blades mounted on heavy duty "Weed Eaters" are also effective for quick removal of Ashe juniper up to 2 inches in stem diameter at ground level.

There are no currently recommended broadcast chemical treatments for Ashe juniper control. However, there are IPT practices that are recommended for use, including picloram (Tordon 22k), Hexazinone liquid (Velpar L) and Hexazinone pellets (Pronone Power Pellets). All of these treatments will give a very high level of Ashe juniper mortality if properly applied. Texas Cooperative Extension Bulletin 1466 (2007) provides explicit instructions for selection, mixing and application of herbicides.

Perhaps the most economically effective treatment alternative for Ashe juniper control is prescribed burning. Fire can be very effective for causing mortality of small Ashe juniper plants that are up to about 3 feet tall and even taller if the fine fuel load is adequate in amount and continuity to carry an effective fire. When small, Ashe juniper can be effectively controlled with cool season prescribed burns that limit risk compared to hot summer burns. Combination of prescribed burning with other practices, such as mechanical or chemical control is highly recommended to preserve the benefits of high cost initial practices by low-cost maintenance practices. An excellent discussion on the use of fire in juniper ecosystems can be found in Blair et al. (2004).

Biological control is accomplished in the MLRA via the use of goats. Angora goats are still significant in the area, but have declined in numbers over the past decade. Meat goats, including Spanish and Boer goats and crosses thereof, as well as other meat breeds, have increased in the area during this same time period. Overall, goats are still very much present and have an impact on woody plant competition with herbaceous species. For example, goats will utilize seedling cedar plants or young regrowth until the plants have reached a threshold when leaf material age diminishes use with the increased content of terpenoids (Taylor 2000). Goats also utilize oak sprouts and harvest buds, leaves and small twigs of trees up to a browse line of about 6 feet. Goats can be concentrated in high densities and rotated through pastures to help suppress woody plants. They can also be used following mechanical brush management practices to utilize woody plant regrowth when it is succulent and within reach. The Texas Agricultural Experiment Station at Sonora is experimenting with goats that will consume a higher percent of juniper in their diets in order to maximize biological control (Taylor 2004).

Gulf Coast Prairies and Marshes

General

All of Refugio and Calhoun Counties, most of Victoria County and a small portion of Goliad County that are contained within Region L are included within the Gulf Coast Prairies and Marshes MLRA. The USDA NRCS divides the MLRA into two components, the Gulf Coast Marshes (150B), covering approximately 500,000 acres, that are on a narrow strip of lowlands adjacent to the coast and the barrier islands (e.g., Padre Island) and which extend from Mexico to Louisiana, as well as the Gulf Coast Prairies (150A), about 9 million acres, that include the nearly flat plain extending 30 to 80 miles inland from the Gulf Marshes.

The Gulf Coast Marshes are a low, wet, marshy coastal area, commonly covered with saline water, and range from sea level to a few feet in elevation. The Gulf Coast Prairies are nearly level and virtually undissected plains having slow surface drainage and elevations from sea level to 250 feet.

Soils of the Gulf Coast Marshes are dark, poorly drained sandy loams and clays, and light neutral sands, typically showing little textural change with depth. The loamy and clayey soils are commonly saline and sodic. Prairie soils are dark, neutral to slightly acid clay loams and clays in the northeastern parts. Further south in the subhumid Coastal Bend, the soils are less acidic. A narrow band of light acid sands and darker loamy to clayey soils stretches along the coast. Inland from the dark clayey soils is a narrow belt of lighter acid fine sandy loam soils with gray to brown, and red mottled subsoils. Soils of the river bottomlands and broad deltaic plains are reddish brown to dark gray, slightly acid to calcareous, loamy to clayey alluvial.

The climate of MLRA is humid subtropical with mild winters. Canadian air masses that move southward across Texas and out over the Gulf in winter produce cool, cloudy, rainy weather. Precipitation is most often in the form of slow and gentle rains. Spring weather

is variable though moderate overall. March is relatively dry while thunderstorm activities increase in April and May. Summer weather varies little by having abundant sunshine and drier than in the spring. Occasional slow-moving thunderstorms or other weather disturbances may dump excessive amounts of precipitation on the area. Fall has moderate temperatures. Fall experiences an increase of precipitation and frequently has periods of mild, dry, sunny weather. Heavy rain may occur early in fall in association with tropical disturbances, which moves westward from the gulf. Tropical storms are a threat to the area in the summer and fall but severe storms are rare.

The total annual precipitation ranges from 28 inches in the southwest part of the region to 44 inches in the eastern part of the region. On average, approximately 38 inches occur around Victoria. Approximately 65 percent of the rainfall falls between April and September which includes the growing season for most crops. In two years out of ten, the rainfall for April through September is less than twenty inches. Thunderstorms occur on about fifty days each year and most occur during the summer.

The Gulf Coast Marsh areas, being variously salty, support species of sedges (*Carex* and *Cyperus*), rushes (*Juncus*), bulrushes (*Scirpus*), several cordgrasses (*Spartina*), seashore saltgrass (*Distichlis spicata* var. *spicata*), common reed (*Phragmites australis*), marshmillet (*Zizaniopsis miliacea*), longtom (*Paspalum lividum*), seashore dropseed (*Sporobolus virginicus*), and knotroot bristlegrass (*Setaria geniculata*). Marshmillet and maidencane (*Panicum hemitomon*) are two of the most important grasses of the fresh-water marshes of the upper coast. Common aquatic forbs are pepperweeds (*Lepidium*), smartweeds (*Polygonum*), docks (*Rumex*), bushy seedbox (*Ludwigia alternifolia*), green parrotfeather (*Myriophyllum pinnatum*), pennyworts (*Hydrocotyle*), water lilies (*Nymphaea*), narrowleaf cattail (*Typha domingensis*), spiderworts (*Tradescantia*), and duckweeds (*Lemna*). Common halophytic herbs and shrubs on salty sands are spikesedges (*Eleocharis*), fimbries (*Fimbristylis*), glassworts (*Salicornia*), sea-rockets (*Cakile*), maritime saltwort (*Batis maritima*), morningglories (*Ipomoea*), and bushy sea-ox-eye (Jones 1982).

The low marshy areas provide excellent natural wildlife habitat for upland game and waterfowl. The higher elevations of the Gulf Coast Marshes are used for livestock and wildlife production. Ranch units are mostly in large landholdings. These marshes and barrier islands contain most of our National Seashore parks. Urban, industrial, and recreational developments have increased in recent years. Most land is not well suited for cultivation because of periodic flooding and saline soils. The Gulf Coast Prairies are used for crops, livestock grazing, wildlife production, and increasingly for urban and industrial centers. About one-third of the area is cultivated mostly for rice, sorghum, corn, and tame pastures. Bermudagrass and several introduced bluestems (*Dichanthium* and *Bothriochloa*) are common tame pasture grasses.

Ranches in both components of the MLRA are primarily cow-calf operations that use forage produced from rangeland and tame pasture. Zebu or crossbreeds having Zebu blood are the most widely adapted and used cattle. Recreation, hunting, and fishing provide excellent multiple-use opportunities in the Gulf Prairies and Marshes.

The original vegetation types of the Gulf Coast Prairies were tallgrass prairie and post oak savannah. However, trees and shrubs such as honey mesquite (*Prosopis glandulosa*), oaks (*Quercus*), and acacia (*Acacia*) have increased and thicketized in many places. Characteristic oak species are live oak (*Quercus virginiana*) and post oak (*Q. stellata*). Typical acacias are huisache (*Acacia smallii*) and blackbrush (*A. rigidula*). Bushy sea-ox-eye (*Borrichia frutescens*), a dwarf shrub, is also typical.

Principal climax grasses of the Gulf Coast Prairies are Gulf cordgrass (*Spartina spartinae*), big bluestem (*Andropogon gerardii* var. *gerardii*), little bluestem (*Schizachyrium scoparium*), indiangrass (*Sorghastrum nutans*), eastern gamagrass (*Tripsacum dactyloides*), gulf muhly (*Muhlenbergia capillaris*), tanglehead (*Heteropogon contortus*), and many species of Panicum and Paspalum. Common increasers and invaders are yankeeweed (*Eupatorium compositifolium*), broomsedge bluestem (*Andropogon virginicus*), smutgrass (*Sporobolus indicus*), western ragweed (*Ambrosia psilostachya*), tumblegrass (*Schedonnardus paniculatus*), threeawns (*Aristida*), and many annual forbs and grasses. Pricklypear (*Opuntia*) are common throughout the area. Characteristic forbs include asters (*Aster*), Indian paintbrush (*Castilleja indivisa*), poppy mallows (*Callirhoe*), phloxs (*Phlox*), bluebonnets (*Lupinus*), and evening primroses (*Oenothera*) (Jones 1982).

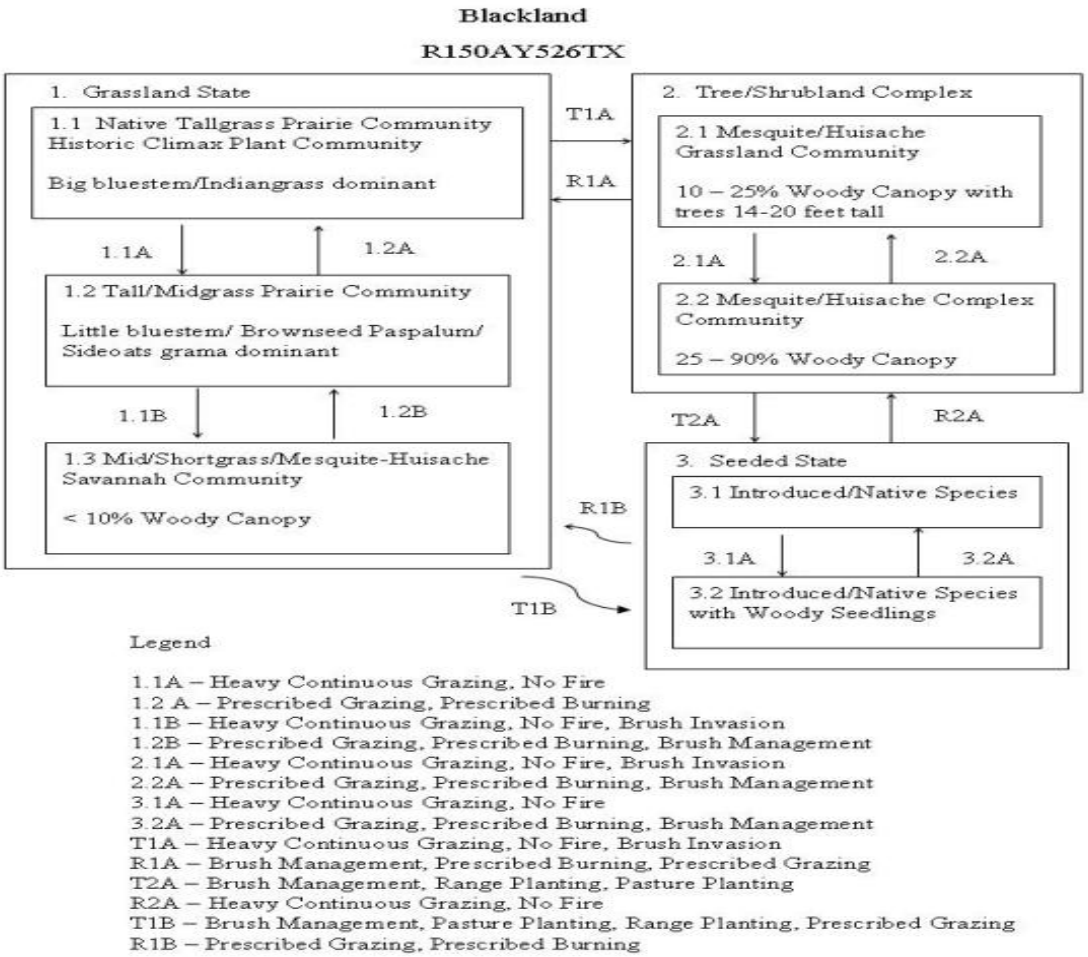
Specific Reference to a Dominant Ecological Site

Ecological Site Descriptions (ESD) developed by the Natural Resources Conservation Service provide a detailed means to view landscapes in the MLRA. For the purpose of this paper, a dominant ecological site in the Gulf Coast Prairies (150A) will be used to show the vegetation steady states and transitions that occur from the HCPC through the process of retrogression to those communities more commonly existing today. A Blackland ecological site is one of the most commonly occurring sites in the Gulf Coast Prairie component of the MLRA.The ESD for a Blackland site includes the state and transition model shown in Figure 2.

The Blackland site in MRLA 150A was formed by clayey fluviodeltaic sediments in the Beaumont Formation of Late Pleistocene age. These nearly level to very gently sloping soils are on the South Texas coastal plain. Slopes are mainly less than 1 percent but can range as high as 8 percent. Runoff is medium on 0 to 1 percent, high on 1 to 3 percent, and very high on slopes greater than 3 percent. Undisturbed areas exhibit gilgai microrelief. Elevation ranges from 15 to 200 feet.

The average relative humidity in mid afternoon is about 60 percent. Humidity is higher at night and the average at dawn is about 90 percent. The sun shines 70 percent of the time possible in summer and 50 percent in winter. The prevailing wind is from the south-southeast. Average windspeed is highest, about 12 miles per hour, in spring.

Figure 2. State and Transition Model for a Blackland Site, Gulf Coast Prairies and Marshes MLRA



The HCPC for the site is shown as plant community 1 (Grassland state). It was composed of tall and midgrasses and is the reference plant community for the site. Tallgrasses make up over 60% of annual production percent, midgrasses approximately 30 percent, and associated grasses, forbs, shrubs and woody vines make up the remainder. Bison grazing was intermittent and fires were both frequent (3 to 8 years) and intense. Annual forbs occur in greater or lesser amounts in response to grazing intensity, fire, drought, or excessive precipitation. This prairie site was extensively heavily grazed by large numbers of domestic livestock by the late 1800's. Overgrazing with no rest was exacerbated by the introduction of barbed wire fencing and water development. Overgrazing resulted in reduced production of biomass, reduced litter accumulation, loss of tallgrass and some midgrass species and reduction of fire frequency and intensity. Some mid and shortgrasses increased as a result of this overgrazing and eventually annual forbs and grasses replaced some perennials. Representative composition by different plant types and total annual production of the HCPC are provided in Table 3.

Table 3. Annual Production (lbs/ac) by Plant Type (HCPC)

	Annual Production (lbs/ac)		
Plant Type	Low	Representative Value	High
Forb	325	400	475
Grass/Grasslike	5850	7200	8550
Shrub/Vine	325	400	475
Tree	0	0	0
Total:	6500	8000	9500

As a contrast and to show the influence of heavy invasion on the site from woody species, Table 4 provides plant types and production from plant community 2.2, Mesquite/Huisache Complex Community of the S/T model.

Over time, with continued heavy grazing, no fire, and no brush management, the Blackland Site may be transformed into a Mesquite-Huisache and Macartney rose Woodland community with canopies of 90 percent. The herbaceous community is greatly reduced and is dominated by low panicums and paspalums, Texas wintergrass, gaping panicum, bentgrass, sedges, and annual forbs and grasses.

Major cultural inputs, both chemical and mechanical, are often required and applied to restore this community to grassland or a savannah state. A common practice is the use of aerial applied herbicides to reduce the canopy, allow sunlight to penetrate to the soil surface, and grow enough herbaceous fuel loads for suitable burning. Aerial spraying is followed by the use of prescribed fire to remove some of the woody vegetation and maintain semi-open wooded grassland for several years following treatment. Although these practices kill some of the woody vegetation, much of it remains and re-sprouts from the crown and in a relatively short period of time will again attain a dominating woody plant canopy. Often with this community, mechanical means such as rootplowing and raking are utilized and the land is converted to cropland or tame pasture (see seeded state in S/T model Figure 2). A key difference between plant community 1 and 2.2 is herbaceous forage production. Plant community 1 can produce up to 8,500 lbs./acre of grass/grasslike plants in an above average year versus only 750 lbs./acre in plant community 2.2. This difference in production on the same site is the result of retrogression from the tall and midgrass community to the brush dominated state that is prevalent over much of the rangeland in the MLRA today.

Table 4. Annual Production (lbs/ac) by Plant Type (Community 2.2)

	Annual Production (lbs/AC)		
Plant Type	Low	Representative Value	High
Forb	200	250	300
Grass/Grasslike	300	500	750
Shrub/Vine	400	450	550
Tree	500	650	975
Total:	1400	1850	2575

Distribution of woody vegetation follows the major soil types on the Coastal Prairie. Live oak savannahs are common in the southern and western portions. Live oak forms dense, almost pure stands on deep sands or is associated on the heavier soils with various *acacias*, such as huisache and with species such as spiny hackberry and lotebush. Post Oak and blackjack oak occur with live oak or in isolated communities in the northwest part of the Coastal Prairie. The post oak-blackjack oak vegetation type is characterized by moderate to dense stands of underbrush including many species characteristic of the Post Oak Savannah.

Honey mesquite occurs throughout the Coast Prairie but more sparsely than in other parts of the state except for the Pineywoods. Honey mesquite inhabits deep loams and clays in the eastern portion of the area (Refugio, Bee and Victoria Counties). It intermingles with post oak, blackjack oak, and live oak on lighter soils and with low-growing, xerophytic mixed brush characterized by *acacias* on the uplands.

In addition to honey mesquite, the most characteristic troublesome species of the Coastal Prairie are huisache and Macartney rose. These species combine to form unique communities in some areas, especially on the heavy, slowly permeable soils. Such communities are typical in Victoria County on Victoria and Lake Charles clays where brush control is practiced regularly. Huisache is distributed throughout the Coast Prairie. It may form dense, almost pure stands on lowland areas, and it thrives on the more mesic upland in association with species typical of mixed-brush communities. Macartney rose may occur with an overstory of honey mesquite and huisache but may dominate the vegetation on heavier soils.

Brush Management Practices

The western portion, or the more inland side of the Gulf Coast Prairies and Marshes MLRA, is joined by the South Texas Plains MLRA and shares the same reputation as being part of the “South Texas brush Country”. Rangeland areas of both MLRA are often heavily invaded by a wide array of woody plant species that suppress herbaceous forage production, while at the same time providing a significant component of high quality

habitat for income producing wildlife, primarily white-tailed deer and quail. Therefore, land managers commonly seek ways to modify brush stands to optimize a dual vegetation composition between herbaceous and woody plant species.

The Brush management treatment alternatives commonly used in the Gulf Coast Prairies and Marshes MLRA include mechanical and chemical practices and prescribed fire. When considered in combination with the South Texas Plains, no other MLRA in Texas have had greater implementation of brush management practices. The two most prevalent broadcast mechanical practices, chaining and rootplowing, were used early and frequently over vast acreages in the area beginning as early as the 1930's (Hamilton and Hanselka 2004). The mechanics of these practices are explained in the section of this paper for the Edwards Plateau MLRA. However, unlike the shallow, rocky soils that dominate the Edwards Plateau, the soils of the Gulf Coast Prairies are mostly deep and well suited to use of rootplowing. The practice is used for brush management; that is, to remove the resident woody plant composition and allow native herbaceous plant species to be restored, or, in other cases, rootplowed areas are seeded to promote more rapid response of grasses, commonly introduced species, such as buffelgrass (*Cenchrus ciliaris)*. There is a variety of degrees of treatment involved with rootplowing for brush management. Since the practice leaves the land very rough and with large amounts of debris from downed woody plants, it is often followed by raking to gather the debris, both from the surface and below ground in the plowed portion of the soil profile. The raking, usually followed by stacking and burning of brush piles, breaks up the massive clods left by the rootplow and smoothes the soil surface, greatly enhancing seedbed preparation and subsequent stands of seeded species. A still greater degree of land clearing that follows rootplowing involves raking in two directions, stacking and burning piles, additional cleanup, such as hand picking or the use of farm-type tractors to finally prepare the land for planting. At this point, the land can be changed from rangeland to pastureland use, denoting a perennial forage species that will receive some cultural inputs for maintenance, or even to cropland (annual crops) based on the management objective for land use.

Chaining was accomplished in the MLRA on many thousands of acres beginning in the 1930's and 40's, but like rootplowing, primarily with greatest emphasis in the post-World War II era when powerful crawler tractors became more readily available. The greatest value of chaining is the low initial cost of quickly knocking down, uprooting and thinning out moderate to dense stands of medium to large trees. Chaining alone generally offers only temporary benefits, particularly if the trees in the treated area are not large enough to allow uprooting. If a high percentage of the woody plants are not uprooted by the chain, regrowth from the species composing the brush complex in the region is extremely fast, quickly reducing the initial benefits of greater forage plant production. However, when used in combination with other methods, such as prescribed fire and/or chemical treatments, it may contribute to significant brush control for extended time periods. Chaining is also used in the region as the initial treatment in dense stands of very large plants to take down trees prior to rootplowing for brush control or land use conversion to pastureland or cropland. It should be noted that rootplowing and chaining, as well as other mechanical practices applied in the MLRA, are known to spread pricklypear

(*Opuntia* spp.). Any method that breaks the pricklypear plant into individual cladophylls (pads) and scatters the pads simply serves to transplant the species. Therefore, where pricklypear exists in the stand of brush to be treated mechanically, an additional treatment, such as a modified front-end stacker that can remove a high percentage of the pricklypear plants (Hamilton and Hanselka 2004), or an effective chemical treatment, such as the broadcast use of picloram (Tordon 22K®, may be necessary to prevent an increased density of the pricklypear.

Broadcast simple top removal practices, such as roller chopping or shredding, are also used in the MLRA, but the resprouting ability of the plants in the brush complex greatly limits the time that relief from woody plant competition can be expected. Studies have shown that several of the woody species in the area are capable of replacing 50% of more of their pretreatment height within the same growing season following spring top removal (Hamilton et al. 1981, Rasmussen et al. 1983). Bulldozing that cuts off woody plants and leaves the root system in place below ground is equally ineffective at causing plant mortality compared to roller chopping and shredding. Still, roller chopping and shredding are used to reduce the stature of brush, increase visibility, improve cattle working and increase forage production. Much the same as with broadcast herbicides, roller chopping and shredding can be done in patterns that optimize the benefits of the treatment for both increased forage production and wildlife habitat.

In addition to the standard or traditional-type roller chopper described in the section of this report for the Edwards Plateau, a unit known as an "aerator/renovator", but that functions in brush as a roller chopper, is being used effectively in the Coastal Prairie and South Texas Plains. This recent advancement in roller choppers is the use of small blades welded to the heavy drums in a staggered, cylindrical pattern. The advantage of the aerators is that the small blades chop debris and form basins in the soil to capture and hold rainfall. In addition, the staggered, cylindrical blade pattern prevents the vibration caused by the longitudinal blade placement on a standard roller chopper. The blade design and positioning on the drums direct more of the total weight of the unit to the area of contact with woody plant material, thus improving the cutting effect. The aerators are usually two drums mounted on a frame similar to on offset disk, and are pulled by a crawler tractor or a specially-equipped rubber-tired tractor. The drum diameters measure from 18 to 42 inches and can be filled with water for increased weight. Aerators are used in moderate to dense shrub-infested rangeland or pastures to remove top growth of shrubs and to improve rainfall retention. Removal of top growth produces a flush of regrowth. This is desirable for browsing animals when used on palatable brush species in the region. When seeding is used in combination with chopping, the basins enhance seedbed preparation and seedling establishment (Weidemann 2004).

Heavy disks suitable for use on rangeland are another option for broadcast brush management given an appropriate soil and brush species for the equipment to work. Blade diameters for rangeland disks usually range from 24 to 36 inches and many are scalloped. Thirty-six inch disks are used for brush management, while the smaller disks are normally used for seedbed preparation. Disk units can range in width from 8 to 12 feet. Whitebrush and blackbrush acacia are species that have been successfully controlled

with disking in the South Texas Plains and Gulf Coast Prairie. Several other species, including, Texas colubrina (*Colubrina texensis*), desert yaupon (*Schaefferia cunnefolia*), shrubby blue sage (*Salvia ballotiflora*) and small blackbrush (*Acacia rigidula*), are also susceptible to disking. Disking is especially suited to species that have relatively shallow and lateral roots, rather than tap-rooted plants, such as huisache and mesquite.

The high density of woody species that generally exist on rangeland in the MLRA makes broadcast treatments more economically efficient for initial treatments, rather than individual plant treatments (IPT). However, once brush densities have been reduced by broadcast treatments, IPT may be effective as a follow-up or maintenance practices. There are a variety of chemical IPT that can be used, as well as the practice of mechanically grubbing individual plants. Among the IPT mechanical practices, the low-energy grubbers are effective and economical depending on plant density of up to about 300 plants per acre. These grubbers have the capacity in the deep soils to remove all the below ground plant tissue that can potentially produce new sprouts.

The MLRA has a long history of the use of broadcast chemical brush management treatments. Prior to the late 1960's when picloram was labeled for use in Texas, 2,4-D and 2,4,5-T were the "standby" chemicals for broadcast weed and brush control in Texas. Of the two compounds, 2,4,5-T was superior for woody plant control. Dow Chemical Co. marketed a product, Tordon 225E®, a mixture of 2,4,5-T with picloram (Tordon 22k®) in a 1:1 ratio applied at 1.0 lb. per acre for brush control. This product was more effective for mesquite control and improved the spectrum of woody species that could be controlled in the south Texas mixed brush complex. Since this time there have been several new products introduced that are effective for individual species and mixed species composition. For example, Bulletin 1466 that provides guidance to herbicides for rangeland brush and weed control suggests the following application for south Texas mixed brush that includes blackbrush, catclaw acacia (*Acacia greggii*), guajillo (*Acacia berlandieri*), spiny hackberry (*Celtis pallida*), mesquite, pricklypear, retama (*Parkinsonia aculeata*), tasajillo (Opuntia leptocaulis) and twisted acacia (*Acacia Schaffneri*): a broadcast application of a mixture of 2 pints [.5 lb.active ingredient (a.i.)] picloram (Tordon 22k) + 1 pint (.5 lb.a.i.) triclopyr (Remedy®) applied aerially as a 4 gallon per acre oil-in-water emulsion (1 quart to 1 gallon diesel fuel oil and water to make 4 gallon per acre (1:5 oil to water ratio is optimum.). This application is expected to give an overall moderate level of mortality (36-55%) of the target species when applied under optimum conditions.

Certain herbicide compounds provide more optimum results for individual target plant species. For example, clopyralid (Reclaim®) applied broadcast alone or in combination with picloram or triclopyr will give a moderate to high (36-75%) mortality of honey mesquite. The soil applied herbicide tebuthiuron (Spike 20P®) provides a very high level (76-100%) of mortality on oak species. Several of the approved herbicides for broadleaf weed control will give very high levels of mortality.

Individual plant treatments with herbicides, either foliar applied or stem basal spray, offer moderate to very high levels of control of several problem species in the Gulf Coast

Prairie, including huisache, mesquite and pricklypear These woody species are included in the "Brush Busters" IPT method for brush control that is highly effective. Other species common to the area can be successfully controlled with herbicides shown in Bulletin 1466 with rates of applications, mixing instructions, timing of application and other information.

South Texas Plains

General

The South Texas Plains MLRA includes the largest portion of Region L. All or part of the following Region L Counties are in the MLRA; Uvalde, Zavala, Dimmitt, Medina, Frio, La Salle, Bexar, Atascosa, Wilson, Karnes, Goliad, DeWitt, and Gonzales. The area is the western extension of the Gulf Coast Plains merging with the Mexico Plains on the west. The area is a nearly level to rolling, slightly to moderately dissected plain. Scifres and Hamilton (1993) adapted Welch and Haferkamp (1987) to delineate four components within the area considered the South Texas Plains, the Northern Rio Grande Plains, Western Rio Grande Plains, Central Rio Grande Plains and Lower Rio Grande Valley. Other authors have divided the area into many more physiognomic regions and vegetation types (McMahan et al. 1984). Therefore, it is noted that much more detailed information related to soils and vegetation is available. For the purposes of this paper, the South Texas Plains MLRA will follow Hatch et al. (1990) which encompasses the area that lies roughly south of a line from San Antonio to Del Rio, Texas and continues until it joins the Gulf Coast Prairies and Marshes on the east and the Rio Grande River on the south and west.

Upland soils are of three groups: dark, clayey soils over firm clayey subsoils; grayish to reddish brown, loamy to sandy soils; and brown loamy soils. Gray, clayey, saline, and sodic soils are extensive on the coastal fringe, along with Galveston deep sands. Bottomlands are typically brown to gray, calcareous silt loams to clayey alluvial soils.

South Texas climate is recognized as unique, being the only east-coast subtropical steppe anywhere on earth, and a question exists among meteorologists as to why a semiarid climate lies where it should not, immediately downwind of the great moisture reservoir of the Gulf of Mexico (Trewartha 1968, Norwine and Bingham 1985).Mean annual precipitation ranges from near 36 inches in the eastern part of the area (DeWitt and Gonzales Counties) to 20 inches in the extreme western portion (Dimmitt County). The area is notoriously prone to great fluctuations in precipitation, ranging from extreme droughts to floods, primarily from Gulf disturbances in the late summer and fall. In a study by Norwine and Bingham (1985), "normal years", those with precipitation between 90 and 110 percent of the long-term median rainfall, were observed only 30 percent of total years, while 36 percent of the years had rainfall less than normal and 34 percent had rainfall of more than 110 percent of the median.

The original vegetation was an open grassland or savannah-type along the coastal areas and brushy chaparral-grassland in the uplands (Johnston 1963). Originally, oaks and

mesquite and other brushy species formed dense thickets only on the ridges, and oak, pecan, and ash were common along streams (Inglis 1964). Continued grazing and cessation of fires altered the vegetation to such a degree that the region is now commonly called the Texas Brush Country. Many woody species have increased, including mesquite, live oak, acacias, brazil (*Zizyphus obovata*), spiny hackberry (*Celtis Pallida*), whitebrush (*Aloysia gratissima*), lime pricklyash (*Zanthoxylum fagara*), Texas persimmon (*Diospyros texana*), shrubby blue sage (*Salvia ballotiflora*), and lotebush (*Zizyphus obtusifolia*).

Characteristic grasses of the sandy loam soils are seacoast bluestem (*Schizachyrium scoparium* var. *littorale*), bristlegrasses (*Setaria*), paspalums, windmillgrasses (*Chloris*), silver bluestem, big sandbur (*Cenchrus myosuroides*), and tanglehead. The dominants on the clay and clay loams are silver bluestem, Arizona cottontop (*Digitaria californica*), buffalograss, common curlymesquite (*Hilaria belangeri*), and species of *Setaria, Pappophorum, and Bouteloua*. Low saline areas are characterized by gulf cordgrass, seashore saltgrass, alkali sacaton (*Sporobolus airoides*), and switchgrass. Forbs include orange zexmania (*Zexmania hispida*), bush sunflowers (*Simsia*), velvet bundleflower (*Desmanthus velutinus*), tallowweeds (*Plantago*), lazy daisies (*Aphanostephyus*), Texas croton (*Croton texensis*), and western ragweed. Grasses of the oak savannahs are mainly little bluestem, Indiangrass, switchgrass, crinkleawn (*Trachypogon secundus*), and species of Paspalum. Pricklypear is characteristic throughout most of the area. Forbs generally associated with all but the most saline soils are bush sunflower, orange zexmania, shrubby oxalis (*Oxalis berlandieri*), white milkwort (*Polygala alba*), American snoutbean (*Rhynchosia americana*), and greenthread (*Thelesperma nuecense*).

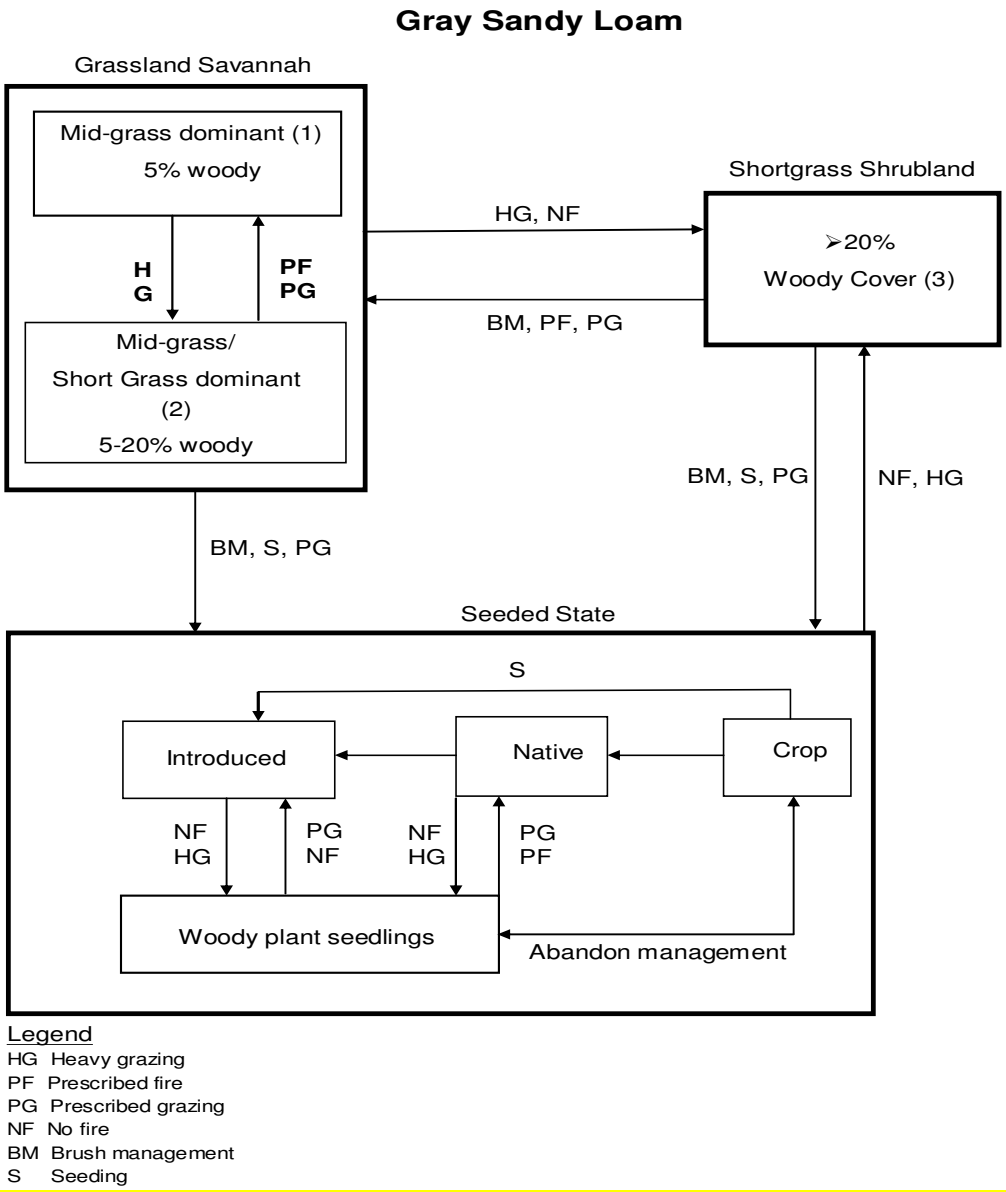
Because the South Texas Plains lie almost entirely below the hyperthermic line, introduced tropical species do well. The introduced species buffelgrass (*Cenchrus ciliaris*) has proliferated and is common on loamy to sandy soils in the western half of the area. Coastal bermudagrass, kleingrass (*Panicum coloratum*), and rhodesgrass (*Chloris gayana*) are also common introduced species in tame pastures.

Range is the major land use, but irrigated and dryland cropping of cotton, sorghum, flax, small grains, and forages are also important. Citrus, vegetables, and sugarcane do well in the Lower Rio Grande Valley. Many acres are in large landholdings, such as the King Ranch (825,000 acres). Livestock production is primarily cow-calf range operations, and wildlife production for hunting and recreational use are becoming increasingly important. The South Texas Plains vegetational area is known nationwide for its large white-tailed deer (*Odocolieus virginianus*). Quail (*Colinus virginiana*), mourning dove (*Zenaida macroura*), turkey (*Meleagris gallopavo*), feral pigs (*Sus scrofa*), and javelina (*Dicotyles tajacu*) are other major game species. Stocker operations and feedlot operations are intermixed with cow-calf operations. Sheep and goat enterprises, once common throughout the area, are now confined mostly to the northernmost part because of coyote predation. Integrated use of range, crops, and forages is increasing as is vegetable and peanut production where irrigation is possible.

Specific Reference to a Dominant Ecological Site

For the purpose of this paper, a proposed ecological site (submitted but not yet available in approved ESD on NRCS web site) in the South Texas Plains (83B) will be used to illustrate the vegetation steady states and transitions that occur from the HCPC through the process of retrogression to those communities more commonly existing today. A Gray Sandy Loam ecological site is a commonly occurring sites in the MLRA.The proposed ESD for a Gray Sandy Loam site includes the state and transition model shown in Figure 3.

Figure 3. State and Transition model (proposed), Gray Sandy Loam site, South Texas Plains PE 19-31.



The plant communities that can be found on this site range from a mid-grass dominant to a brush covered site with bare ground. This diversity in plant communities is in direct response to grazing management, fire, and drought.

The historic climax plant community (1) was composed of predominantly mid-grasses such as, trichloris (*Chloris spp.*), Plains bristlegrass (*Setaria macrostachya*), pink pappusgrass (*Pappophorum bicolor*), Arizona cottontop (*Digitaria californica*), silver bluestem (*Bothriochloa laguroides*), green sprangletop (*Leptochloa dubia*), sideoats grama and lovegrass tridens (*Tridens eragrostoides*). A small percentage of woodies such as guajillo, blackbrush, spiny hackberry, vine ephedra (*Ephedra antisyphilitica*), condalias (*Condalia* spp.) and many others were scattered across the landscape. Numerous perennial forbs occurred on the site including snoutbean, velvet bundleflower, sensitivebrier, bush sunflower, orange zexmenia, gaura, skeletonleaf goldeneye and numerous annual forbs. It was maintained by periodic grazing by roaming herds of wildlife, and numerous fires that were set by lightning and the native Americans. The site was productive, and maintained a high percentage of ground cover with forage production ranging from 1000 (low year) to 3400 (high year) pounds per acre (Table 5). Runoff of rainfall was medium, being in the hydrologic group B, with a hydrologic curve number of about 60. Soil fertility and available water-holding capacity are low to medium.

After settlement by European man, the area was fenced and in many instances stocked beyond its natural capacity with livestock. Fires were stopped by the reduction of fine fuel due to over grazing and the efforts of ranchers to extinguish wildfires to protect their investments in forage, livestock, facilities, and life. The combination of these activities coupled with periodic drought natural to the area, caused the plant community to change.

In the historic climax plant community, the mid-grasses dominated the short grasses due to their ability to capture sunlight and shade the shorter grasses. The mid-grasses also had deeper root systems that allowed them to capture the deep moisture while the short grasses had shorter root systems and could capture only the shallow moisture. Due to these differences, the mid-grasses maintained dominance over the short grasses as they could produce more food and maintain a higher state of health and vigor in times of drought. Fire occurred on a regular basis as there was normally good fine fuel. When fires started They could often burned for days, as there was nothing but rivers or denuded low producing ecological sites to stop them. These fires maintained the woody component to a small percentage of the total production, as well as canopy cover. Fires assisted in maintaining a good component of perennial forbs on the site by opening the ground cover to allow their establishment and regeneration and breaking the dormancy of the seeds.

As the stocking rates exceeded the carrying capacity of he land and the natural graze-rest cycles were broken by continuous grazing, the mid-grasses were grazed to the point that they could no longer produce the food in their leaves to maintain there health and vigor. When they were consistently grazed to the point where little leaf area was left, they stopped supplying the root system with food, as all available food produced was being

used to grow more leaf area to enhance the food manufacturing process. If overgrazing persisted, root systems of the overgrazed plants continued to recede. In time, with continued close grazing, the mid-grasses would become more shallow rooted, weaker plants with small leaf area less able to survive the frequent droughts in the area. Long-term over utilization of the mid-grasses caused these species to decline and fostered spread of the short grasses on the site. These short grasses were fall witchgrass (*Panicum dichotomiflorum*), sand dropseed (*Sporobolus cryptandrus*), hooded windmillgrass (*Chloris cucullata*), curlymesquite (*Hilaria belangeri*), buffalograss (*Buchloe dactyloides*), perennial threeawn (*Aristida* spp.), and slim tridens (*Tridens muticus*). If heavy continuous grazing continued, common invaders were croton, ragweed (*Ambrosia* spp.), tumblegrass (*Schedonnardus paniculatus*), perennial broomweed (*Gutierrezia sarothrae*), grassbur (*Cenchrus incertus*), Texas bristlegrass (*Setaria texana*), and halls panicum (*Panicum hallii*).

As this reduction of mid-grasses and expansion of short grasses was occurring, fires were reduced as explained above. This allowed guajillo to dominate the site to form a dense canopy together with blackbrush, condalia, wolfberry (Lycium berlandieri), pricklypear, Texas persimmon (*Diospyros texana*), paloverde (*Parkinsonia texana*), ceniza (*Leucophyllum frutescens*) and coma (*Bumelia* spp). With their domination, these plants now captured the sunlight first and occupied the soil profile with root systems, therefore placing the short grasses and the remnants of mid-grasses in a sub-dominant position. At this point the area is represented by the Shrubland site (3) with a canopy of brush greater than 20 percent and often reaching between 60 percent to total closure. In the heavy brush cover, understory vegetation will range from a cover of short and mid grasses to bare ground. The Shrubland state is a new steady state that will exist until energy is applied to reduce the brush competition, increase the mid-and tallgrass species through proper grazing and a brush management maintenance program. The area may need to be seeded with a seed source of native seeds and a good grazing management program established to maintain the health and vigor of the forage component.

Plant community 1 in the S/T model (Table 5) represents the HCPC. It is a fire climax, midgrass plant community that has less than 5 percent canopy of woody plants. The grasses are trichloris, Arizona cottontop, Plains bristlegrass, pink pappusgrass, silver bluestem, green sprangletop, sideoats grama, lovegrass tridens, fall witchgrass, sand dropseed, hooded windmillgrass, curlymessquite, buffalograss, perennial threeawn, and slim tridens. The woody plants are blackbrush, spiny hackberry, vine ephedra, condalias, wolfberry, guajillo, guayacan, Texas persimmon, paloverde, cactus, desert yaupon, Texas kidneywood, allthorn, ceniza coma and mesquite. There are numerous forbs including snoutbean, velvet bundleflower, sensitivebrier, dalea bushsunflower, orange zexmenia gaura, skeletonleaf goldeneye and numerous annual forbs. Recurrent fire and grazing by bison and other wildlife were natural components of the ecosystem.

With settlement by European man came long-term overstocking the range with domestic animals. Naturally occuring fires no longer provided control of the woody plants as the fine fuel (primarily grasses) was reduced so that it would not carry a fire, or the fire was stopped by ranchers to protect their investment. The change of these two very

important components of the ecosystem caused a dramatic change in the plant communities. The midgrasses gave way to the short grasses and the brush started to increase causing a shift to the Mid-grass/ Short Grass Dominant, 5-20 % canopy phase, plant community (2). This phase can be managed back to the Mid-grass Dominant, 5% woody phase through the use of prescribed grazing and prescribed fire. Once the woody canopy exceeds approximately 20 %, a threshold will have been passed to the Shrubland steady state. In this case, energy in the form of heavy equipment and/or herbicides will be required along with prescribed grazing to shift the plant community back to the Grassland Savannah steady state.

The Grassland Savannah steady state can be converted to the Seeded steady state by controlling the brush and seeding to native or introduced grasses. It may also be plowed and converted to cropland.

Table 5. Annual Production (lbs/ac) by Plant Type (HCPC)

Plant Type	Low	Representative Value	High
Grass/Grasslike·	750	2295	3060
Forb	100	128	170
Shrub/Vine	150	127	170
Total	1000	2550	3400

This phase of the Grassland Savannah steady state (community 2) still exhibits a savannah plant structure with the woody species canopy being as much as 20%. Guajillo is the major increaser brush species with blackbrush, condalia, wolfberry, pricklypear, Texas persimmon, paloverde, ceniza and coma. This is a result of fire being removed as a component of the site. Heavy continuous grazing takes many of the mid-grasses out of the site and they are replaced by short grasses such as hooded windmillgrass, sand dropseed, perennial threeawn, slim tridens, buffalograss, and curly mesquite. If heavy grazing continues, tumblegrass, grassbur, Texas bristlegrass, halls panicum, croton, and ragweed invade the site. This phase can still be managed back to the Midgrass Dominant, 5% woody phase if desired. It will take the introduction of fire to the ecosystem or some method of brush management that allows selective removal of the plants. A Prescribed Grazing plan will be essential to reverse the trend toward the short grass dominant community and increasing the midgrasses in the plant community.

Table 6. Annual Production (lbs/ac) by Plant Type (Community 2)

Plant Type	Low	Representative Value	High
Grass/Grasslike	360	1560	1850
Forb	100	200	300
Shrub/Vine	440	440	600
Total	900	2200	2750

If prolonged heavy grazing continues, and with the exclusion of fire, community 2 will transition to the Shortgrass Shrubland, >20% Woody Cover steady state. This plant community is a result of an irreversible transition from the Grassland Savannah to the Shrubland steady state. This threshold is passed when the woody canopy becomes such that insufficient fuel is produced to carry a fire that will control the woody canopy. The under story is very limited in production due to the competition for sunlight, water and nutrients. Guajillo dominates the site and forms a dense canopy together with blackbrush, condalia, wolfberry, pricklypear, Texas persimmon, paloverde, ceniza and coma. Invading forbs are croton, ragweed and perennial broomweed. Tumblegrass, grassbur, Texas bristlegrass and halls panicum invade the site. At this point there is very little under story production. There is much bare ground. Water infiltration is reduced on the site. Water infiltration does occur directly under some of the woody species such as mesquite as it moves down the trunk of the tree to the base. During the growing season, light showers are captured in the canopy of the shrubs and evaporate. Energy flow is predominantly through the shrubs and most nutrients are used by the shrubs. Winter rains can produce under story forage by the cool season annual forbs and grasses. Notice the decline in the high level of production of grass/grasslike from 3060 lbs/ac in community 1 to 1850 lbs/ac in community 2 and 300 lbs/ac in community 3. This represents a dramatic decrease in both forage resources and potential fuel load for prescribed fires.

Table 7. Annual Production (lbs/ac) by Plant Type (Community 3)

Plant Type	Low	Representative Value	High
Grass/Grasslike	50	200	300
Forb	50	200	300
Shrub/Vine	1200	1300	1400
Total	1300	1500	2000

Brush Management Practices

The South Texas Plains are the heart of the Texas “Brush Country”, sharing that designation with the Gulf Coast Prairie, as previously noted. Brush stands in the area are often aggregates of 15 or more species, most characterized by thorns or spines and existing in three strata – overstory of trees, mid-story of shrubs and an understory of

subshrubs and cacti. Frequently the cover is so heavy that only shade-tolerant herbaceous plants exist and the access to grazing animals is precluded.

The brush management practices described for the Gulf Coast Prairies earlier in this paper are similar for the South Texas Plains. Chaining and rootplowing where the most popular of the early mechanical practices utilized in the area and have been applied on hundreds of thousand of acres in the MLRA. While rootplowing may obtain near 100 percent mortality of the existing woody plant species on the treated area, the soil seed bank ensures that most species will eventually recover on the treated sites. However, there is a differential recovery rate by species, with some of the least desirable browse species, such as mesquite and twisted acacia recovering much more quickly than the better browse plants, such as spiny hackberry (Hamilton et al.1981). With proper grazing management, rootplowing is expected to provide an increase in forage production for as long as 15-20 years when used on heavily brush infested sites in the area. If follow-up maintenance practices, such as IPT chemical or mechanical are used, the increase in productivity of the site can be extend for many additional years.

Chaining was used primarily in the 1940' and 50's on the original stands of large mesquite infesting the area. Where the practice was applied on sandy or sandy loam soils (rather than heavy clay soils) and/or if soil moisture was optimum, large areas were essentially cleared of mesquite or other large trees in the same treatment area. However, as has been well documented, the shrubby species that were present at the time of chaining and that were not uprooted grew vigorously in the post-treatment are a following their release form the over story mesquite competition. Chaining and rootplowing are credited also with the spreading of pricklypear on many sites (Dodd 1968). Other mechanical practices, including roller chopping, shredding, disking, bulldozing and grubbing are all used in the region, both as broadcast treatments or as IPT when feasible based on brush size and densities. The resprouting nature of woody species in the area limits the effectiveness of the skid steer loaders and shears, however, some operators are using a "cut stump" herbicide application on the plants immediately following shearing. The herbicide application equipment is built into the machine so that the shearing and herbicide applications are done in a single operation.

Chemical brush management practices also have a long history of use in the MLRA and are similar to the Gulf Coast Praires previously described herein. Mesquite and pricklypear tend to be greater problems in the South Texas Plains, while huisache is reduced in significance compared to the Gulf Coast Prairies, especially in the more western counties, such as Zavala and Dimmitt.

POST OAK SAVANNAH and BLACKLAND PRAIRIES

General

There are two additional MLRA that include portions of Counties within Region L. The Post Oak Savannah includes portions of DeWitt, Guadalupe and Caldwell Counties, as well as very minor portions of Victoria, Goliad, Gonzales and Wilson Counties. The

Blackland Prairies includes portions of Hayes, Comal, Bexar, Guadalupe, Caldwell, Gonzales and DeWitt Counties. Compared to the Edwards Plateau, Gulf Coast Prairies and Marshes and South Texas Plains, the land areas of the Post Oak Savannah and Blackland Prairies within Region L are very small and will be included together for this paper.

The Post Oak Savannah lies just to the west of the Pineywoods and mixes considerably with the Blackland Prairies area in the south. The Post Oak Savannah is a gently rolling, moderately dissected wooded plain.

Upland soils are gray, slightly acid sandy loams, commonly shallow over gray, mottled or red, firm clayey subsoils. They are generally droughty and have claypans at varying depths, restricting moisture percolation. The bottomland soils are reddish brown to dark gray, slightly acid to calcareous, loamy to clayey alluvial. Short oak trees occur in association with tallgrasses. Thicketization occurs in the absence of recurring fires or other methods of woody plant suppression. This distinctive pattern of predominantly post oak and blackjack oak (*Quercus marilandica*) in association with tallgrasses also characterizes the vegetation of the Cross Timbers and Prairies vegetational area. Associated trees are elms, junipers (*Juniperus*), hackberries (*Celtis*), and hickories (*Carya* spp.). Characteristic understory vegetation includes shrubs and vines such as yaupon (*Ilex vomitoria*), American beautyberry, coralberry (*Symphoricarpos orbiculatus*), greenbriar, and grapes.

Climax grasses are little bluestem, indiangrass, switchgrass (*Panicum virgatum*), silver bluestem (*Bothriochloa saccharoides*), Texas wintergrass (*Stipa leucotricha*), brownseed paspalum, purpletop, narrow leaf woodoats (*Chasmanthium sessiliflorum*), and beaked panicum (*Panicum anceps*). Lower successional species include brownseed paspalum, threeawn, broomsedge bluestem, splitbeard bluestem (*Andropogon ternarius*), rosette grasses, and lovegrasses (*Eragrostis*).

Forbs similar to the true prairie species are wild indigo, indigobush (*Amorpha fruticosa* var. *augustifolia*), senna, tickclover, lespedezas (*Lespedez* spp.), prairie clovers (*Petalostemon* spp.), western ragweed, crotons (*Croton* spp.), and sneezeweeds (*Helenium*).

The area is well suited to grain crops, cotton, vegetables, and fruit trees. It was extensively cropped through the 1940's, but many acres have since been returned to native vegetation or tame pastures. Pasturelands have frequently been seeded with introduced species such as bermudagrass, bahiagrass, weeping lovegrass (*Eragrostis curvula*), and clover.

Deer, quail, and squirrel are perhaps the most economically important wildlife species for hunting enterprises although many other small mammals and birds exist in the region. The major livestock enterprise is mixed cow-calf-yearling operations with many small herds on small landholdings. Livestock use either tame pastures, native pastures, or the

woodland areas for forage throughout the year. Wheat, oats, and rye are often planted for winter pasture.

The Blackland Prairies area intermingles with the Post Oak Savannah in the southeast and has divisions known as the San Antonio and Fayette Prairies. This rolling and well-dissected prairie represents the southern extension of the true prairie that occurs from Texas to Canada.

The upland blacklands are dark, calcareous shrink-swell clayey soils, changing gradually with depth to light marls or chalks. Bottomland soils are generally reddish brown to dark gray, slightly acid to calcareous, loamy to clayey and alluvial. The soils are inherently productive and fertile, but many have lost productivity through erosion and continuous cropping.

This once-luxuriant tallgrass prairie was dominated by little bluestem, big bluestem, indiangrass, tall dropseed (*Sporobolus asper* var. *asper*), and Silveus dropseed (*S. silveanus*). Minor species such as sideoats grama (*Bouteloua curtipendula*), hairy grama (*B. hirsuta*), Mead's sedge (*Carex meadii*), Texas wintergrass, and buffalograss (*Buchloe dactyloides*) have increased with grazing pressure. Common forbs are asters (*Aster* spp.), prairie bluet (*Hedyotis nigricans* var. *nigricans*), prairie-clover, and late coneflower (*Rudbeckia serotina*). Common legumes include snoutbeans (*Rhynchosia* spp.) and vetch. Mesquite, huisache, oak, and elm are common invaders on poor-condition rangelands and on abandoned cropland. Oak, elm, cottonwood, and native pecan (*Carya*) are common along drainages.

About 98 percent of the Blackland Prairie was cultivated to produce cotton, sorghum, corn, wheat, and forages during the latter part of the 19th century and the first part of the 20th century. Since the 1950's, pasture and forage crops for the production of livestock have increased, and now only about 50 percent of the area is used as cropland. Tame pastures occupy more than 25 percent of the land area, and the rest is used as rangeland. Small remnants of native vegetation exist for grazing or for native hay production. Livestock production with both cow-calf and steer operations are the major livestock use. Winter cereals are used extensively for livestock grazing in conjunction with tame pasture forages. Potential is good for increased production of food and fiber crops as well as forages. Mourning dove and bobwhite quail on the uplands and squirrel along streams are the most important game species.

Specific Reference to an Ecological Site

A Claypan Prairie site is typical of the Blackland Prairie MLRA and will also be used to illustrate the Post Oak Savannah MLRA as well. This tallgrass prairie site evolved and was maintained by the grazing and herding effects of native large ungulates, by rodents and rabbits, and by insects as well as the occurrence of periodic fire. Extreme climatic fluctuations over time may also have been important in the maintenance of the historic plant community.

The soils of this site are deep, noncalcareous sandy loams and clay loams. The topsoil is underlain at rather shallow depths by dense, hard, clayey material which restricts air, water movement, and root growth. The soils take in water slowly, but can hold large amounts of water and plant nutrients. The soils of this site give up water grudgingly to growing plants. Plants may wilt even though the soil has comparatively high moisture content. Heavy surface crusts develop in the absence of good vegetative cover.

The first killing frost occurs about November 15th and the last killing frost about March 15th. The growing season is about 300 days. Site specific weather data should be used for land management decision making. For site specific weather conditions, obtain data from a weather station close to the site. Site specific weather data may be obtained at NRCS county offices or from the Internet at http://www.wcc.nrcs.usda.gov/water/wetlands.html.

Table 8. Climatic data for a Claypan Prairie site, Blackland MLRA

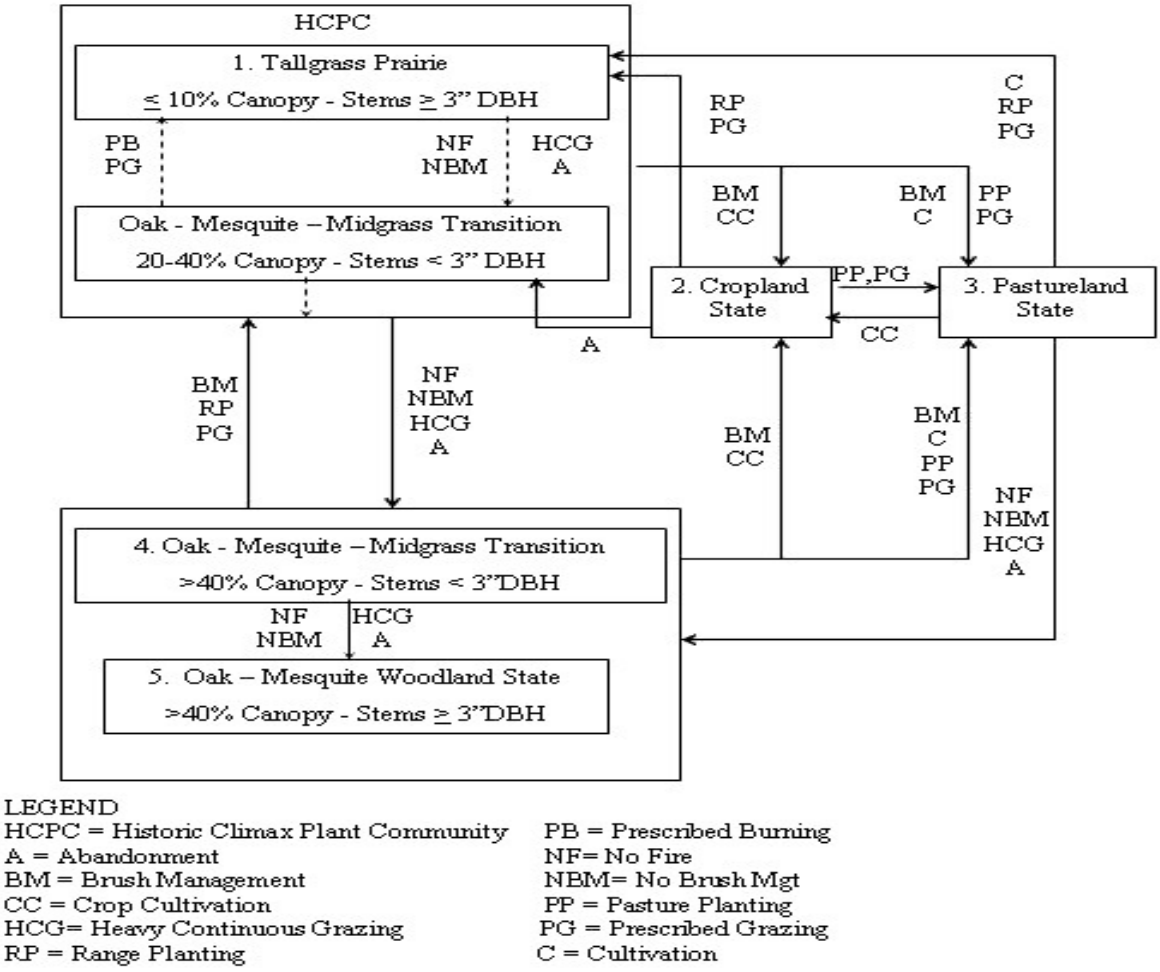
	Minimum	Maximum
Frost-free period (days):	266	274
Freeze-free period (days):	298	302
Mean annual precipitation (inches):	34.0	42.0

Continuous overgrazing by confined livestock or wildlife and the suppression of fire degrades the historic climax plant community. Continuous grazing will remove big bluestem (*Andropogon gerardii*), Indiangrass (*Sorghastrum nutans*), little bluestem (*Schizachyrium scoparium*), switchgrass (*Panicum virgatum*), and preferred forbs such as Engelmanndaisy (*Engelmannia peristenia*), Illinois bundleflower (*Desmanthus illinoensis*), gayfeather (*Liatris* spp.), and compass plant (*Silphium* spp.). These plants will be replaced by less productive perennial and annual grasses and forbs including silver bluestem (*Bothriochloa laguroides*), windmillgrass (*Chloris* spp.), threeawns (*Aristida* spp.), croton (*Croton* spp.), annual broomweed (*Amphiachyris dracunculoides*), and snow on the prairie (*Euphorbia bicolor*). With continued overgrazing, no brush management, and the absence of fire, a community dominated by woody species including mesquite (*Prosopis glandulosa*), post oak (*Quercus stellata*), hackberry (*Celtis* spp.), winged elm (*Ulmus alata*), and Eastern red cedar (*Juniperus virginiana*) will replace the grassland.

The historic climax plant community (HCPC) of this site is a prairie or very open savannah. Live oak (Quercus virginiana), winged elm, or hackberry may occur along water courses or in scattered motts and provide 5 to 10 percent canopy cover. Large old post oak trees may be widely scattered over this site. The herbaceous plant community is dominated by little bluestem and Indiangrass which usually constitutes 50 to 65 percent of the total annual yield. Switchgrass, big bluestem, Florida paspalum (*Paspalum floridanum*), sideoats grama (*Bouteloua curtipendula*), silver bluestem, and tall dropseed (*Sporobolus compositus*) are important components of the warm season grass population. Virginia (*Elymus virginicus*) and Canada (*Elymus canadensis*) wildrye and Texas

wintergrass (*Nassella leucotricha*) are components of the cool season grass population. Important forbs include Engelmanndaisy, gayfeather (*Liatris* spp.), bundleflower, prairie petunia (*Ruellia humilis*), and yellow neptunia (*Neptunia lutea*). Grazing prescriptions that permit acceptable grazing periods and allow adequate rest periods along with prescribed fire every three to five years are important in the maintenance of the historic climax plant community and the prairie landscape structure. Continuous overgrazing or over-rest and the absence of fire tend to favor a vegetative shift towards woody species such as mesquite, elm, hackberry, post oak, persimmon (*Diospyros virginiana*), and honey locust (*Gleditsia triacanthos*). Without corrective measures, this shift will continue to a mesquite-oak shrub dominated community.

Figure 4. State and Transition Model, Claypan Prairie Site, Blackland Prairie MLRA



LEGEND

HCPC = Historic Climax Plant Community
A = Abandonment
BM = Brush Management
CC = Crop Cultivation
HCG= Heavy Continuous Grazing
RP = Range Planting
PB = Prescribed Burning
NF= No Fire
NBM= No Brush Mgt
PP = Pasture Planting
PG = Prescribed Grazing
C = Cultivation

As with other sites discussed previously, the S/T Model for the Claypan Prairie site indicates the dramatic decline in production of forage species as retrogression away from the HCPC occurs. To illustrate this for a site representative of the MLRA, the following annual production tables are provided. The first table (Table 9) shows at the high level of production 6050 lbs/ac, of which 4850 lbs/ac is from grass and grasslike plants. Most of this production is from tall and midgrasses..

Table 9. Annual Production (lbs/ac) by Plant Type (HCPC)

	Annual Production (lbs/AC)		
Plant Type	Low	Representative Value	High
Forb	300	450	600
Grass/Grasslike	2425	3600	4850
Shrub/Vine	150	225	300
Tree	150	225	300
Total:	3025	4500	6050

Table 10 provides the annual production (lbs/ac) for the Oak-Mesquite-Midgrass transition state in the S/T model. This plant community is a transitional community between the prairie, pastureland, or cropland and the oak-mesquite woodland state. It develops in the absence of fire or mechanical or chemical brush management treatments. It is usually the result of abandonment following cropping or yearly continuous grazing. In addition to the naturally occurring winged elm, hackberry, bumelia (*Sideroxylon lanuginosum*), live oak, and post oak - mesquite and Eastern red cedar increase in density and canopy coverage (20 to 40 percent). In some cases, especially in abandoned cropland situations, mesquite may dominate the woody component of the community. Species whose seed is windblown (elm) or animal dispersed (mesquite, Eastern red cedar, bumelia) are the first to invade and dominate the site. Remnants of little bluestem and Indiangrass may still occur, but the herbaceous component of the community becomes dominated by lesser producing grasses and forbs. Silver bluestem (*Bothriochloa saccharoides*), windmill grass (*Chloris* spp.), white tridens (*Tridens albescens*), fall witchgrass (*Digitaria cognata*), threeawn (*Aristida* spp.), Texas wintergrass (*Nassella leucotricha*), Halls panicum (*Panicum hallii*), western ragweed (*Ambrosia psilostach*ya), croton (*Croton* spp.), annual broomweed (*Amphiachyris dracunculoides*), and snow on the prairie (*Euphorbia bicolor*) commonly occur.

If the woody shrub canopy has not exceeded 40 percent prescribed burning on a 3 to 5 year interval in conjunction with prescribed grazing is a viable option for returning this community to a tallgrass prairie that may resemble the historic clima x plant community. If the woody canopy has exceeded 40 percent (Oak-Mesquite-Midgrass transition state, community 4), chemical or mechanical brush control must be applied to move this transitional community back towards the historic plant community. Total production on the site has dropped from 6050 lbs/ac in the HCPC community to 4200 lbs/ac in the Oak-

Mesquite-Midgrass transitional community (4). Grass and grasslike species provide approximately 2400 lbs/ac, most of which is composed of mid and short grasses that are less desirable as forage plants than plant community 1.

Table 10. Annual Production (lbs/ac) by Plant Type (Plant Community 4)

	Annual Production (lbs/AC)		
Plant Type	Low	Representative Value	High
Forb	300	450	600
Grass/Grasslike	1200	1800	2400
Shrub/Vine	450	675	900
Tree	150	225	300
Total:	2100	3150	4200

The final Community (5) used to contrast site production based on deviation from the HCPC steady state is the Oak-Mesquite-Woodland state (Table 11). This plant community is dominated by woody species including post oak, mesquite, hackberry, Eastern red cedar, honey locust, prickly ash, and bumelia. Canopy cover exceeds 40 percent. Understory shrubs and vines include coral berry, greenbriar (Smilax sp.), grape (Vitis sp.), prickly pear (Opuntia sp.), and baccharis (Baccharis halimifolia). Herbaceous composition and production is directly related to canopy cover. Texas wintergrass, purpletop tridens (Tridens flavus), silver bluestem, threeawn, sedges (Carex sp.), croton, and annual broomweed commonly occur. If the site is not abandoned cropland, chemical brush control along with prescribed grazing and prescribed burning is a viable treatment option for moving this community back towards the historic plant community. Mechanical brush control and seeding is usually the most viable treatment option when the objective is to return this state to a community that resembles the historic climax plant community. Production of forage species is dramatically reduced, with the shrubs, vines and trees making up over 55 percent of total site production at the high level. Grass and grasslike plants account for only 1200 lbs/ac at the high level of production. It is also significant that at the low level of production, indicative of frequent drought conditions, community 5 produces only about 600 lbs/ac of grass and grasslike plants.

Table 11. Annual Production (lbs/ac) by Plant Type (Plant Community 5)

	Annual Production (lbs/AC)		
Plant Type	Low	Representative Value	High
Forb	150	225	300
Grass/Grasslike	600	900	1200
Shrub/Vine	500	750	1000
Tree	850	1275	1700
Total:	2100	3150	4200

Brush Management Practices

When a Claypan Prairie site has retrogressed to plant communities 4 and 5, there is a thicketizing of woody vegetation that may include trees, such as post oak, elms, mesquite and hackberry, large enough to be effectively controlled with chaining. Soils on the site are deep and favorable in many areas for use of rootplowing. Bulldozing to push and uproot large trees is also a common practice. For woody species that are smaller than mature trees and where tree density is low (100-200 trees/ac), power grubbing is another mechanical treatment alternative. In low tree densities and where size is not limiting (stem diameters of <4 inches), low-energy grubbing is also a mechanical alternative. Understory vegetation including yaupon, coralberry, greenbrier and others will quickly expand in density following overstory removal. Simple top removal practices, such as shredding and roller chopping will give temporary relief from these shrub species, but should be followed with prescribed fire or IPT mechanical or chemical treatments to maintain brush control. For individual plants that occur in the woody plant composite and that are not resprouting species, sheering with a skid-steer loader would be an option. Eastern red cedar that occurs on the site is an example of a non-sprouting species that can be effectively controlled by sheering. The mechanical equipment discussed here has been described in detail in other sections of the paper.

Innovative IPT equipment, such as “El Tiburon”, the shark, has been developed to uproot woody plants with stem diameters up to 5 inches. This equipment operates on a 3-point hitch behind a rubber-tired tractor and “grabs” the tree trunk with two claw-type arms by closing hydraulic cylinders and then pulls the plant from the soil profile.

Chemical control on the site can be very effective for oak species. Broadcast chemical treatment with tebuthiuron (Spike 20P) at a rate of 10 lbs. of pellets (2 lbs. a.i.) will give a very high level of mortality of blackjack oak, post oak and winged elm. For other woody species, including hackberry, baccharis, elm, greenbrier, yaupon, Chinese tallow and pricklyash, chemical IPT provides a very high level of control (76-100% mortality). Eastern red cedar is effectively contolled chemically with IPT using picloram (Tordon 22K) or hexazinone (Velpar L® or Pronone Power Pellets®). Chemical control methods

for huisache and mesquite will be the same as described earlier in this paper for these species. For example, clopyralid (Reclaim®) applied broadcast alone or in combination with picloram (Tordon 22k) or triclopyr (Remedy) will give a modenate to high (36-75%) mortality of honey mesquite. Huisache and retama do not respond as well to broadcast chemicals as mesquite, but can be controlled to a moderate level (36-55%) of mortality with several herbicide compounds, including combinations of picloram (Tordon 22k) and triclopyr (Remedy) or picloram and clopyralid (Reclaim). Huisache can also be controlled at the same level with boardcast applications of fluroxypyr and picloram (1:1) (Surmount) and picloram (Tordon 22k) alone. Both mesquite and huisache can be effectcively controlled (very high mortality 76-100%) with IPT chemical treatments applied as either stem basal, cut stump or foliage sprays.

Potential to Augment Recharge and Streamflow Within Region L Through Shrub Control

In this section, we examine the scientific basis for using shrub control as a means of increasing groundwater recharge with an explicit focus on two of the landcover types within the Region L Planning area: (1) juniper woodlands within the Edwards Plateau Major Land Resource Area (MLAR) and (2) South Texas shrublands within the South Texas Plains MLRA—in particular those shrublands overlying the Carizzo-Wilcox recharge zone within Zavala and Dimmitt counties. We are focusing on these two areas because they offer the greatest opportunities for enhanced recharge through land management.

General Overview-Shrub Control and Water

Despite the uncertainties that remain, we are confident of a number of things regarding the connection between woody plants and streamflow. We know, for example, that this connection becomes stronger as annual rainfall and/or available water increases. There is extensive literature showing that in forests, streamflow increases following a reduction in the number of trees (Bosch and Hewlett 1982, Stednick 1996, Zhang et al. 2001). For rangelands, however, relatively fewer studies have shown that streamflow and or recharge can be increased by reducing the cover of woody plants. In most but not all semiarid regions, the energy available for evaporation of water is sufficiently high that most of the comparatively low amount of precipitation is “lost” to evapotranspiration, regardless of the type of vegetation present.

Rangeland areas with the most potential for increasing recharge through shrub control are those areas where deep drainage (water movement beyond the herbaceous rooting zone) can occur (Seyfried et al. 2005, Wilcox et al. 2006). This characteristic is found, for example, where soils are shallow and overlie relatively permeable bedrock (such as karst limestones). An example in Texas is the Edwards Plateau area, which supports large tracts of juniper woodlands and has considerably more “flowing water” than would be expected for a semiarid or subhumid climate (ca. 700 mm/yr). The explanation lies in the karst geology—a substrate of fractured limestone that allows rapid flow of water to the subsurface. Other soil types that may enable deep drainage are sandy soils. Shrublands in

region L that exhibit these characteristics are the juniper shrublands within the Edwards Plateau and the South Texas shrublands overlying the recharge zone of the Carrizo-Wilcox Aquifer. In this report, we summarize the available literature for both of these two areas.

Part I: Ashe Juniper Woodlands of the Edwards Plateau

The presence of springs is an excellent indication that subsurface flow exists in a region. On Texas rangelands, springs are most commonly associated with limestone or karst geology. Two important features of such sites—namely, shallow soils (which cannot store much water) and fractured parent material (which allows rapid, deep drainage of rainfall)—facilitate the presence of springs. Rangelands of this type, which in Texas mainly occupy the central part of the state, are typically dominated by Ashe juniper and live oak. There is a significant body of work examining how Ashe juniper affects the water cycle. We summarize these findings for the following spatial scales: (1) individual tree or small plot (the space occupied by a single tree); (2) hillslope or stand (large enough to encompass many trees, and thereby to manifest important hillslope processes such as overland flow, depression storage, and sediment deposition); (3) small catchment (large enough to incorporate channel and groundwater flow processes); and (4) landscape (encompasses watersheds of 20 km^2 or larger).

Tree Scale

Evergreen shrubs such as juniper have a large capacity for capturing precipitation, not only because they retain their leaves year round, but because they have a high leaf area per tree (Hicks and Dugas 1998). Owens *et al.* (2006) estimated that the canopy and litter layer of an Ashe juniper tree together intercept about 40% of the precipitation that falls on the tree annually. At the same time, the percentage varied dramatically depending on the size of the storm: close to 100% of the rainfall from small storms (<12 mm) was captured by interception, whereas a much smaller percentage (around 10%) was intercepted and evaporated during large storms. Transpiration from an Ashe juniper community should be greater than that from an herbaceous community because Ashe juniper transpires throughout the year, typically has a much greater community leaf area, and can access water at greater depths. Owens and Ansley (1997), on the basis of direct measurement of Ashe juniper transpiration rates, concluded that a mature Ashe juniper tree transpired as much as 150 l/d, which they estimated would be equivalent to 400 mm/yr.

In summary, dense stands of juniper intercept and transpire large quantities of water. In regions where juniper cover is extensive and dense, therefore, this species can have a major impact on the water cycle at the tree scale. However, because removal of juniper may result in increased growth and density of other vegetation, which would also transpire and intercept water, it is uncertain how much water would be "saved" by juniper removal. As discussed below, larger-scale studies are required to make such an assessment.

Stand Scale

At this scale, the primary measurements of evapotranspiration have been direct estimates made by means of micrometeorological technology. We know of only one such study for Ashe juniper communities: Dugas *et al.* (1998) measured evapotranspiration from an Ashe juniper community using the Bowen ratio/energy balance method. Two paired areas, each 200 x 600 m in size, were selected for measurement over a 5-year period. After the first 2 years, all Ashe juniper trees were removed from one of the areas by hand-cutting and burning. For the 2-year period following this treatment, the difference in evapotranspiration between the two areas was about 40 mm/yr; but this treatment effect disappeared in the third year of the study, after which evapotranspiration was similar in the treated and untreated areas. Some very recent work, also using micrometeorological technology, however estimates that evapotranspiration rates may be as much as 90 mm higher for woodlands than grasslands (James Heilman—personal communication)

Small Catchment Scale

Small catchments with springs. Over the past 150 years, many springs in Texas have dried up, perhaps owing to increased groundwater pumping (Brune 2002) and/or the spread of woody plant cover. There are many anecdotal accounts of springs drying following the encroachment of woody plants, and of spring flow returning after woody plant cover was removed or reduced. Increases in discharge from springs or spring-fed catchments following the removal of Ashe juniper have been documented in two studies. Wright (1996), working on a 3-ha catchment in the Seco Creek Watershed of central Texas, reported an increase in spring flow from 11.7 l/min during the 2-year pre-treatment period to 14.4 l/min following partial removal of Ashe juniper—this despite the fact that precipitation was lower in the post-treatment period. This increase in flow translates to about 40 mm/yr of additional water. Similarly, Huang et al. (2006) estimate that runoff from a small spring-fed catchment increased by about 45 mm/yr following removal of Ashe juniper from around 60% of the catchment.

Small catchments without springs. A few studies have examined the effect of juniper removal on small catchments where no springs were present. Richardson et al. (1979) compared runoff from two 3.7-ha catchments for an 11-year period. Juniper was removed from one of the catchments the fifth year, by root plowing. Surface runoff (presumably generated as Horton overland flow) was about 20% (13 mm/yr) lower following this treatment, but this was attributed to increased surface roughness that enhanced shallow surface storage. In another paired-catchment study (in the Seco Creek watershed), Dugas *et al*. (1998) found that when juniper cover was removed by hand-cutting, the treatment had little influence on surface runoff from these small (6- and 4-ha) catchments. Runoff accounted for about 5% of total precipitation and occurred only when precipitation intensity was high. Similarly, Wilcox *et al.* (2005) concluded that changes in density of Ashe juniper had little influence on streamflow from small catchments in the western portion of the Edwards Plateau.

Landscape Scale

For Ashe juniper rangelands, no large-scale experiments have been conducted. However, we may be able to infer information from analysis of historical streamflow.

Streamflow data going back to the early 1900s are available for many of the major rivers in Texas. These long-term data can provide insight into the nature and variability of streamflow and the relationship of streamflow to climate. In addition, such records may shed light on the sensitivity of streamflow to landscape-scale changes in vegetation cover. For example, we have good evidence that woody plant cover on the Edwards Plateau increased dramatically during the last century (Smeins et al. 1997). Therefore, if there is indeed a strong connection between streamflow and woody plant cover, we should be able to detect a decrease in streamflow that is independent of precipitation differences.

To date, only a few attempts at such analysis have been made for the Edwards Plateau. One of these studies, by the Lower Colorado River Authority, examined flow from 1939 to 2000 on one of the major rivers in the region, the Pedernales, which drains an area of over 2300 km^2 (LCRA 2000). The results showed no evidence of changes in streamflow that were independent of changes in climate during this period. If woody plant cover has increased in this basin, as it has throughout much of the Edwards Plateau (Smeins et al. 1997), then these results would indicate that at very large scales, rivers are relatively insensitive to changes in woody plant cover. Unfortunately, since there has been no detailed assessment of vegetation change in the Pedernales basin, we cannot definitively say to what extent woody plant cover has changed during the last 60 years—if it has changed at all.

Part II: South Texas Shrublands

Within the South Texas Shrublands MLRA, the areas with the most potential for enhanced groundwater recharge through vegetation management, would be those overlying sandy soils. Of particular importance would be those areas overlying the recharge zone of the Carrizo-Wilcox aquifer.

Field Studies

There have been relatively few investigations in the South Texas Plains that examine the influence of woody plants on recharge. We will review what literature is available and then relate it to work in other landscapes.

The only published study completed in South Texas is that by Weltz et al. (1995). This work was conducted at the La Copita Research Area in Jim Wells County. Dominant woody plants at this location are mesquite, brasil, spiny hackberry, and lime prickly ash. Soils on the site were within the Delfina fine sand loam-Miguel fine sandy loam soil complex. This study compared recharge rates on three vegetation type: bare, herbaceous cover, and woody plants. Recharge was estimated on the basis of soil water monitoring

to a depth of 2 meters. Monitoring occurred for two years, but rainfall during one of those years was well below normal and no recharge occurred on any of the sites. During the other year, when rainfall was 887 mm recharge was 78, 22, and 0 on the bare, grass, and shrub plots respectively. On the basis of this study, we would conclude (1) that little to no recharge occurs if woody plants dominate (2) if woody plants are removed there will be some recharge that is equivalent to around 3% of rainfall and finally (3) recharge may be around 10% of rainfall in the complete absence of vegetation cover. This would perhaps be comparable to fallow dryland agriculture.

There have been no other studies conducted in South Texas but the results of this study are generally consistent with work conducted elsewhere in Texas (Wilcox 2002, Wilcox et al. 2006). Work on mesquite rangelands in the Rolling Plains of Texas suggests that annual recharge rates are 3 mm or less for mesquite covered areas and 5-10 mm if the mesquite are removed. In the absence of vegetation annual recharge was around 15 mm (Carlson et al. 1990). Mesquite removal had a much larger effect on deep recharge in the Blackland Prairie region of Texas and recharge in general was much higher(Richardson et al. 1979). This is because the soils in the Blackland Prairie will form deep cracks during dry periods which periodically provide opportunities for significant and deep recharge. In all of the studies mentioned above, recharge rates were determined by monitoring soil moisture. An alternative approach is that of using flux towers for determining evapotranspiration rates. A study of this type on mesquite rangelands of North Texas (Dugas and Mayeux 1991) concluded that recharge rates were little affected by mesquite removal.

The studies that have been completed in Texas are generally consistent with work in other semiarid locations which highlights the strong control that vegetation cover has on recharge (Sandvig and Phillips 2006, Scanlon et al. 2006). Almost without exception, recharge rates are low to zero under shrub canopies (Seyfried et al. 2005). Also, the complete removal of vegetation generally results in significant increases in recharge (Scanlon et al. 2005).

Hydrological Modeling

Hydrological models can provide insight concerning recharge dynamics. A comprehensive modeling exercise of recharge dynamics for the state of Texas has just been completed (Keese et al. 2005). This work highlights the strong influence of climate, soils and vegetation on recharge (Figure 5). Their simulations would suggest that for the Region L area, recharge would be less than 5-10 mm/year.

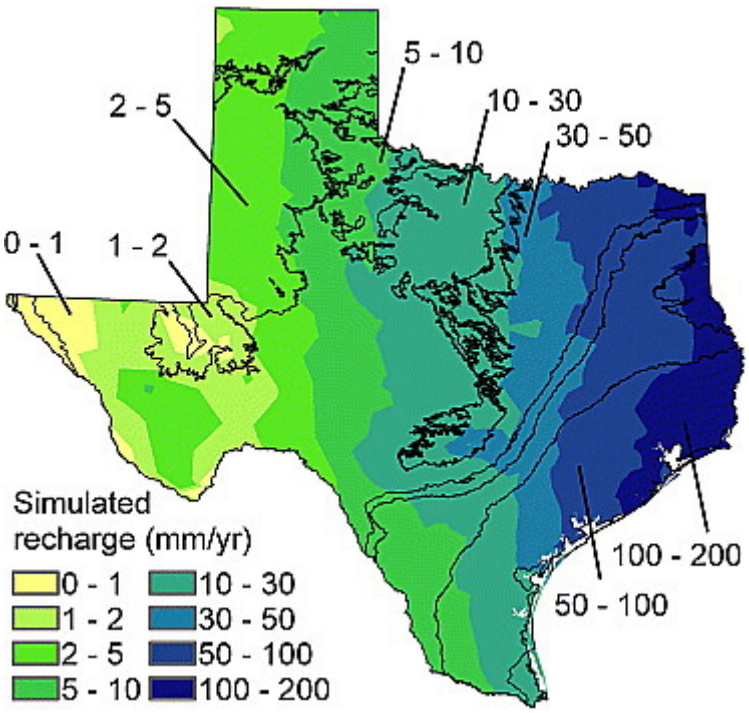


Figure 5. Simulated recharge rates for the state of Texas (Keese et al. 2005).

The influence of soil texture and vegetation on simulated recharge is summarized in Figure 6 below. Keese et al. (2005) found that the recharge rate declined by a factor of 2-30 times when vegetation was added to the model. These results would suggest that vegetation management on sandy soils can have a strong affect on recharge.

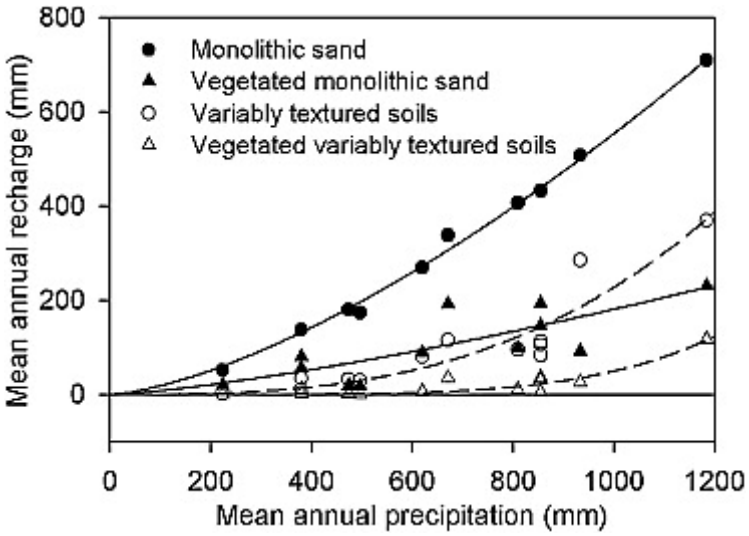


Figure 6. Results from the Keese et al. (2005) modeling study showing the relationship between simulated recharge, vegetation cover and soil texture.

Summary and Implications

Ashe Juniper Rangelands on the Edwards Plateau

The influence of Ashe juniper on the water budget remains the subject of some confusion and disagreement, in part because the implications of the scale at which measurements were made have not been fully considered. For example, at the tree scale, the most common measurement is some index of evapotranspiration by trees. After removal of trees, these numbers have often been extrapolated up without taking into account the compensatory effects of regrowth of trees or replacement by other vegetation. These measurements do not take into account water use by replacement vegetation, as the larger-scale studies do. For example, at the tree scale, for an area with an average annual precipitation of 750 mm/yr, an individual tree will intercept and transpire virtually all of the available water. At the stand scale, however, as estimated by Dugas *et al.* (1998), the difference in water consumption between a woodland and a grassland is between 40-50 mm/yr. Newer work suggests differences as high as 90 mm/year however. Water balance studies at the small-catchment scale (where springs exist) indicate water savings of around 50 mm/yr. (Huang et al. 2006).

From these results, we are increasingly confident that conversion of Ashe juniper woodlands to grasslands or more open savannas will translate to increases in spring flow and/or groundwater recharge at the small catchment scale. But it remains uncertain whether similar results will be seen at larger scales. At the landscape scale we have not found evidence of water savings due to changes in vegetation cover. The reason for this lack of evidence is not yet clear—whether (1) there has been no net change in woody plant cover; (2) there has been a change in woody plant cover but this has no influence on streamflow; or (3) there has been a change in woody plant cover and it has affected streamflow, but the signal cannot be detected because of too much "noise" in the data.

On the basis of the literature available, our current best estimate is that conversion of Ashe Juniper woodlands into open savannas would result in an average increase in water yield (streamflow and recharge) of around 50 mm/year.

South Texas Shrublands

On the basis of this review, we believe that recharge in the South Texas shrublands is very limited if shrub cover is dense. All of the available data strongly suggest that in the presence of dense shrub cover, there will be little if any recharge. However, both the modeling and field work suggest that in the absence of shrubs, recharge will be appreciably higher—especially for sandy soils. For example, Weltz et al (1995) found that when rainfall was slightly above average, recharge was around 20 mm/year for grass covered areas. The implications of this then are that shrub control over the recharge area would in the long term increase distributed recharge.

Our estimate that for the South Texas shrublands, average recharge on sandy soils could be increased by shrub control anywhere from 10 -20 mm/year. In the figure below, we

make a rough calculation of the potential increase in recharge that may occur if shrubs were removed within the Carrizo Wilcox recharge zone. For example, distributed recharge would be around 5000 ac-ft / year if shrubs were cleared on 200,000 acres of rangeland if recharge rates were about 10 mm/ year.

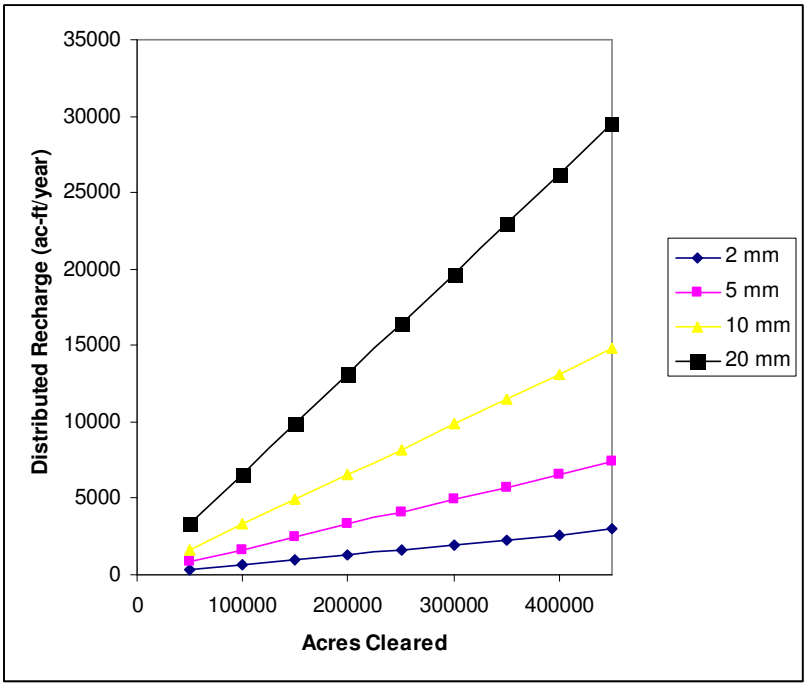


Figure 7. The potential increase in recharge from shrub control over the recharge zone in the Wintergarden Groundwater Area.

Assessing the Cost Effectiveness of Brush Control to Enhance Off-site Water Yield

Introduction

This section reports the assumptions and methods for estimating the cost effectiveness of a program to encourage rangeland owners to engage in brush control for purposes of enhancing groundwater recharge. Vegetative cover, applicable methods of brush control and the estimation of increased water yield from control of the dominate brush species are described in earlier sections of this report.

This section provides details on how the costs per acre foot (ac.ft.) of added water resulting from brush control were calculated for the different brush types-regions. The estimates of additional groundwater recharge resulting from the control of Ashe juniper in the areas of the Edwards Plateau which contribute to recharge of the Edwards Aquifer and estimates of additional groundwater recharge resulting from the control of mixed brush on sandy soils in the areas of Dimmit and Zavala counties which contribute to recharge of the Carrizo-Wilcox Aquifer are used along with brush control cost estimates from other studies to obtain estimates of per acre-foot costs of added water.

Cost of Brush Control Methods

Data on costs of various brush control practices for Texas have recently been obtained from an array of contractors, technical experts and agricultural technical service agency personnel in conjunction with another study being conducted by two of the authors of this report (Pestman, 2007). The data indicate that brush control costs are highly variable. Factors that influence cost and contribute to the high variability include the type, size and density of the target brush species; the type, rock content and slope of soil in which the target species is growing; whether the target species sprouts re-growth from root buds; whether cost effective herbicides are available for controlling the target species; etc.

Edwards Plateau

In a previous section, it was reported that any of several different mechanical practices were appropriate for use in the control of Ashe juniper. The costs of these various mechanical practices may vary from less than $100 to as much as $400 per acre (Pestman, 2007). Also in a previous section of this report the added ground water recharge estimated to result from control of Ashe juniper was reported to be 50mm/year. The inch equivalent of 50mm/yr. is 2 in. which is also equal to 0.167 ft. Therefore, control of Ashe juniper on an acre of land is estimated to result in 0.167 added ac.ft. of groundwater recharge per year.

Another consideration in estimating the cost of the added groundwater recharge is the duration of the impact of the brush control practice on the increase in the annual rate of groundwater recharge. For example, if the brush control program is limited to only the initial practice, then re-growth of the brush will occur, such that 5 to 10 years after the initial treatment, the brush canopy will approach its pre-treatment level and there will no longer be any increase in groundwater recharge. Alternatively, by using follow-up brush control practices after the initial treatment to control the brush re-growth, the increased groundwater recharge gained from the initial brush control practice can be maintained for many more years into the future.

Fortunately, the follow-up brush control practices, like prescribed fire or chemical or mechanical individual plant treatments, are relatively inexpensive compared to the cost of the initial treatments. Therefore, brush control programs consisting of an initial practice plus appropriate follow-up practices at 3-6 year intervals after the initial practice can result in maintaining brush canopy at low levels and also maintaining the resulting increases in ground water recharge for many years into the future.

The results of extending the years of reduced brush canopy, and the resulting increased groundwater recharge, on the cost per acre foot of added groundwater recharge are illustrated in Table 12. below. The cost estimates or obtained by taking the per acre cost of the brush control practice, or cost of a program consisting of an initial plus follow-up practices, and dividing it by 0.167. This results in the estimated cost per acre foot of added groundwater recharge resulting from brush control if the practice, or program, is effective for only one year. Results of this calculation for several alternative levels of

brush control costs are shown in the second column of Table 12. Alternatively, the third and fourth columns illustrate the per acre foot costs of added groundwater recharge resulting from brush control if the brush control practice, or program, is effective for a period of five and ten years respectively.

Table 12. Cost/ac.ft. of added water for selected control costs and years of life of brush control practice – Edwards Plateau

Brush control cost/ac	Years brush control effective		
	1yr	5yr	10yr
$ 70.00	$ 419.16	$ 83.83	$ 41.92
$ 150.00	$ 898.20	$ 179.64	$ 89.82
$ 200.00	$1,197.60	$ 239.52	$ 119.76
$ 300.00	$1,796.41	$ 359.78	$ 179.64

South Texas Shrublands

In a previous section, it was stated that several herbicides and several different mechanical practices were appropriate for use in the control of mixed brush in South Texas. The costs of these various chemical practices are less variable and generally less costly than the mechanical practices in the Edwards Plateau as discussed above. In addition, the mechanical practices applicable to the control of mixed brush in South Texas would generally be less costly than when used in the Edwards plateau because the soils tend to be less rocky and the terrain is generally flatter in South Texas. Therefore, costs for mixed brush management in South Texas may vary from less than $50 to more than $100 per acre (Pestman, 2007). Also in a previous section of this report the added groundwater recharge estimated to result from control of mixed brush was reported to be between 10 and 20mm/year. To be conservative, we will use 10mm/year in the following analysis. The inch equivalent of 10mm/yr. is 0.4 in. which is also equal to 0.033 ft. Therefore, control of Ashe juniper on an acre of land is estimated to result in 0.033 added ac.ft. of groundwater recharge per year.

The need for follow-up practices to extend the effective life of initial control practices for mixed brush is as critical as it is for Ashe juniper control in the Edwards Plateau. The results of extending the years of reduced brush canopy, and the resulting increased groundwater recharge, on the cost per acre foot of added groundwater recharge is illustrated in Table 13. below. The cost estimates or obtained by taking the per acre cost of the brush control practice, or cost of a program consisting of an initial plus follow-up practices, and dividing it by 0.033. This results in the estimated cost per acre foot of added groundwater recharge resulting from brush control if the practice, or program, is effective for only one year. Results of this calculation for several alternative levels of brush control costs are shown in the second column in Table 13. Alternatively, the third and fourth columns illustrate the per acre foot costs of added groundwater recharge resulting from brush control if the brush control practice, or program, is effective for a period of five and ten years respectively.

Table 13. Cost/ac.ft. of added water for selected control costs and years of life of brush control practice – Carrizo - Wilcox

Brush control cost/ac	Years brush control effective 1yr	5yr	10 yr
$ 35.00	$1,060.61	$ 212.12	$ 106.06
$ 50.00	$1,515.15	$ 303.03	$ 151.52
$ 75.00	$2,272.73	$ 454.55	$ 227.27
$ 100.00	$3,030.30	$ 606.06	$ 303.03

Cost Effectiveness Summary

If brush control programs were implemented for the two regions described above, and if provisions of the programs require participating landowners to reduce brush canopies to 5 percent and maintain them at this level or less for 10 years, then the costs per acre foot of added ground water recharge would be expected to range between $40 and $180 per acre foot in the Edwards Plateau and between $100 and $300 per acre foot in The Carrizo – Wilcox Aquifer recharge area. It should be noted that these estimates of added groundwater recharge cost are based only on the highly variable costs of the brush control practices and/or programs. There are many other factors which would impact the ultimate costs, several of which are discussed in the next section.

Additional Considerations

It should be noted that public benefit in the form of additional water depend on landowner participation and proper implementation and maintenance of the appropriate brush control practices. It is also important to understand that landowner participation in a brush control program primarily depends on the landowner's expected economic consequences resulting from participation (Bach and Conner , 1998). With this in mind, the analyses described in this report are predicated on the objective of limiting rancher costs associated with participation in the program to no more than the benefits that would be expected to accrue to the landowner as a result of participation. Landowner benefits are usually based on expected increases in net returns from the typical livestock (cattle, sheep, or goats) and wildlife enterprises that would be reasonably expected to result from implementation of the brush control program (Conner and Bach, 2000). Previous studies based on these limits to landowner costs have shown that landowner's share of brush control costs would vary from 37 to 8 percent of total direct costs of brush control programs (Olenick, et al., 2004a) .

It is explicitly assumed that the difference between the total cost of the brush control practices and the value of the practice to the participating landowner would have to be contributed by the state in order to encourage landowner participation. Thus, the state (public) must determine whether the benefits, in the form of additional water for public

use, are equal to or greater than the state's share of the costs of the brush control program.

Success of each brush management scenario in improving groundwater recharge depends on the willingness of landowners to participate. One reason why landowners may be reluctant to participate is the perceived impacts to hunting enterprises, especially deer hunting. These impacts could include loss of wildlife habitat due to fragmentation, loss of thermal and/or escape cover, loss of wildlife diversity, and a potential loss of food sources (Rollins, 2000). Another reason that less than 100% of the brush will be enrolled is that many of the tracts containing brush will be so small that it will be infeasible to enroll them in the control program. Similarly, much of the brush infested land, particularly in the Edwards Plateau, will have more than 15% slope, and thus not practical for mechanical brush control practices due to safety considerations (Olenick, et al., 2004a).

Another reason why brush management programs may cause landowners to be reluctant to participate is the importance of brush to property values. The top motives for the purchase of the majority of landholdings throughout the state are recreation followed by the desire for rural homesites (Wilkins et al., 2000). Agriculture production, which generally benefits from decreased levels of brush, is not the driving force behind property purchases that it once was.

One cost not incorporated into the cost effectiveness calculations is the transaction costs associated with implementing any cost-share program. These include costs associated with contract development, monitoring, and any public hearings.

In order for brush control programs to work, the public must be willing to enroll their land in such a program. Landowner surveys conducted by the TAES (Narayanan, et al., 2002; Olenick , et al., 2005) indicate that landowners in the Edwards Plateau would include only 49.15 percent of their moderate cover and 52.73 percent of their heavy cover in a brush management program. An additional consideration is found in research work by Thurow, et. al. that indicated that only about 66% of ranchers surveyed were willing to enroll their land in a similarly characterized program.

Finally, some aspects of the expected changes in ecosystem health and services, including groundwater recharge, provided by brush control practices can be extremely difficult or impossible to economically quantify (Olenick, et al., 2004b). Improvements in ecosystem stability and resilience, changes in non-game animal composition and abundance, and alterations of carbon sequestration capacity, all important concepts from an ecological viewpoint, are not addressed in this analysis.

Future Reports

Two additional reports on Land-based Water Conservation & Water Yield Practices in Region L will be produced if the Sponsor desires to continue this contract. Report II will contain a prioritized set of spatially explicit recommendations based on the information obtained and described in this report. Report II will include recommendations for the

most cost effective land-based water conservation practices that could be implemented to enhance ground and/ or surface water availability.

Report III will include recommended monitoring protocols that, if used with the implemented conservation practices to be delineated in Report II, would provide effective measures of the effectiveness of each practice implemented. The recommendations would be consistent with Texas Water Development Board protocols.

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Restoring Native Texas Rangelands for Increased Water Yield: Executive Summary

Canyon Lake. Photo credit: Edward Jackson ©2008

Performance of water catchments and the land-based water cycle is heavily influenced by vegetation and the management of that vegetation. Vegetation in south central Texas has undergone significant change over time, shifting from a grassland-dominated savanna to a heavily wooded landscape. This is due to the invasion of Ashe juniper (sometimes called "cedar") in the Edwards Plateau and mesquite in the South Texas Plains. This transformation to woodland may have reduced water available for recharge and streamflow. Woody plant invasion can be reversed through rangeland restoration. Initial costs, however, are generally more than a landowner can justify when considering livestock production alone.

Under certain circumstances, additional water yield results from rangeland restoration. As is suggested by several studies, there may be opportunities for creating incentive-based programs that lead to additional water yield through rangeland restoration.

Photo credit: Zereshk ©2008

Texas Hill Country, just north of Garner State Park.

With sponsorship from the Texas Wildlife Association Foundation, a team of Texas A&M University scientists have conducted a technical evaluation of land-based water conservation practices and their potential for water yield in south central Texas. The purpose of this evaluation was to determine the feasibility of rangeland restoration for increasing water yield. This team identified areas in south central Texas suitable for rangeland restoration programs. This report is a summary of their findings.

TEXAS A&M | Institute of Renewable Natural Resources

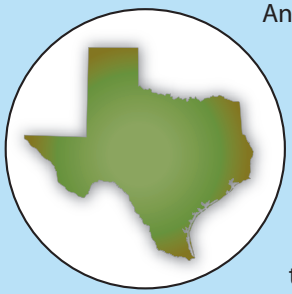
A summary of a technical report by:
Richard Conner
Wayne Hamilton
Brad Wilcox

With input from:
Neal Wilkins
David K. Langford
Todd Snelgrove

Background

The South Central Texas Regional Water Planning Group, also known as Region L, is one of 16 regional water planning groups across the state. These groups identify water needs, assess potential water supplies, and recommend strategies for meeting those needs for the Texas Water Development Board. It includes over 20 counties and the seventh largest city in the United States—San Antonio. The population of this area was about 2.0 million in 2000 and is projected to grow to about 4.3 million by 2060. Obviously, securing adequate supplies of fresh water for Region L is a mounting concern. Total water use (municipal, industrial, and agricultural uses) in the region was approximately 896,000-acre feet/year (an acre-foot is about 325,000 gallons) in 2000 and is projected to increase by 43 percent to 1.28 million acre-feet/year by 2060 (SCTRWPG 2006). Nearly 80 percent of the region's fresh water is obtained from underground aquifers—primarily the Edwards and the Carrizo-Wilcox. Due to the high demand placed on these aquifers, the amount of water withdrawn exceeds recharge. Thus the need to increase water available for recharge and streamflow is essential.

LAND STEWARDSHIP LANGUAGE IN THE TEXAS CODE



Anyone seeking to officially fund and implement land stewardship programs can now find authorization in our state law. Senate Bill 3 of the 2007 Session of the Texas Legislature amended Article 2, Section 2.02, Subchapter A, Chapter 1 of the Texas Water Code by adding Section 1.004. In this section, our leaders note the benefits of voluntary land stewardship and define the term. It reads:

Sec. 1.004. FINDINGS AND POLICY REGARDING LAND STEWARDSHIP.

(a) *The legislature finds that voluntary land stewardship enhances the efficiency and effectiveness of this state's watersheds by helping to increase surface water and groundwater supplies, resulting in a benefit to the natural resources of this state and to the general public. It is therefore the policy of this state to encourage voluntary land stewardship as a significant water management tool.*

(b) *"Land stewardship," as used in this code, is the voluntary practice of managing land to conserve or enhance suitable landscapes and the ecosystem values of the land. Land stewardship includes land and habitat management, wildlife conservation, and watershed protection. Land stewardship practices include runoff reduction, prescribed burning, managed grazing, brush management, erosion management, reseeding with native plant species, riparian management and restoration, and spring and creek-bank protection, all of which benefit the water resources of this state.*

With this language, the Texas Legislature officially recognized voluntary land stewardship practices as a means to improve water quality and quantity, opening the door for the development of effective land conservation/management programs designed to benefit water resources.

Influence of Woody Species on the Water Cycle

The two major natural areas of Region L are the Edwards Plateau and the South Texas Plains. Prior to European settlement in the 1800s, the Edwards Plateau and South Texas Plains were dominated by grassland. In the absence of fire and the presence of overgrazing, Ashe juniper has invaded large areas of the Edwards Plateau, and mesquite and mixed brush have overtaken much of the South Texas Plains. There is some evidence that rangelands dominated by these woody shrubs and trees may not yield as much water as rangelands dominated by grasses and herbaceous vegetation. A significant amount of research has been performed that addresses this issue at several scales.

EDWARDS PLATEAU—Research within the Edwards Plateau has focused on the water use of Ashe juniper at the individual tree level. A single, mature juniper tree can transpire approximately 33 gallons per day (Owens and Ansley 1997). In addition, as much as 40% of the precipitation that falls on a juniper tree is intercepted by the canopy and lost to evaporation (Owens et al. 2006). As a consequence, in an area that receives approximately 29.5 inches of annual rainfall, a mature juniper tree will intercept and transpire nearly all of the available water falling within its canopy.

How much water yield?

An additional acre-foot can be gained for every 5 to 8 acres of brush converted to native rangeland in the Edwards Plateau and for every 15 to 30 acres converted in the South Texas Plains.

Based on this, available water can be negatively impacted in regions where extensive juniper cover exists. However, this does not take into account the difference in water usage between juniper and the grasses and other vegetation that would replace it when restored.

Studies conducted at the stand scale have compared the differences in water usage between rangeland grasses and Ashe juniper. These studies show that in areas cleared of juniper, evapotranspiration rates (water lost to the atmosphere through evaporation and use by plants) were 1.6 inches/acre/year less than areas with intact juniper (Dugas et al. 1998).

There are several anecdotal accounts of springs drying following encroachment by juniper. Studies at the small catchment scale that focus on catchments with springs have shown increases in spring discharge following the removal of juniper. In some instances this occurred even when precipitation was below average following juniper removal. These studies estimate that 1.6 to 1.8 inches/acre/year of additional water were made available after restoration of rangelands (Wright 1996, Huang et al. 2006).

Balcones Escarpment.

Although there have been no large-scale experiments conducted that look at the landscape-scale impacts of juniper encroachment on streamflow, confidence is increasing that restoring rangelands on the Edwards Plateau will increase streamflow and recharge at the small catchment scale.

Based on current research, the best estimate is that converting 5 to 8 acres of juniper to rangeland would result in an approximate increase in recharge and streamflow of 1 acre-foot of water per year.

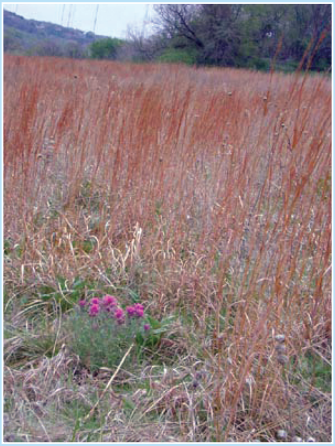
SOUTH TEXAS PLAINS— Compared to the Edwards Plateau, there has been little effort to study the influence of woody plants on recharge in the South Texas Plains. In studies that have been conducted, there has been evidence that rangeland restoration increases recharge. One field study indicated that there was no recharge on plots with dense shrub cover and 0.9 inches/acre/year of recharge on plots with grass cover (Weltz and Blackburn 1995). On the basis of this study, it can be concluded that recharge is limited on sites dominated by brush and that recharge can be increased if dense shrub cover is converted to grassland. Studies in other regions of Texas dominated by brush have yielded similar results.

Recent work using hydrologic modeling focuses on the strong influence of climate, soils, and vegetation on recharge in Texas. Based on these simulations, it

is estimated that recharge for the South Texas Plains is less than 0.2 to 0.4 inches/acre/year (Keese et al. 2005). Further investigation shows that the recharge rate declined by a factor of 2 to 30 times when vegetative cover was included in the model rather than focusing solely on climate and soil texture (Keese et al. 2005). This suggests that rangeland restoration on sandy soils where water has a chance to make it past the root zone may have a strong effect on recharge in the South Texas Plains.

All of the available research in the South Texas Plains suggests that little, if any, recharge occurs in the presence of dense shrub cover. However, both hydrologic modeling and fieldwork suggest that when rangeland grasses are restored, recharge will be higher—especially on sandy soils. ***On the basis of current research, best estimates are that 15 to 30 acres of south central Texas brushland restored to rangeland would yield 1 acre-foot of water per year.***

RANGELAND RESTORATION



Rangelands comprise 60 percent (90 million acres) of Texas land. In addition to supporting livestock production and providing habitat for native wildlife, they serve as the state's largest watershed.

The precipitation that falls on Texas rangeland is a major source of surface flow and aquifer recharge. The management of rangelands can have major impacts on the water available to Texas. Healthy rangelands provide high-quality drinking water, promote recharge, conserve soil, filter overland flow of water, provide forage for livestock, and provide wildlife habitat (Hays et al. 1998). Over the last century, encroachment of woody species across much of Texas' rangelands has degraded many of these services.

Rangeland restoration programs strive to reverse this trend. Through the use of sound management practices, woody species on Texas rangelands can be controlled, and rangelands can be restored.

There are many benefits to rangeland restoration including increased forage for livestock production. This allows the opportunity to increase stocking rates and ultimately increase revenue for landowners. Rangeland restoration can enhance wildlife habitat, thus enhancing hunting opportunities—a major source of income for Texas landowners.

Healthy rangelands provide a tremendous public benefit to Texans. Wise stewardship of this resource will have positive impacts on Texas for many generations—the greatest of which is a plentiful and clean supply of fresh water.

Saving the water and the soil must start where the first raindrop falls.
—Lyndon B. Johnson, 1947

Rangeland Restoration Techniques and Brush Management

The vast differences in terrain and vegetation between the Edwards Plateau and South Texas Plains require different approaches to rangeland restoration and brush management. Costs for both regions are highly variable based on a number of factors including size and density of the target brush species; the type, rock content, and slope of soil in which the target species is growing; whether the target species sprouts re-growth from root buds; and whether cost-effective herbicides are available for controlling the target species.

EDWARDS PLATEAU—Within the Edwards Plateau, Ashe juniper is the primary species targeted for brush management and subsequent restoration of rangelands. Ashe juniper is a non-sprouting species; i.e., juniper will die when all of the aboveground green material is removed. There are three primary methods used for controlling Ashe juniper—mechanical, prescribed fire, and biological. There are limited chemical treatments for the control of Ashe juniper.

Mechanical treatments involve the use of large equipment such as a bulldozer or skid steer loader that physically removes the aboveground portion of the juniper. Costs are variable, but based on current market

How much does it cost?

Assuming rangeland restoration practices are effective for at least 10 years, the cost to produce an additional acre-foot of water in the Edwards Plateau would be $40 to $180 depending on the method. Likewise, over the Carrizo-Wilcox Aquifer in south central Texas, the range is $100 to $300 per additional acre-foot.

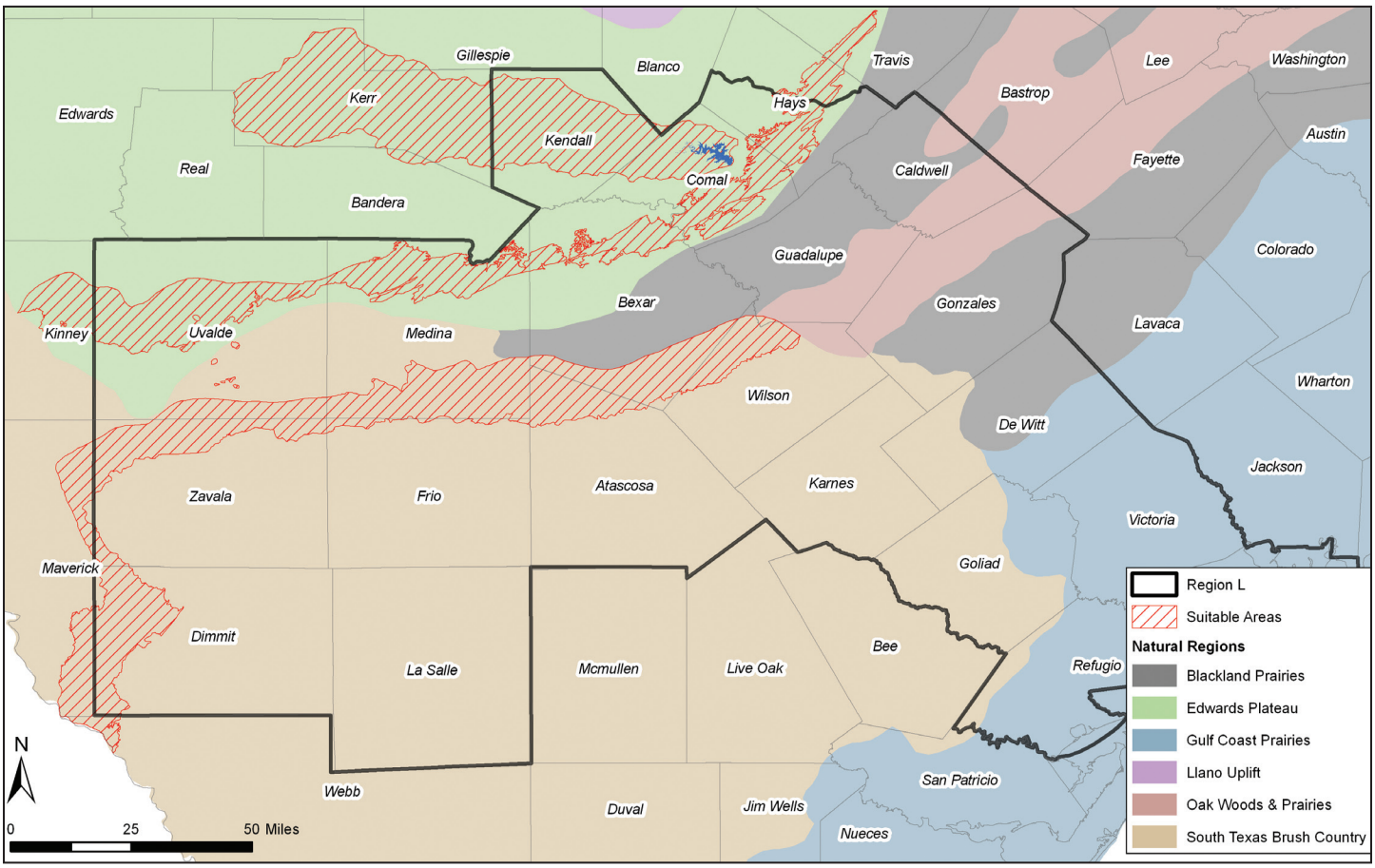
rates, they range from $75 to $400/acre (Pestman 2007). Perhaps the most economically effective treatment for juniper control is prescribed fire. Prescribed fire can be combined with other high-cost initial practices such as mechanical brush control to enhance or maintain brush control benefits for many years. Costs are variable, but based on current market rates, they can range from $3 to $8/acre. Biological control of Ashe juniper can also be achieved through the use of goats. Goats will browse on the young saplings of both juniper and hardwoods. When concentrated in high densities and rotated through pastures, they represent an effective means of controlling woody brush.

SOUTH TEXAS PLAINS—The South Texas Plains are the heart of the Texas "Brush Country," and no other region in Texas has seen more widespread implementation of brush management practices. Brush stands in this region are often mixtures of more than 15 species such as mesquite, acacia, and prickly pear. Most brush species in this region will re-sprout after treatment, which causes significant management challenges. The primary methods of controlling brush in the South Texas Plains are mechanical, chemical, and prescribed fire (Hamilton et al. 2004).

Mechanical methods that involve the use of a root plow, bull dozer, or chaining are highly variable depending on density and target species. These methods range from $30 to $250/acre based on current market rates (Pestman 2007). Due to the re-sprouting nature of most target species in the South Texas Plains, chemical methods represent a cost- effective method for controlling brush and maintaining range conditions. Based on current market rates, costs for chemical control methods range from $20 to $120/acre. Prescribed burning can be combined with other initial practices such as mechanical brush control to enhance or maintain brush control benefits for many years. Costs are variable, but based on current market rates, they range from $3 to $8/acre.

Where does rangeland restoration work?

Water yield resulting from rangeland restoration is likely to be effective only on sites receiving at least 18 inches of annual rainfall and having geology and soil characteristics leading to rapid runoff and infiltration (Hibbert 1983, Seyfreid et al. 2005, Wilcox et al. 2006).



Aquifer recharge zones and river basins within Region L suitable for rangeland restoration efforts to increase water yield based on vegetative cover, geology, and soil characteristics.

Cost of other methods?

The cost of additional water yield through rangeland restoration compares favorably to other methods of acquiring additional available water. For example, municipal conservation efforts cost $50 to $200/acre-foot, and seawater desalination costs $619/acre-foot (SCTRWPG 2006).

Rangeland Restoration and Water

Areas within Region L with the greatest potential for increasing recharge through brush management and rangeland restoration are those areas where deep drainage (water movement beyond the root zone) can occur. This characteristic is found where soils are shallow and overlie relatively permeable bedrock. The Edwards Plateau region is a prime example of this type of situation. It has considerably more "flowing water" than would be expected for a semiarid climate (about 27.5 inches of precipitation per year). The explanation lies in the karst geology—a substrate of fractured limestone that allows rapid flow of water to the subsurface. Other soil types that may enable deep drainage are sandy soils—like those found in the Carrizo-Wilcox Aquifer recharge zone. Large areas of Region L exhibit these characteristics and support vast expanses of brush that provide opportunities for increasing water yield through rangeland restoration.

Based on current research within the Edwards Plateau, the best estimate is that the conversion of Ashe juniper woodlands into grassland-dominated savannas (woody cover < 10%) would result in an average increase in water yield (streamflow and recharge) of approximately 1.5 to 2.4 inches/acre/year. Thus, for every 5 to 8 acres of Ashe juniper converted to open savannas, an additional acre-foot of water would become available for recharge and streamflow. Current research within the south central Texas shrublands indicates that average recharge on sandy soils could be increased by shrub control from 0.4 to 0.8 inches/acre/year. This translates to an additional acre-foot of water for every 15 to 30 acres of brush cleared. For example, if recharge rates were at the lowest estimated level (0.4 inches/acre/year), restoring 200,000 acres of rangeland over the Carrizzo-Wilcox recharge zone would increase recharge by about 5,000 acre-feet/year. Based on average annual water consumption, an acre-foot is enough water to satisfy the needs of five Texans for an entire year.

The cost-effectiveness of implementing a brush management program for increasing recharge and streamflow cannot be assessed strictly on the basis of the initial cost of rangeland restoration. For example, if a rangeland restoration program is limited to the initial practice, re-growth of brush will eventually occur to the point that there will no longer be any increase in groundwater recharge. Alternatively, by using follow-up brush control practices after the initial treatment to control brush re-growth, the increased groundwater recharge gained from the initial brush control practice can be maintained for many more years into the future. Fortunately, follow-up range management practices, like prescribed fire, are relatively inexpensive. Therefore, rangeland restoration programs consisting of an initial treatment plus appropriate maintenance practices at 3- to 6-year intervals after the initial practice can result in maintaining range condition and the resulting increase in ground water recharge for many years into the future.

For example, clearing juniper on the Edwards Plateau ranges from $100 to $400 per acre. On average, this yields an increase in recharge of approximately 0.167 acre-feet per year. The results of extending the years of reduced brush cover, and the subsequent increased groundwater recharge, on the cost per acre-foot of added groundwater recharge are illustrated in Table 1. The cost estimates are obtained by taking the per-acre cost of the restoration practice, or cost of a program consisting of an initial restoration plus follow-up practices, and dividing it by 0.167. This yields the estimated

	YEARS BRUSH CONTROL EFFECTIVE			
	Brush Control Cost/Acre	1 Year	5 Years	10 Years
	COST/ACRE-FOOT/YEAR OF ADDED WATER			
EDWARDS PLATEAU	$70	$419	$83	$41
	$150	$898	$179	$89
	$200	$1,197	$239	$119
	$300	$1,796	$359	$179
CARRIZO-WILCOX	$35	$1,060	$212	$106
	$50	$1,515	$303	$151
	$75	$2,272	$454	$227
	$100	$3030	$606	$303

Table 1. Cost per acre-foot of added water for selected control costs and effective duration of brush control practice within the Edwards Plateau and Carrizon-Wilcox Aquifer.

cost per acre-foot of added groundwater recharge resulting from brush control if the program is effective for only one year. Results for several alternative levels of brush control costs are detailed in Table 1. The third and fourth columns of Table 1 illustrate the per-acre-foot costs of added groundwater recharge resulting from brush control if the brush control practice, or program, is effective for a period of five and ten years, respectively.

If rangeland restoration programs were implemented that require participating landowners to maintain range conditions with 5 percent woody cover for a period of 10 years, then the costs per acre-foot of added groundwater recharge would be expected to range between $40 and $180 per acre-foot in the Edwards Plateau and between $100 and $300 per acre-foot in the Carrizo-Wilcox Aquifer recharge zone. It should be noted that the estimates of added groundwater recharge costs are based on the highly variable costs of the brush control practices and/or programs. Additionally, there are many other factors that would impact the ultimate costs, including landowner participation rates, proper implementation and maintenance of brush management, and availability of cost-share funding.

Pedernales River.

Incentive-Based Programs

Rangeland restoration is generally recognized to be a long-term investment that often requires a large monetary investment with benefits extending several years into the future. Landowner benefits are based on expected increases in returns from livestock and wildlife enterprises (Conner and Bach 2000). Even after benefits are realized, they may not be enough to cover the costs of clearing and maintenance activities. Landowners who receive cost-share funding will realize a profit from their investment more quickly regardless of the cost of clearing if they are reimbursed for a portion of restoration expenses. In addition, studies have shown that when cost-share funds are available, landowner participation rates increase (Olenick et al. 2004). An incentive-based program that shares the cost of rangeland restoration with the landowner could provide opportunities for increasing water yield.

Golden-cheeked warbler.

Endangered Species Management

A rangeland restoration program, if implemented, would need to account for endangered species habitat. Within Region L, the golden-cheeked warbler, a federally listed endangered bird, inhabits mature oak-juniper woodlands. This habitat would not be a candidate for rangeland restoration efforts. Impacts to the Black-capped vireo, another federally listed endangered bird, would also have to be considered. Any juniper removal performed in areas that have the potential for becoming black-capped vireo habitat would have to be done selectively and followed with prescribed fire to enhance that potential. Any brush clearing should be conducted by a certified brush management contractor who has received training on how to recognize and work around endangered species habitat.

Black-capped vireo.

Where do we go from here?

Additional work should be performed to determine the number of acres suitable for rangeland restoration efforts to increase water yield. In addition, studies should be conducted that assess the impact of incentive-based programs on landowner participation. When combined, these two efforts will give a better estimate of expected water yield from rangeland restoration.

Conclusion

Over the next several decades, Region L will continue to face an ever-increasing demand for a limited resource—fresh water. Based on the research available, there is a better understanding of the influence of vegetation and vegetation management on the performance of water catchments and the land-based water cycle. Land-based water conservation practices, specifically rangeland restoration, offer great promise for augmenting fresh water supplies in the Edwards Plateau and South Texas Plains of Texas. With long-term costs per acre-foot of added water ranging from $40 to $180 for the Edwards Plateau and $100 to $300 for the South Texas Plains, brush management represents a cost-effective alternative for increasing available water when compared to other water management strategies. In order for a rangeland restoration program to be successful, an incentive-based program that helps defray the high initial landowner costs of brush clearing must be developed. Additional programs should be developed that provide incentives for landowners to maintain rangeland in a manner producing the greatest public benefit, i.e., increased water yield and the other benefits healthy rangelands provide.

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LAND-BASED WATER CONSERVATION & WATER YIELD PRACTICES IN REGION L: GUIDELINES FOR SPATIAL ANALYSIS AND RECOMMENDED BRUSH MANAGEMENT PRACTICES

SUBMITTED TO
REGION L
SOUTH CENTRAL TEXAS REGIONAL WATER PLANNING GROUP
BY

TEXAS A&M | Institute of Renewable Natural Resources

&

GRAZINGLAND MANAGEMENT SYSTEMS, INC.

STUDY SPONSORED BY
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ABSTRACT

Spatial analysis is to be conducted for three sub-areas of Region L: the Carrizzo-Wilcox aquifer recharge zone, the Edwards aquifer recharge zone and the Guadalupe River watershed above Canyon Lake. The spatial analysis should delineate: aquifer/watershed and county boundaries, land cover by type, canopy density category for brush, land ownership (public/private), tract size of privately owned land, areas with slope > 15%, areas with moderate to high probability of containing golden-cheeked warbler (GCW) habitat and for the Carrizzo-Wilcox aquifer recharge zone, areas with deep sandy soils.

Brush management practices in the Edwards Plateau and Guadalupe watersheds will be primarily directed at Ashe juniper, a non-sprouting species that suffers mortality when the above ground live plant material is removed. Both individual plant treatments (IPT) and broadcast mechanical treatments are recommended for Ashe juniper control. Chemical treatment is limited to IPT. Fire is an especially effective treatment alternative for Ashe juniper and is, under some conditions, used as an initial reclamation practice or, most commonly, as a maintenance practice to extend benefits from an initial mechanical practice. South Texas brush is a composite of as many as 20 species, the majority of which are resprouting species that do not suffer mortality from top removal. Brush management practices for south Texas include both mechanical and chemical as IPT or broadcast treatments, depending on plant density and need for revegetation. Because of the regrowth potential, rootplowing, a whole plant removal broadcast practice, is especially effective for south Texas brush stands. Recommended maintenance treatments that follow initial applications include mechanical and chemical IPT, as well as prescribed fire. Costs of the various treatment alternatives vary widely due to different plant densities, size and regrowth potential of the species.

GUIDELINES FOR SPATIAL ANALYSIS

Spatial analysis is to be conducted for three sub-areas of Region L:

1. Carrizzo-Wilcox aquifer recharge zone in Dimmit, Caldwell, Guadalupe, Bexar, Atascosa, Wilson, Medina, and Zavala counties. Counties outside the boundary of Region L which also contain areas of the Carrizzo-Wilcox aquifer recharge zone and which may also be considered for inclusion in the program are Maverick and Webb.
2. Edwards aquifer recharge zone in Uvalde, Medina, Bexar, Comal and Hays counties. Kinney, Travis, Williamson and Bell counties are outside of the Region L boundary, but contain parts of the Edwards aquifer recharge zone and could be considered for inclusion in the program.
3. The Guadalupe River watershed above Canyon Lake including Comal and Kendall counties which are in Region L and Blanco and Kerr counties which are outside the Region L boundary.

The spatial analysis should delineate:

Aquifer/watershed boundaries
County boundaries
Land cover by type (brush –other) and by canopy density category for brush (eg., < 20%, 20-40%, and > 40%)
Land ownership (public/private) and for private land, tract size (eg., < 25ac, 25-50ac, 50-100ac, > 100ac, etc.)
For private land, with Tract sizes > 50 ac, areas with slope > 15%
For private land, with Tract sizes > 50 ac, areas with low, moderate and/or high probability of containing GCW habitat
For the Carrizzo-Wilcox aquifer recharge zone, delineate areas of the recharge zone with deep sandy soils.

The spatial analysis report should provide maps showing locations and acres of parcels of private land that were within the aquifer/watershed boundaries, with parcel size of 50 acres or more, with > 10% shrub/brush canopy cover and slopes < 15% and, for the Carrizzo-Wilcox aquifer recharge zone, areas with deep sandy soils. The report should also indicate which such parcels have low, moderate or high probability of containing GCW habitat.

RECOMMENDED BRUSH MANAGEMENT PRACTICES

Introduction

All herbicide applications must follow EPA label directions and be in accordance with state and county restrictions. Applications will be made during weather conditions and at distances from critical off-target areas conducive to the avoidance of herbicide drift. It is recommended that Texas AgriLife Extension bulletin 1466 be used as a basis for matching herbicide compounds with target plant species and for instructions in timing, additives and application methods. The use of prescribed fire should be under the direction of Certified Prescribed Burn Managers and applied within guidelines provided by the State of Texas for outdoor burning and any county or other regulations that may be in effect. All brush management applications; chemical, mechanical and prescribed fire, will avoid adverse impacts to rare, threatened or endangered species and other sensitive environmental resources found in the area to be treated.

Edwards Plateau and Guadalupe Watershed

Brush management treatment alternatives commonly used in the Edwards Plateau MLRA include mechanical and chemical practices, as well as prescribed fire and biological control associated with the use of goats. Selection of these treatments depends on the size and density of the woody plant species, primarily Ashe juniper (*Juniperus ashei*). Some ranchers will remove oak species (*Quercus spp*.) with brush management practices, but these are more likely shinoak species or oaks that are thinned within mottes, rather than mature oaks. Live oaks, Spanish oaks, post oaks, or other oak species are generally not considered in brush management scenarios, meaning that Ashe juniper is the target woody plant species a very high percentage of the time.

Mechanical brush management treatments can be either broadcast when densities of plants are greater than 300 plants per acre or large enough to respond to treatments such as chaining or cabling, or individual plant treatments (IPT) when densities are low enough and/or plants are small enough to justify treating individual plants. It should be remembered that all brush management is temporary, even when a very high percentage of the resident target species suffer mortality from the initial brush management practice. For example, Ashe juniper will recover very quickly in an area following effective control from seeds in the soil profile that germinate and establish seedlings. Maintenance or “follow-up” practices, either IPT mechanical or chemical or the use of prescribed fire or goats that will utilize juniper seedlings are highly recommended. When fire is used, it is highly recommended that it be under the direction of a Certified Prescribed Burn Manager. It is also recommended that landowners using prescribed fire join the prescribed burning association in their county, if one has been organized. Information on available prescribed burning associations in the Edwards watershed can be obtained from the Edwards Plateau Prescribed Burning Association at the Texas A&M research Station at Sonora, Texas.

Woody plant species in the watershed will be distinguished for recommended brush management practices and cost estimates as follows:

Ashe Juniper and Ashe Juniper – Oak (Quercus spp.) mix

- Individual Plant Treatment (IPT)

  Mechanical
  Chemical
- Broadcast

  Mechanical
  Chemical

Ashe juniper

Ashe juniper is non-sprouting species that it will suffer mortality if all the above ground green material is removed. This allows top removal practices to be effective for brush management and the most popular of these methods currently is the use of a "skid-steer loader" equipped with a front-end attachment of hydraulically operated shears. Since the skid-steer is used to attack individual plants, it can be considered an IPT practice and is recommended primarily for Ashe juniper densities of 300 plants per acre or less. Light to high densities should range in cost between $80 and $300 per acre. Mortality of Ashe juniper treated with this method should be near 100%. The advantage of the skid-steer and IPT is that it is very selective and can remove juniper without damage to associated oaks of other desirable woody speice.s. An alternate selective IPT mechanical method would be use of an excavator, ranging in cost between $40 and $140 per acre depending on density of the juniper.

The recommended IPT chemical treatment for Ashe juniper is a soil applied spot treatment with Hexazinone or picloram liquid at an estimated cost of between $6 and $10 per 100 plants using a $7.00 per hour charge for labor. Mortality of Ashe juniper treated with this method would be very high (76-100% mortality).

When Ashe juniper densities exceed 300 plants per acre, it is generally recommended that broadcast treatments be considered rather than IPT. The use of a crawler tractor and bulldozer blade is a standard practice for broadcast treatment of Ashe juniper and is recommended. Costs will vary widely with density and size of trees, but should be in the range of $75-$150 per acre. Mortality of the target species will be very high. When the topography (slope and surface roughness) are within acceptable levels, two-way chaining of heavy juniper stands is a recommended broadcast treatment alternative. Two-way chaining will cost an estimated $30-$50 per acre. However, chaining cannot be discriminating for oak or other desirable species that will suffer mortality or be damaged. In limited areas of the Edwards Plateau where soil depth and slope permit, rootplowing may be a broadcast alternative mechanical practice. If juniper is in very large, dense stands, a pre-treatment of bulldozing may be required. Rootplowing alone is estimated to

cost $110 per acre and pre-dozing $60 per acre when needed. Seeding to restore grasses following rootplowing would cost an additional $40 per acre (total cost $210 per acre).

There are no recommended broadcast chemical treatments for Ashe juniper control.

Ashe juniper – Oak mix

Where oak species are mixed with Ashe juniper, it is assumed that the juniper will be the target species for brush management and that tree shearing with a skid loader will be the IPT treatment in order to selectively take out the juniper and leave the oak. Light to high densities of juniper should range in cost between $80 and $300 per acre. Mortality of Ashe juniper treated with this method should be near 100%. An alternate selective IPT mechanical method would be use of an excavator, ranging in cost between $40 and $140 per acre depending on density of the juniper.

Chemical IPT for mixed Ashe juniper and oak stands would present a problem if oak trees were considered desirable. The chemical compounds for oak control, hexazinone and tebuthiuron are both soil applied herbicides. Hexazinone and picloram soil applied herbicides are recommended for Ashe juniper control. The possibility of damage to desirable trees with the use of any of these compounds would be high. However in areas where it can be used, hexazinone IPT would cost $10 per 100 plants.

Broadcast mechanical treatments would also present a problem for juniper-oak mixed stands. The use of treatments such as chaining would not be practical in order to leave the oak. Use of a bulldozer would be acceptable to take out primarily the juniper while working around the oak, although in mixed stands the likelihood of some oak removal would be moderate to high. Bulldozing would cost between $75-$150 per acre depending on the density of the juniper in the stand.

There are no recommended broadcast chemical treatments for Ashe juniper control and the use of a broadcast treatment for oak in the Edwards Plateau would not be likely. However, Tebuthiuron is effective for oak control as a broadcast application at a cost of $80 per acre.

South Texas

The South Texas Plains are dominated by a woody plant complex of a dozen or more species, most of which have vigorous resprouting potential after top removal. Resprouting is primarily from basal stem buds and buds contained in the crowns of these woody plants near the soil surface or several inches below the soil surface. Honey mesquite (*Prosopis glandulosa*) is often the dominant species in the mixed brush complex, but other individual species that can dominate on certain ecological sites include pricklypear cactus (*Opuntia berlandieri*), blackbrush acacia (*Acacia rigidula*), and oak (*Quercus spp*.). These species will be addressed as the dominate species in mixed brush stands in the recommendations for brush management treatment alternatives and costs as follows:

- Individual Plant treatment (IPT)
    - Mechanical
    - Chemical
- Broadcast
    - Mechanical
    - Chemical

Mesquite dominated mixed brush

For densities of mesquite less than 300 plants per acre, IPT is recommended. For plants up to 5 inches in stem diameter a “low-energy” grubber can be used effectively. Low-energy grubbing can be accomplished for an estimated cost of $30-$40 per acre. For low densities of mesquite trees that are larger than 5 inches stem diameter, a larger power grubber, is recommended with an estimated cost of $40 -$100 per acre.

Chemical IPT for mesquite includes more than a dozen treatments that provide a very high level of plant mortality. These treatments include foliar herbicide applications to individual plants, stem basal herbicide applications, and a cut stump treatment. For the purpose of these recommendations, a stem basal treatment with triclopyr (concentrate) (a general use herbicide) and diesel at a cost of $10 per 100 plants (smooth barked) and $14 (rough barked) will be used. Mortality of treated plants is expected to be very high, 76-100%.

For a broadcast treatment of mesquite dominated areas, rootplowing is recommended. This practice gives the highest level of mortality and moderate term relief from significant brush reinfestation. Rootplowing alone is estimated to cost and average of $110 per acre, however, it should be noted that in very heavy, dense stands of mesquite and mixed brush, a pre-treatment to rootplowing may be required consisting of bulldozing or the use of a brush stacker. This will increase the cost to approximately $170 per acre. In many instances it is advisable to reseed areas following rootplowing that suffer loss of the resident perennial grass composition. It is also common to rake or disk areas following rootplowing in order to smooth the soil surface left very rough by the rootplowing treatment and to prepare a seedbed for planting. The added seedbed preparation and seeding costs will increase the total cost to approximately $210 per acre.

Broadcast chemical treatments of mesquite dominated areas in south Texas include many options similar to the IPT alternatives, but only one (clopyralid) will give a high level of mesquite control with a broadcast foliar application. Clopyralid is recommended at a cost of $39 per acre (fixed wing application) where mesquite is highly dominant and other species greatly subordinate. If there are significant other species in the mix, then picloram plus clopyralid is recommended at a cost of $50 per acre (fixed wind application). If a helicopter is used to apply the herbicides, add $8.50 per acre to the cost.

Pricklypear dominated mixed brush

There are no mechanical IPT recommended for pricklypear. Pricklypear infestations can be controlled mechanically with a broadcast treatment that uses a large, modified front-end rake called a brush stacker. The cost of stacking averages about $65 to $90 per acre. “Railing” is another broadcast mechanical practice that can be used for pricklypear control at an estimated cost of $30-$40 per acre. Although the brush stacker and railing have the potential to reduce pricklypear infestation, most of the mechanical practices have the potential to spread prickly pear by breaking the cladophylls away from the plants and spreading them across the soil surface where they will root. Where pricklypear is present, a chemical control application should be considered prior to broadcast mechanical treatments, such as rootplowing or chaining.

Chemical IPT for pricklypear includes several choices, all of which will give a very high level of mortality. However, recent research and demonstrations indicate that a combination of picloram and fluroxypyr (1:1) provides a faster kill of the pear than other recommended treatments at the same or slightly less cost. The cost for this treatment is estimated to be $3.20 per 100 plants. Another IPT combination treatment of a low rate application of picloram following fire in the spring will provide a very high level of pricklypear control at an estimated cost of $20 per acre.

The same chemical combination used for IPT for pricklypear control is recommended for broadcast treatment. Picloram:floroxypyr (1:1) will give an estimated high level of mortality (55-76%) on pricklypear plants at an estimated cost of $22 per acre assuming a fixed wing aerial application method. If a helicopter is used add $8.50 per acre.

Shinnery oak

There are no mechanical IPT or broadcast treatments recommended for shinnery oak. While it is unlikely that shinnery oak will occur in densities suitable for chemical IPT, recommendations for IPT can be applied as spot treatments.The recommended chemical treatment for this plant is tebuthiuron (20%) applied IPT at an estimated cost of $47 per 100 plants, or as a broadcast treatment at a cost of $44 per acre.

Tree-type Oak

The recommended mechanical treatment alternative for large tree-type oak control would be two-way chaining followed by raking and stacking . This practice is estimated to cost between $110 and $190 per acre.

Tebuthiuron (20%) is recommended for control of tree-type oaks as a broadcast application at a cost of $80 per acre.

Blackbrush acacia

For densities of blackbrush less than 300 plants per acre, IPT with low-energy grubbing can be used effectively for an estimated cost of $30-$40 per acre and will provide a very high level of plant mortality.

Blackbrush usually does not have stem diameters greater than 2-3 inches and shredding can be used as a broadcast treatment for top removal. In heavy densities of the largest stem diameters of blackbrush and associated species, a self-propelled hydraulic shredder, such as the "Hydro Axe", is recommended for a cost ranging from $115.00 - $230.00 per acre. For light densities of smaller stature plants, a drag-type modified farm shredder can be used for a cost of approximately $20-$35 per acre. However, blackbrush is a resprouting species following top removal and followup maintenance practices will be necessary to maintain control. Rootplowing alone is estimated to cost an average of $110 per acre, however, it should be noted that in very heavy, dense stands of mesquite and mixed brush, a pre-treatment to rootplowing may be required consisting of bulldozing or the use of a brush stacker. This will increase the cost to approximately $170 per acre. In many instances it is advisable to reseed areas following rootplowing that suffer loss of the resident perennial grass composition. It is also common to rake or disk areas following rootplowing in order to smooth the soil surface left very rough by the rootplowing treatment and to prepare a seedbed for planting. The added seedbed preparation and seeding costs will increase the total cost to approximately $210 per acre.

Triclopyr (concentrate) + diesel can be used for IPT in low densities of blackbrush as a stem basal application and will give a very high level of plant mortality. This application will cost approximately $13 per 100 plants.

There is no recommended broadcast chemical treatment for blackbrush that will give a very high level of expected plant mortality. While several chemical compound combinations are recommended for moderate levels of control, only one, tebuthiuron (20%) pellets, will provide a high level of mortality (55-76%) at a cost of approximately $114 per acre. This treatment cost is over twice those recommended for chemical treatments that give the moderate control level.

Edwards Plateau and Guadalupe Watersheds

Species	Treatment	IPT Cost 100 plants	Broadcast Cost/Acre	Alternative	IPT Cost 100 plants	Broadcast Cost/Acre
Ashe juniper	Tree Shear		$80-$300[1]	Excavator		$40-$140[1]
	Hexazinone/picloram	$6.00-10.00				
	Bulldozer		$75-$150	Two-way chain		$30-$50
	Rootplow		$110-$210			
Juniper-Oak	Tree shear		$80-$300[1]	Excavator		$40-$140[1]
	Bulldozer		$75-$150			
	Hexazinone	$10.00				
	Tebuthiuron		$80.00			

South Texas Watersheds

Mesquite	Low-energy grub	$30-$40				
	Power Grub	$40-$100				
	Triclopyr + diesel	$10-$14				
	Rootplowing		$110-$210			
	Clopyralid		$39			
	Clopyralid + picloram		$50			
Pricklypear	Brush Stacker		$65-$90	Railing		$30-$40
	Picloram + fluroxypyr	$3.20				
	PIcloram + fire	$20.00				
	Picloram + fluroxypyr		$22.00			
Oak[2]	Tebuthiuron (20%)	$47.00				
	Tebuthiuron (20%)		$44.00			
Oak[3]	Tebuthiuron (20%)		$80.00			
	2-way chain/stack		$110-$190			
Blackbrush	Low-energy Grub	$40-$100				
	Hydro-Axe		$115-$230			
	Farm Shredder		$20-$35			
	Rootplow		$110-$210			
	Triclopyr + diesel	$13.00				
	Tebuthiuron (20%)		$114.00			

[1]Practice can be used IPT or broadcast

[2]Running or shinnery oak

[3]Tree type oak

APPENDIX 4

Summary of USDA Farm Programs

2008 Farm Bill Conservation Programs
(as of August 2009 – final rules expected by end of this year *see income eligibility statement at end of last page)

Conservation Reserve Program (CRP)*

- Program run by Farm Services Agency (FSA), producer signs up at FSA office.
- Purpose of program is to remove highly erodible and environmentally sensitive land from production.
- Federal lands ineligible, land must have been cropped 4 of 6 years between 1996 - 2001 (soon to be 2002-2007).
- Limited to announced signup periods except for Continuous CRP.
- Application evaluated on environmental benefits, regionally based competition with bonus points for landowners living in same or contiguous county as offered property.
- Counties capped when they reach 25% of total county cropland acres enrolled in the program but cap can be waived for CCRP, CREP or WRP if landowners have difficulty implementing conservation plans and if county government concurs that exceeding the cap will not adversely affect the local economy.
- 50% cost share for establishing cover, plus annual maintenance and rental payments (limited to $50,000/year).
- National acreage cap reduced from 39.2 to 32 million acres starting Oct 1, 2009.
- Midterm management required to maintain land productivity for wildlife, can receive 50% cost share up to $50/acres/yr with a cap of $100/acre on a 10 yr and $125/acre on 15 yr contract.
- Provides for managed haying including biomass, routine gazing, prescribed grazing for the control of invasive species, emergency haying & grazing & placement of wind turbines with reduction in rental rates.
- CRP transition incentive program allows sale/lease of expiring CRP by retired/retiring producers to new, socially or economically disadvantaged producers wishing to put land back into production. Requires comprehensive conservation plan meeting sustainability requirement. Provides former landowners with up to 2 years of payments if new landowner isn't family member. New landowners can to sign up for appropriate EQIP or CSP practices or reenroll a CCRP practice before CRP contract expiration.
- Includes the Continuous Conservation Reserve Program (CCRP) directed at environmentally sensitive land – riparian buffers, field borders, filter & wind strips.
    - Continuous enrollment - 50% Cost Share on required practices
    - Owners receive incentive payments for establishing certain practices, annual rental rate for 10-15 year contract.
    - Signup Incentive Payments (SIP) - $10/acre/yr of contract up to $100/acre, former CRP/some practices ineligible
    - Practice Incentive Payment (PIP) - 40% of eligible practices (on top of 50% cost share)
    - Provides 50% cost share for replanting or thinning trees on CRP to accomplish original practice purpose, provide multi-resources benefits and improve condition of the resources on the land.

- Farmable wetlands program now includes wetlands constructed for nitrogen removal, aquaculture ponds and intermittently flooded farmland cropped at least 3 out of 10 years from 1990 to 2002. Enrollment limited to 40 acres for wetlands/constructed wetlands, 20 acres for intermittently flooded tract. Buffer size to be determined by USDA in consultation with State Tech Committee.

Wetlands Reserve Program (WRP)*

- Program run by NRCS, applications taken year round at NRCS offices, competition for contracts is statewide.
- Purpose of program is to restore, enhance and protect wetlands on private or tribal property.
- Eligible land limited to private or tribal land, outside CRP capped counties (unless CRP cap is waived locally).
- Eligible land includes wetlands farmed under natural conditions, croplands and adjacent land functionally dependent on wetland converted prior to Dec 23, 1985, cropland/grassland used for agricultural production prior to flooding from the natural overflow of a closed basin lake or pothole & adjacent land functionally dependent on the cropland or grassland.
- Prohibits agreements and easements on land where ownership has changed during previous 7 years unless waived by State Conservationist.
- Applications accepted year round, ranked once per year, ranking based on maximizing environmental benefits,
- Caps national acreage enrollment at 3,041,200 acres.
- Options for permanent or 30-year easements (30 year contract option for tribes), or restoration cost share agreements.
- USDA pays 100% of the lowest of one of these 3 amounts: 1) fair market value 2) geographic cap or 3) landowner offer plus restoration costs on permanent easements and 75% of the lowest amount and costs on 30-year easements. Easement recording costs are also paid.
- Restoration cost share agreements receive up to 75% of restoration costs, no easement placed on property but payments limited to $50,000 annually for any person or legal entity.
- Provides cost assistance for maintenance activities.
- Landowner controls access, non-developed recreational activities (hunting, fishing) and right to lease recreational uses for financial gain. Other uses must be approved.
- Wetland Reserve Enhancement Program (WREP) established and available to States, Tribes and NGO's for special wetland programs. WREP contracts can allow retention of grazing rights.

Environmental Quality Incentives Program (EQIP)*

- Program run by NRCS, applications taken year round at NRCS offices.
- Purpose is to install & maintain conservation practices that sustain food & fiber production while enhancing soil, water & related natural resources & energy conservation.
- Eligible land includes confined livestock feeding operations, crop, range, grass and

pastureland and nonindustrial forestland. States and local governments are not eligible. Private individuals operating on government lands maybe eligible under certain circumstances.

- EQIP applications ranked at least once per year, competition is statewide.
- 60% of annual program funding targeted at livestock related activities.
- Includes planning for organic production, forest, wildlife, wetland, grazing, nutrient, air quality, invasive species, residue, animal carcass, pest, pollinator and fuels management and energy conservation.
- Provides an overall payment limitation of $300,000 per individual, regardless of the number of farms or contracts, over 6 years starting with contracts signed after October 1, 2008. Possible waiver to $450,000 for projects having special environmental significance. Contracts over $150,000 require regional NRCS Assistant Chief approval.
- Can provide up to 75% cost-share on most contracts. Can provide up to 90% cost-share for beginning or limited resource or socially disadvantaged farmers and ranchers who can also receive up to 30% advance payments to install practices.
- Payments include planning and income recovery costs. Incentive payments have been eliminated.
- Organic production transition payments limited to $20,000/yr or $80,000 over 6 years.
- Contract length: Minimum 1 yr after implementation of last scheduled practice, Max-10 yrs
- Conservation Innovation Grants (CIG) are used to stimulate innovative approaches in environmental enhancement and protection. Awarded on a competitive basis. Special program for air quality.
- Agricultural Water Enhancement Program (AWEP) promotes water quality, conservation planning, restoration or enhancement projects on ag lands. Includes irrigation efficiency, conversion to dryland farming and drought mitigation. Funding through NRCS or partner.

Wildlife Habitat Incentives Program (WHIP)*

- Program run by NRCS, applications taken year round at NRCS offices
- Purpose of WHIP is to help landowners or lessees develop and improve wildlife habitat.
- Eligible land: tribal lands, private agricultural land and non-industrial private forest land on which livestock, agriculture or forest products are produced. State & federal land ineligible.
- Applications ranked once per year, competition is statewide.
- Prioritizes projects that further state, regional or national habitat goals and priority habitats.
- Up to 75% cost-share for people who own/control land & want to develop/improve habitat. Up to 90% cost share for historically underserved producers and for contracts 15 or more years in length.
- Normally contracts run 5-10 years with a goal of 25% long term (15+ yr) contracts.
- National limit $50,000/person or legal entity/year.

Farm and Ranch Lands Protection Program (FRPP)*

- Program run by NRCS through participating entities, generally local land trusts. Continuous signup.
- Purpose is to protect agricultural use and conservation values by limiting nonagricultural uses of land.
- Eligible land: privately owned and contains at least 50% prime, unique or state or locally important farmland, contains historical or archeological resources or will further a State or local policy consistent with the purposes of the program and is subject to a pending offer from an eligible entity.
- Includes incidental range, grassland, pasture or forestland that contributes to an agricultural operation or buffers development. Offered property must be not more than two-thirds forestland.
- Provides 50% appraised market value to state, tribal or local government or nonprofit entities to purchase conservation easements.
- Minimum entity contribution is 25% of easement acquisition purchase price.
- Entity determines terms & condition of deed, chooses approved appraisal method.
- Secretary certifies approved entities. USDA holds no interest in easements except the right of enforcement.
- Can use charitable donation from the landowner as part of non-Federal cost share.
- Highly erodible land requires conservation plan, may require conversion to less intensive use.

Grasslands Reserve Program (GRP)*

- NRCS administers permanent easements, FSA handles rental contracts. Continuous signup at USDA Service Centers.
- Purpose is to maintain healthy grazing lands and protect them from development. No minimum acreage requirement.
- Eligible land privately or tribally owned and can be restored or restorable, improved, or natural grass, range, pastureland or prairie for which grazing is the predominant use, or which contains historic or archeological resources or addresses State, regional or national conservation priorities.
- Authorizes enrollment of up to an additional 1.22 million acres. Prioritizes enrollment of CRP land whose contract is within 1 yr of expiring, but limits CRP enrollment to 10% of yearly acreage allotment.
- 10, 15 or 20 year rental contracts, permanent or max easement length allowed by state law.
- Not more than 40 percent of the funds are available for 10, 15 or 20 year rental contracts.
- Rental contracts annual rental rate equals 75% of grazing value. Rental payments are limited to $50,000/person or legal entity/year and can be received in addition to other farm bill payments.
- Renters must suspend cropland base and allotment history of land.
- Permanent easements purchased at fair market value, minus grazing value, cropland base permanently eliminated.
- Easements may be transferred to entities, generally trusts. Entity pays at least as much of the purchase price as USDA.

- Restoration agreements provide up to 50% of cost not to exceed $50,000/person or entity/year.

Conservation Stewardship Program (CSP)* (formerly Conservation Security Program)

- NRCS administers the program, runs from 2009-2012.
- Purpose is to reward good stewardship & provide incentives to address additional resource concerns on working lands.
- Eligible land: tribal agricultural lands, private agricultural lands, incidental non-industrial private forest lands not currently enrolled in CRP, WRP, and GRP.
- Eligible land must have a cropping history 4 of the 6 years before 2008, meet stewardship threshold for 1 USDA identified resource concern, and achieve threshold for State identified priority resource concern by the end of contract.
- Contracts are for 5 years with the option to renew for another 5 years.
- May enroll up to 12,769,000 acres/yr with amount based on eligible acres in state.
- Continuous signup with at least one ranking period in the first quarter of each fiscal year (Oct-Jan)
- 3-5 priority resource concerns are to be designated in each state or watershed
- Applications ranked on present and proposed conservation activities, number and extent of resource concerns addressed and cost effectiveness of expected environmental benefits.
- Applicants must account for stewardship operations covering their entire agricultural operation.
- Program payment cap of $200,000/five years/person or legal entity.
- Animal waste storage or treatment facilities are not eligible.
- Payments cover planning, installing, improving and maintaining conservation activities, foregone income and expected environmental benefits.

Healthy Forestry Reserve Program (HFRP)

- Administered by NRCS in coordination with FWS and NMFS, limited signup period advertised on NRCS website.
- Purpose is to assist landowners in restoring and enhancing forest ecosystems, promote recovery of federal, state and NRCS listed species, improve biodiversity and enhance carbon sequestration.
- Eligible land: private land capable of supporting federal candidate, threatened or endangered species, state or NRCS listed species, enhancing biodiversity or storing carbon in a functioning forest ecosystem.
- This includes land owned by Indian Tribes and private industrial forest owners.
- Land enrollment through 10 year restoration cost-share agreements, 30 year contract (only available to Tribes or tribal individuals), or permanent easement.

Community Forest and Open Space Conservation Program provides grants up to 50% to local entities to acquire private forest land that is in danger of conversion to nonforest uses and provides public benefits to communities.

Cooperative Forest Innovation Partnership Project provides grants up to 50% to state or local governments, tribes, land grant universities and private individuals who develop

innovative education, outreach or technology transfer projects designed to increase USDA's ability to address private working forest landscape management for multiple values and uses, protect or restore forests impacted by natural threats and development or enhance public benefits such as air and water quality, soil conservation, biological diversity, carbon storage, forest products and jobs, production of renewable energy, wildlife, wildlife corridors and habitat and recreation.

Conservation Technical Assistance Program – Conservation technical assistance is the help NRCS and its partners provide to land users to address opportunities, concerns, and problems related to the use of natural resources and to help land users make sound natural resource management decisions on private, tribal, and other non-federal lands.

This assistance can help land users:

- Maintain and improve private lands and their management
- Implement better land management technologies
- Protect and improve water quality and quantity
- Maintain and improve wildlife and fish habitat
- Enhance recreational opportunities on their land
- Maintain and improve the aesthetic character of private land
- Explore opportunities to diversify agricultural operations and
- Develop and apply sustainable agricultural systems

This assistance may be in the form of resource assessment, practice design, resource monitoring, or follow-up of installed practices.

Although the CTA program does not include financial or cost-share assistance, clients may develop conservation plans, which may serve as a springboard for those interested in participating in USDA financial assistance programs. CTA planning can also serve as a door to financial assistance and easement conservation programs provided by other Federal, State, and local programs.

Conservation of Private Grazinglands Program - The NRCS Conservation of Private Grazing Land (CPGL) initiative will ensure that technical, educational, and related assistance is provided to those who own private grazing lands. It is not a cost share program. This technical assistance will offer opportunities for: better grazing land management; protecting soil from erosive wind and water; using more energy-efficient ways to produce food and fiber; conserving water; providing habitat for wildlife; sustaining forage and grazing plants; using plants to sequester greenhouse gases and increase soil organic matter; and using grazing lands as a source of biomass energy and raw materials for industrial products.

*__Conservation programs eligibility__ limited to individuals or entities making less than $1 million/yr average adjusted gross nonfarm income (AGI) for the preceding 3 years unless 66% or more of the income comes from farming, ranching or forestry. Secretary of Agriculture can waive AGI limit for projects on environmentally sensitive land of special significance. These payment limitations do not extend to federally recognized Indian tribes.

APPENDIX 5

United States Army Corps of Engineers Programs

US Army Corps of Engineers

Planning Processes

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Study Authorization

- For a study to begin, must have one of the following:
  - Current "existing" authorization
  - Authorization by WRDA or other bill
- After authorization, must be appropriated to begin a feasibility study

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Project Phases

- Four Main Phases
  - Reconnaissance Phase
  - Feasibility Phase
  - Preconstruction, Engineering, and Design Phase
  - Construction Phase

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Reconnaissance Phase

- First phase of any authorized study
  - –$100,000 fully Federally funded
  - –Usually about a year long
  - –Culminates with a 905(b), which determines Federal interest
  - –If Federal interest, begin Feasibility Phase

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Feasibility Phase

- Develop Project Management Plan (PMP)
- Execute a feasibility cost sharing agreement (FCSA)
  - –50/50 cost share for investigation studies
- Conduct 6-step Planning Process
- Normally 3-5 years long
- Results in a Chief's Report and hopefully an authorized Project

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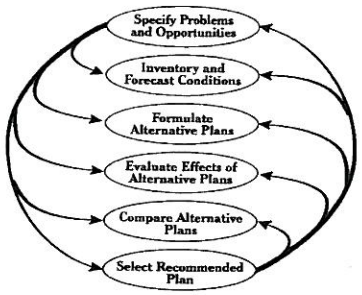
PLANNING PROCESS



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PED Phase

- After Chiefs' Report
  - Project must be Authorized by WRDA
  - Funds must be appropriated
  - PED typically cost shared 75/25
  - Design Agreement must be executed
- Detailed design begins
  - 1-3 years depending on size and cost of study
  - 35% Designs
  - 65% Designs
  - 95% Designs
  - 100% and Ready to Advertise

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Construction Phase

- Funds must be appropriated for construction
- Prepare Project Partnership Agreement (PPA)
- Can take several years depending on funding
- Various cost sharing on projects depending on type of Authorization
  - Typically 65/35
  - Can be as much as 50/50 for structural projects
  - Can be 75/25 for CAP 1135
- Award construction contract
- Manage contract and provide QA/QC
- Closeout when complete and turnover to sponsor for operations and maintenance

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GSAR Studies

- Leon Creek in Feasibility Phase
  - Primarily Flood Risk Management
  - Ecosystem Restoration can be added
  - Recharge potential if there is detention
- Cibolo Creek in Feasibility Phase
  - Multi-purpose flood risk management
  - Ecosystem restoration
  - Recharge
  - Recreation

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Nueces

- Nueces in Feasibility Phase
  - Multi-purpose Flood Risk Management
  - Ecosystem Restoration
  - Recharge
  - Recreation

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Section 206
Aquatic Ecosystem Restoration Authority

Spring Lake & San Marcos River Projects

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Section 206 Aquatic Ecosystem Restoration

Program:	Continuing Authorities Program (CAP)
Authority:	Section 206 of the Water Resources Development Act of 1996, as amended (33 USC 2330)
Objective:	To restore degraded aquatic ecosystem structure, function, and process to a less degraded more natural condition
Requirements:	Improve quality of the environment, is in the public interest, and is cost effective
Cost Sharing:	Feasibility Phase (50/50), Design & Implementation Phase (65/35)
Sponsor Share:	LERRDs, Cash, or WIK credit

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Project Phases

Feasibility Phase	Design & Implementation Phase
Request for Assistance *(Sponsor letter of request)*	**Plans & Specifications** *(Project Partnership Agreement)*
Federally Funded Portion *(Federal Interest Determination)*	**Construction**
Cost Shared Portion *(Feasibility Cost Sharing Agreement)*	**Close-Out** *(Project Completion Report)*
Final Decision Document *(MSC Commander approval)*	**Sponsor O&M** *(OMRR&R Manual)*

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Project Phases

Feasibility Phase – Federally Funded Portion

- Initiated through a non-Federal Sponsor letter of request
- First $100,000 of Feasibility costs are fully Federally funded
- Determine if the proposed project meets Federal interests
- Problem(s) specification and potential project solutions
- Identify non-Federal project sponsor(s)
- 6 to 9 months to complete

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Project Phases

Feasibility Phase – Cost Shared Portion

Feasibility Cost Sharing Agreement (FCSA) – feasibility costs above and beyond the initial $100 K are cost shared 50/50

Identify & describe existing environmental degradation

Evaluate potential restoration alternatives

Recommend potential restoration features

Integrated Environmental Assessment (NEPA compliance)

District & Division approval

18 to 24 months to complete

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Project Phases

- **Design & Implementation Phase**
  - First action is to execute the Project Partnership Agreement (PPA) – design & implementation is cost shared 65/35
  - Complete final design, real estate requirements, and compliance with environmental regulations
  - Award of construction contract(s)
  - Completion of physical construction and warranty period
  - OMRR&R Manual and Project Completion Report
  - Non-Federal Share – cash, work-in-kind credit (100%), and the value of project lands (LERRDs)

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Program Limitations

Section 206 Projects

- Studies and projects are subject to the availability of Federal funds
- The total Federal participation in a single project is limited to $5 million
- Recreation features are cost shared at 50% Federal and 50% non-Federal and cannot increase the total Federal restoration costs by more than 10%

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Restoration Activities

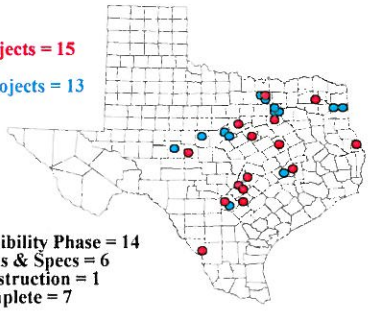
- Riparian corridor rehabilitation
- Aquatic habitat restoration
- Bank stabilization
- Wetland creation
- Prairie restoration
- Debris removal
- Invasive and exotic vegetation removal
- Recreation Amenities (trails, observation points, docks)

Fort Worth District – Building Strong!

US Army Corps of Engineers

206 Projects = 15

1135 Projects = 13

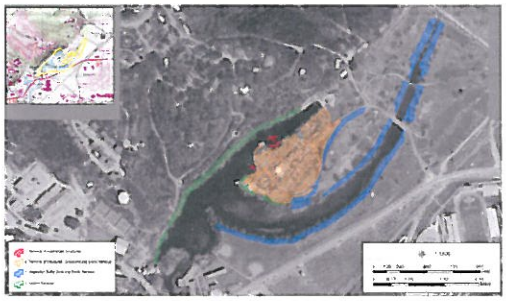


Feasibility Phase = 14
Plans & Specs = 6
Construction = 1
Complete = 7

Fort Worth District – Building Strong!

US Army Corps of Engineers

Spring Lake 206 Project

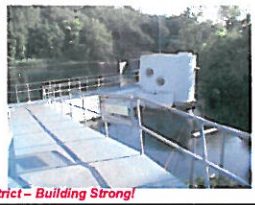


Fort Worth District – Building Strong!

US Army Corps of Engineers

Debris Removal / Prairie Restoration

Aquatic Habitat Improvement

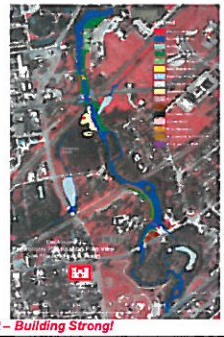


Fort Worth District – Building Strong!

US Army Corps of Engineers

San Marcos River 206 Project

- Riparian corridor revegetation
- Exotic terrestrial & aquatic vegetation removal
- Dam removal & modification
- Debris & hardpan removal
- Nutrient & sediment control
- Sediment removal
- Wetland creation
- Recreational & educational enhancement
- Bank stabilization



Fort Worth District – Building Strong!

US Army Corps of Engineers

To Request Assistance or for Additional Information, Please Contact:

Ms. Marcia Hackett
Programs and Project Management Division
U.S. Army Engineer District, Fort Worth
P.O. Box 17300, Fort Worth, Texas 76102
Email: Marcia.R.Hackett@swf02.usace.army.mil
Phone: (817) 886-1373, Fax: (817) 886-6443

Fort Worth District – Building Strong!

Sample Project Request Letter

District Engineer
U.S. Army Corps of Engineers
CESWF-EN
P.O. Box 17300
Fort Worth, Texas 76102-0300

Dear Sir:

This letter is to seek the assistance of the U.S. Army Corps of Engineers under (reference specific authority under which assistance is requested) to (identify the type and location of the problem).

(Briefly describe your perception of the nature and severity of the problem).

(Briefly describe the known issues which could affect the acceptability of any recommended solutions, from the perspective of municipal and local governments, and/or the public).

We are aware as a local non-Federal sponsor that we will assume costs for lands, easements, rights of way, relocations, and disposal areas (LERRDs) and/or assume costs to demonstrate ownership of such. We also will assume responsibility for any operation and maintenance of the proposed project.

Your consideration of this request will be appreciated. Please contact (name, address, telephone, e-mail) for future coordination.

Sincerely,

(April 2009)

Prepared by:
Jeffry A. Tripe
U.S. Army Corps of Engineers
Fort Worth District
Environmental Branch
P.O. Box 17300
Fort Worth, Texas 76102-0300

817-886-1716

Project Milestones

- Sponsor notifies the Fort Worth District of the problem(s) with a letter requesting assistance
- The Corps conducts an initial site investigation to determine Federal interest
- The Corps request Feasibility study funds
- The Corps conducts the Feasibility study
- The sponsor and Corps sign the PPA agreement to design, implement, and maintain the project
- The Corps prepares the Plans & Specifications
- The Corps initiates project construction
- Following completion of physical construction, a warranty period, monitoring, and/or adaptive management may be performed
- After project close-out, the non-Federal sponsor is responsible for the project's long-term operation and maintenance

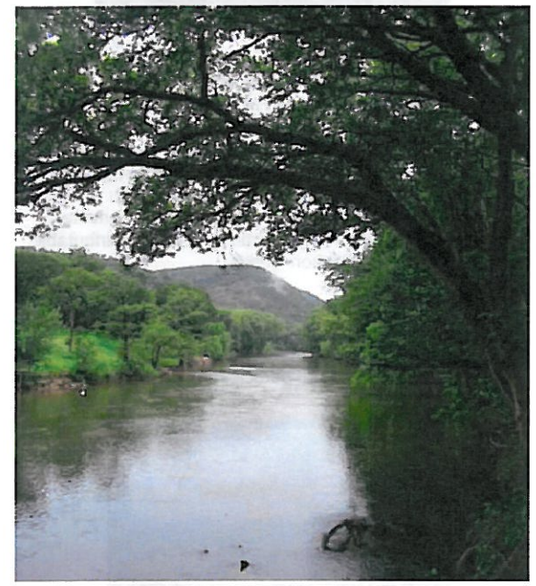
For further information contact the Fort Worth District:

Call: 817-886-1373
Fax: 817-886-6443
http://www.swf.usace.army.mil

Or write to:
Programs & Project Management Division
U.S. Army Corps of Engineers
Fort Worth District
P.O. Box 17300
Fort Worth, Texas 76102-0300

Working With You

Continuing Authorities Program



US Army Corps of Engineers
Fort Worth District

Introduction
The Continuing Authorities Program (CAP) consists of a group of 10 legislative authorities under which the Secretary of the Army, acting through the Chief of Engineers, is authorized to plan, design, and implement certain types of water resources projects without additional project specific congressional authorization. A requirement for application is sponsorship and cost sharing. The sponsoring agency may be a state, county, city, or other group. Additional requirements for each of the small project authorities are detailed in this brochure.

Purpose and Scope
The purpose of the CAP is to plan and Implement projects of limited size, cost, scope, and complexity. To promote comprehensive collaborative planning, the formulation of multipurpose projects may be accomplished under CAP. Examples of multipurpose project categories include: flood risk management, ecosystem restoration, recreation, water supply, navigation, storm damage reduction, and education.

Project Phases
CAP projects shall be implemented in two phases: the Feasibility phase and the Design & Implementation phase. Each phase is carried out under the provisions of a separate cost sharing agreement that is executed between the District Engineer and the non-Federal sponsor.

Project Cost Sharing & Agreements
The first $100,000 of the Feasibility phase is 100 percent Federally funded. Any additional costs during this phase shall be cost shared 50 percent Federal and 50 percent non-Federal sponsor pursuant to the terms of a Feasibility Cost Sharing Agreement (FCSA). All Costs beyond the Feasibility phase are considered part of the Design & Implementation phase, with cost sharing to be specified in the authorizing legislation for that purpose. Specific requirements for the Design & Implementation phase shall be detailed in the Project Partnership Agreement (PPA).

Sponsor Contributions
The non-Federal sponsor has the opportunity to provide their share of project costs in the form of cash, Work-In-Kind (WIK) credit, and/or lands, easements, rights-of-way, relocations, and disposal areas (LERRDs). Cost sharing for LERRDs as well as operation, maintenance, repair, replacement, and rehabilitation (OMRR&R) varies by project authority.

Emergency Streambank and Shoreline Erosion Protection of Public Works and Non-Profit Public Services
Section 14 – Flood Control Act of 1946

Project Scope:
Provides the authority to the Corps for emergency streambank erosion protection to prevent damage to public, non-profit, or historic facilities endangered by floods or storms.

Project Costs:
- Sponsor pays 35% of total project costs with a minimum of 5% cash
- Maximum Federal participation is $1 million

Beach Erosion and Hurricane & Storm Damage Reduction Projects
Section 103 – Rivers & Harbors Act of 1962

Project Scope:
Provides authority to the Corps for protecting public and private properties against damages caused by storm driven waves and currents.

Project Costs:
- Sponsor pays 35% (hurricane/storm damage reduction), 50% (recreation), and 100% (privately owned shores) of total project costs
- Maximum Federal participation is $3 million

Navigation Improvement Projects
Section 107 – Rivers & Harbors Act of 1960

Project Scope:
Provides Corps Authority for construction of small commercial navigation projects such as jetties, channels, and breakwaters to ensure safe and efficient use of the nation's navigable waterways.

Project Costs:
- Sponsor cost varies by depth and type
- Maximum Federal participation is $4 million

Shore Damage Prevention or Mitigation Caused By Federal Navigation Projects
Section 111 – Rivers & Harbors Act of 1968

Project Scope:
Provides authority to the Corps for investigation and construction of projects for prevention or mitigation of shore damages to public or privately owned shores along coastlines that are attributable to Federal navigation works.

Project Costs:
- Cost sharing percentage correlates to the existing navigation project
- Maximum Federal participation is $5 million

Placement of Dredged Material on Beaches
Section 145 – WRDA of 1976

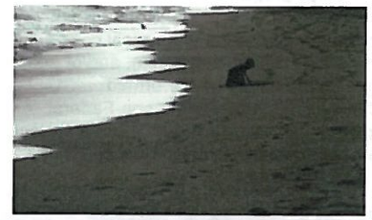
Project Scope:
Provides Corps authority for placement of beach quality sand, that has been dredged in navigation inlets and channels adjacent to such beaches, when the costs are greater than the least cost disposal plan, provided that (1) a State requests it, (2) it is in the public interest, (3) it is justified by a reduction in hurricane and storm damages,(4) the sponsor participates in cost sharing, and (5) public use and access are provided.

Project Costs:
- Sponsor pays 35% of total project costs during design & implementation

Beneficial Uses of Dredged Material
Section 204 – WRDA of 1992

Project Scope:
Provides authority to the Corps for restoration, protection, and creation of aquatic-wetland habitats associated with dredging for authorized projects.

Project Costs:
- Sponsor pays 25% of total project costs during design & implementation



Small Flood Control Projects
Section 205 – Flood Control Act of 1948

Project Scope:
Provides for local protection from flooding by the construction or improvement of flood control works.

Project Costs:
- Sponsor pays 35% of total project costs with a minimum of 5% cash
- Maximum Federal participation is $7 million

Aquatic Ecosystem Restoration
Section 206 – WRDA of 1996

Project Scope:
Provides authority to the Corps for aquatic ecosystem restoration and protection if the project will improve the quality of the environment, is in the public interest, and is cost effective.

Project Costs:
- Sponsor pays 35% of total project costs during design & implementation
- Maximum Federal participation is $5 million

Snagging & Clearing for Flood Risk Management
Section 208 – Flood Control Act of 1954

Project Scope:
Provides authority for minimal measures to reduce nuisance flood damages caused by debris and minor shoaling of rivers.

Project Costs:
- Sponsor pays 35% of total project costs with a minimum of 5% cash
- Maximum Federal participation is $500,000

Project Modifications for Improvement of the Environment
Section 1135 – WRDA of 1986

Project Scope:
Provides authority to the Corps to review and modify water resources structures and operations constructed by the Corps for the purpose of improving the quality of the environment.

Project Costs:
- Sponsor pays 25% of total project costs
- WIK credit toward the Sponsor share is limited to 80%
- Maximum Federal participation is $5 million

APPENDIX 6

United States Fish and Wildlife Service Programs

Endangered Species Act
Section 6
Cooperative Endangered Species Conservation Fund

Section 6 grants are awarded through the state, for information about how to apply, contact Dr. Craig Farquhar at TPWD:

Dr. Craig Farquhar, Endangered Species Grants Coordinator Wildlife Division Texas Parks and Wildlife Department 4200 Smith School Road Austin, TX 78744 Office telephone: 512-389-4933 Office fax: 512-389-8043

Or for more information about the program, contact Christina Williams for questions about the "Traditional" program, or Nathan Allan for the "Nontraditional" program.

Christina Williams
Fish & Wildlife Biologist
US Fish and Wildlife Service
Austin Ecological Field Office
107ll Burnet Rd., Suite 200
Austin, TX 78758
Office (512) 490 0057 x 235
Fax (512) 490 0974

Nathan Allan
Fish & Wildlife Biologist
US Fish and Wildlife Service
Austin Ecological Field Office
107ll Burnet Rd., Suite 200
Austin, TX 78758
Office (512) 490 0057 x 237
Fax (512) 490 0974

U.S. Fish & Wildlife Service

Cooperative Endangered Species Conservation Fund Grants

(Section 6 of the Endangered Species Act)

Because more than half of all species currently listed as endangered or threatened spend at least part of their life cycle on privately owned lands, the U.S. Fish and Wildlife Service (FWS) recognizes that success in conserving species will ultimately depend on working cooperatively with landowners, communities, and Tribes to foster voluntary stewardship efforts on private lands. States play a key role in catalyzing these efforts.

A variety of tools are available under the Endangered Species Act (ESA) to help States and landowners plan and implement projects to conserve species. One of the tools, the *Cooperative Endangered Species Conservation Fund* (section 6 of the ESA) provides grants to States and Territories to participate in a wide array of voluntary conservation projects for candidate, proposed, and listed species. The program provides funding to States and Territories for species and habitat conservation actions on non-Federal lands. States and Territories must contribute a minimum non-Federal match of 25% of the estimated program costs of approved projects, or 10% when two or more States or Territories implement a joint project. A State or Territory must currently have, or enter into, a cooperative agreement with the Secretary of the Interior to receive grants. Most States and Territories have entered into these agreements for both plant and animal species.

The FWS awarded approximately $67 million in Federal funding in FY 2009 under four grant programs that are available through the Cooperative Endangered Species Conservation Fund:

Section 6 funding has helped fragile ecosystems and the species that depend on them, such as the endangered hairy rattleweed. Photo credit Georgia DNR

Conservation Grants ($10 M) provide financial assistance to States and Territories to implement conservation projects for listed species and at-risk species. Funded activities include habitat restoration, species status surveys, public education and outreach, captive propagation and reintroduction, nesting surveys, genetic studies, and development of management plans.

Habitat Conservation Planning Assistance Grants ($ 7.6 M) provide funds to States and Territories to support the development of Habitat Conservation Plans (HCPs) through support of baseline surveys and inventories, document preparation, outreach, and similar planning activities.

HCP Land Acquisition Grants ($36 M) provide funding to States and Territories to acquire land associated with approved HCPs. Grants do not fund the mitigation required of an HCP permittee; instead, they support conservation actions by the State or local governments that complement mitigation.

Recovery Land Acquisition Grants ($14.1 M) provide funds to States and Territories for acquisition of habitat for endangered and threatened species in support of draft and approved recovery plans. Acquisition of habitat to secure long-term protection is often an essential element of a comprehensive recovery effort for a listed species.

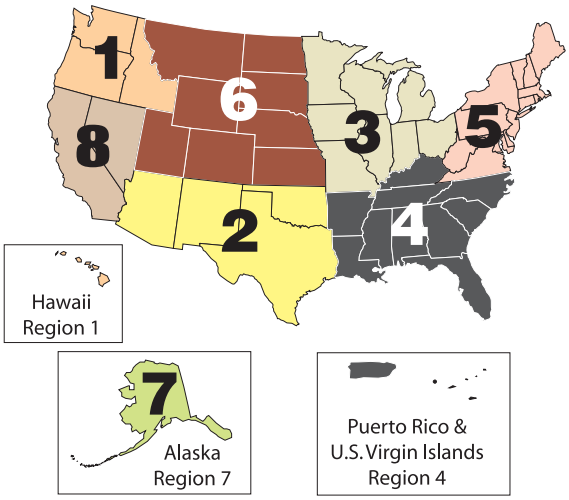
Regional Office Boundaries

Region One — Pacific
U.S. Fish and Wildlife Service
Eastside Federal Complex
911 N.E. 11th Avenue
Portland, OR 97232-4181
Program Contact: Heather Hollis,
503/231-2372

Region Two — Southwest
U.S. Fish and Wildlife Service
500 Gold Avenue SW., Room 4012
Albuquerque, NM 87102
Program Contact: Vanessa Sanchez,
505/248-5420

Region Three — Great Lakes – Big Rivers
U.S. Fish and Wildlife Service
Bishop Henry Whipple Federal Building
One Federal Drive
Fort Snelling, MN 55111-4056
Program Contact: Peter Fasbender,
612/713-5343

Region Four — Southeast
U.S. Fish and Wildlife Service
1875 Century Boulevard, Suite 200
Atlanta, GA 30345
Program Contact: Kelly Bibb,
404/679-7132 OR
David Dell, 404/679-7313



Region Five — Northeast
U.S. Fish and Wildlife Service
300 Westgate Center Drive
Hadley, MA 01035-9589
Program Contact: Alison Whitlock,
413/253-8536

Region Six — Mountain-Prairie
U.S. Fish and Wildlife Service
134 Union Blvd., Suite 645
Lakewood, CO 80228
Program Contact: Amelia Orton-Palmer,
303/236-4211

Region Seven — Alaska
U.S. Fish and Wildlife Service
1011 East Tudor Road
Anchorage, AK 99503-6199
Program Contact: Judy Jacobs
907/786-3472

Region Eight — California and Nevada
U.S. Fish and Wildlife Service
Federal Building
2800 Cottage Way, Room W-2606
Sacramento, CA 95825-1846
Program Contact: Diane Elam,
916/414-6464

Section 6 funding has helped States provide unfragmented habitats for imperiled species including the grizzly bear. The purchased habitat will help meet the recovery goals for this species by providing critical connectivity of landscapes and long-term protection. Photo Credit - Dr. Christopher Servheen, U.S. Fish and Wildlife Service

Contact Us

For more information on how to apply for Federal grants to assist States, Territories, and landowners in conserving species on non-Federal lands, please contact the FWS Regional office from the list below with responsibility for the State or Territory in which the proposed project would occur.

Additional information is also available at **http://www. fws.gov/endangered/grants/section6/index.html** You may also access www.grants.gov and search the site using the program title Cooperative Endangered Species Conservation Fund or by the Catalog of Federal Domestic Assistance (CFDA) number 15.615.

U. S. Fish and Wildlife Service
Endangered Species Program
Branch of State Grants, Don Morgan
4401 N. Fairfax Drive, Room 420
Arlington, VA 22203
703-358-2171
http://www.fws.gov/endangered/
July 2009

Partners for Fish and Wildlife

The following link provides information about Partners for Fish and Wildlife, which is a voluntary program that provides technical and financial assistance to private landowners to restore or enhance fish and wildlife habitats for Federal trust species (e.g. migratory birds, threatened, endangered, and candidates species and other declining species).

http://www.fws.gov/partners/

A copy of the Texas Partners for Fish and Wildlife Program brochure can be downloaded here:

http://www.fws.gov/southwest/es/arlingtontexas/pdf/PFW%20Fact%20Sheet.pdf

The statewide coordinator is Don Wilhelm, who can be contacted at:

Don R. Wilhelm, State Coordinator
Partners for Fish and Wildlife Program
U.S. Fish and Wildlife Service
711 Stadium Drive, Suite 252
Arlington, Texas 76011
817-277-1100
817-277-1129 Fax

For Central Texas, Wade Harrell and Tim Schumann are the primary points of contact for the Partners Program, and they can be contacted at:

Wade Harrell
Supervisory Fish & Wildlife Biologist
Partners for Fish and Wildlife Program
107ll Burnet Rd., Suite 200
Austin, TX 78758
Office (512) 490 0057 x 244
Fax (512) 490 0974
Mobile (512) 203 6043

and

Tim Schumann
Fish & Wildlife Biologist
Partners for Fish and Wildlife Program
107ll Burnet Rd., Suite 200
Austin, TX 78758
Office (512) 490 0057 x 245
Fax (512) 490 0974

Process

1. Landowner, agency personnel, etc. contacts appropriate FWS field office.

2. FWS private lands biologist conducts a site visit.

3. Proposed project developed with landowner, often with other conservation partner input.

4. Private Lands Agreement which stipulates FWS/ landowner's cost-shares, project design, and management plan is signed by landowner and submitted to FWS field office.

5. Once the project is approved at the field office level and based upon the availability of funds, the Agreement is sent to the Regional office (Albuquerque, NM) for final approval, archeological/pesticide use clearances (if necessary), and other processing.

6. Landowner receives signed agreement from FWS regional office; project construction may begin.

Restoration of native grassland using seed hay
Photograph by: U.S. Fish and Wildlife Service

If you would like to learn more about the PFW program, our contact information is at the end of this brochure. We look forward to hearing from you!

For Further Information:
Don R. Wilhelm, *State Coordinator*
Partners for Fish and Wildlife Program
U.S. Fish and Wildlife Service
711 Stadium Drive, Suite 252
Arlington, Texas76011
817-277-1100
817-277-1129 Fax
Visit our National PFW Program website:
http://partners.fws.gov/

PFW Program Biologists in Texas:

Northcentral/Northeast Texas:
Steve Arey, Arlington, 817-277-1100

East Texas:
Jeff Reid, Lufkin, 936-639-8546

Texas Panhandle:
John Hughes, Canadian, 806-323-6636

Central Texas:
Tim Schumann, Austin, 512-490-0057

West (Trans Pecos)/Southwest Texas:
Aimee Roberson, Alpine, 432-837-0747

Southeast Texas/Upper Texas Coast:
Ron Jones, Houston, 281-286-8282

South Texas/Lower Texas Coast:
Tim Anderson , Corpus Christi, 361-994-9005

October 2008

Front cover: Texas Coastal Prairie
Photo by: U.S. Fish and Wildlife Service

U.S. Fish and Wildlife Service

Partners for Fish and Wildlife Program

Texas

ACCOMPLISHMENTS
1990-Present

The U.S. Fish and Wildlife Service has entered into over 1,300 voluntary partnerships with private landowners, involving the restoration or enhancement of over 325,000 acres of fish and wildlife habitat in Texas, including:

- **62,000 acres of wetlands,**
- **6,500 acres (188 miles) of riparian area,**
- **165,000 acres of grasslands,**
- **43,000 acres of woodlands and shrublands, and**
- **49,000 acres of habitat for endangered, threatened, or candidate species.**

General Information

The Partners for Fish and Wildlife (PFW) program is a voluntary conservation program that provides technical and financial assistance to private landowners to restore or enhance fish and wildlife habitats for Federal trust species (e.g. migratory birds, threatened, endangered, and candidates species and other declining species). The PFW program has been very well received by our participating private landowner Cooperators. Several Cooperators have been honored as recipients of National and Regional wetland stewardship awards and also with local Wildlife Conservationists awards. A close working relationship exists with personnel from other State and Federal conservation agencies and private conservation organizations.

Texas PFW Activities

- **Restoring habitat for migratory birds and declining, threatened, and endangered species in:**
  - **Grasslands**
  - **Riparian corridors and other wetland areas**
  - **Longleaf pine forests, central Texas shrublands, and south Texas brushlands**
  - **Other specific habitats for rare species**
- **Establishment of native vegetation**
- **Wildlife and livestock management**
- **Protection of rare natural resources**
- **Controlling invasive & non-native vegetation**
- **Public outreach and education**

Habitats of Special Concern

Grasslands

Native grasslands are some of our most imperiled habitats in North America. Today, less than .5% of the tallgrass prairie in Texas remains in relatively pristine condition. What remains of our native grasslands is being rapidly consumed by urbanization and brush encroachment.

Lesser prairie-chickens during courtship displays on lek at a PFW project site in the Texas panhandle
Photograph by: U.S. Fish and Wildlife Service

Riparian Areas and Other Wetlands

Of an original 16 million acres of wetlands in Texas, it has been estimated that over one-half have been lost. Restoration of coastal wetlands, wetlands within the floodplains of river, and other isolated wetlands scattered across Texas, provide wetland functions lost due to human activities which have adversely affected natural ecological functions.

Landowner and future generation enjoying restored wetland area
Photograph by: U.S. Fish and Wildlife Service

Unique Habitats and Restoration Activities

The PFW program also places a high priority on opportunities to restore unique or rare habitat types across the State. These include the longleaf pine forest in east Texas, south Texas brush, Karst systems in central Texas, as well as habitats which support federally listed plants or animals.

Longleaf pine restoration project in east Texas
Photo by: U.S. Fish and Wildlife Service

Outdoor Learning Areas

The PFW Program funds outdoor learning areas intended to provide schoolchildren and communities with "hands-on" educational opportunities. These projects benefit fish and wildlife and the human communities that learn from them.

APPENDIX G:

EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM ECOSYSTEM RESTORATION SUBCOMMITTEE, "RESTORATION AND MITIGATION ACTIONS FOR THE COMAL SPRINGS ECOSYSTEM," AND "REPORT ON RESTORATION OPTIONS FOR THE SAN MARCOS RIVER," DECEMBER 2009

Restoration and Mitigation Actions For the Comal Springs Ecosystem

Edwards Aquifer Recovery Implementation Program
December 2009

Prepared by:
Ecosystem Restoration Subcommittee

Submitted to:
Steering Committee of the Edwards Aquifer Recovery Implementation Program

The Edwards Aquifer Recovery Implementation Program (EARIP) is a collaborative stakeholder process, working to develop a plan to protect the federally-listed species potentially affected by the management of the Edwards Aquifer and other related activities. The goals of the plan include contributing to the recovery of these species and producing the Program Documents that will include a Habitat Conservation Plan. The EARIP was created by the Texas Legislature in Senate Bill 3 (2007) and is overseen by a legislative appointed Steering Committee whose members include water utilities, cities, groundwater conservation districts, agricultural users, industrial users, environmental organizations, individuals, river authorities, downstream and coastal communities, and state and federal agencies. Additional information regarding the EARIP can be found at: http://earip.tamu.edu/.

While evaluating the previously created subcommittees that were formed to address specific issues within the EARIP process, the lack of information regarding restoration and mitigation actions was evident. To address this gap, an Ecosystem Restoration Subcommittee was formed to specifically identify and evaluate possible actions.

On May 14, 2009, the EARIP Steering Committee approved the creation of the Ecosystem Restoration Subcommittee and delegated the four charges below.

- To report to the EARIP at its July 9, 2009 meeting regarding the identified opportunities to date for the development of options or potential implementation of the Comal River restoration work by or through the United States Army Corps of Engineers.
- To assess existing conditions and restoration needs for the Comal River. The assessment should specifically identify and evaluate possible restoration actions for the Comal River and include an estimate of the ecological effectiveness and cost of each option.
- To consider opportunities for coordination with and eventual integration of the EARIP process with on-going restoration assessments of restoration options for the San Marcos River.
- To submit its report on restoration options for the Comal and San Marcos rivers to the Steering Committee and EARIP as soon as possible but no later than March 1, 2010.

The Steering Committee appointed as voting members to the Ecosystem Restoration Subcommittee Ken Diehl (SAWS), Melani Howard (City of San Marcos), Chad Norris (TPWD), Nathan Pence (City of New Braunfels), and Todd Votteler (GBRA); and as non-voting members USFWS, USGS, and USACE staff. Members from the non-voting agencies who participated on a regular basis included: Mara Alexander (USFWS), Kevin Connally (USFWS), Patrick Connor (USFWS), Evan Horing (USGS), Catherine Phillips (USFWS), and Jeffery Tripe (USACE). Additionally, Steve Bereyso (SAWS) participated with and contributed to the Subcommittee. At its initial meeting, Nathan Pence was selected as Chair of the Subcommittee and served in that role throughout the duration of the Subcommittee's work.

The Subcommittee identified possible restoration actions through a combination of channels including: review of the 1996 San Marcos and Comal Springs & Associated Aquatic Ecosystems (revised) Recovery Plan, review of the 2003 Draft Comal Springs Ecosystem Management Plan, subcommittee field trips, brainstorming sessions, and soliciting input from the science community, stakeholders, and public. The geographic scope of actions considered included the

contributing and recharge zones of the Edwards Aquifer that we believe potentially affect the Comal Springs ecosystem, the tributaries and watersheds of the Comal Springs ecosystem, all spring runs, Landa Lake, the old and new channels of the Comal River, and the entire Comal River. Actions identified could generally be placed into one of five broad restoration categories:

1. Recreation and Education
2. Bank Stabilization and Riparian Management
3. Dam Alteration and Water Control Structures
4. In-stream Habitat Improvement and Species Management
5. Stormwater Management and Water Quality

Identified actions were assessed for viability and evaluated based on direct benefit to the listed species, contribution to improved water quality, limited negative impacts, estimated cost, increased ecosystem resilience during critical periods, and other related criteria. The Subcommittee developed an informal scoring table (available on EARIP website) which was used internally to help evaluate each restoration action. Final prioritization of the restoration actions as High, Moderate, or Low priority was determined by a vote of the Subcommittee that was then averaged.

Throughout the process, numerous items and actions were identified that require additional research. Many of these research items apply to multiple actions and would be beneficial to the overall management of the Comal Springs ecosystem and EARIP restoration efforts. Additional research items are listed in Appendix I and are intended to be used in the development of future activities and/or the ongoing Adaptive Management Process.

Given the short timeline to meet EARIP goals and funding limitations, the process was abbreviated and largely dependent on existing information. As a result the final report includes no bibliography. However, at the conclusion of the process, members of the Science Community were asked to review the Report Matrix and provide comments. Provided comments were mostly grammatical in nature, and resulted in no significant additions or edits.

The information included in the following report matrix is intended to assist the Steering Committee and EARIP contractors in identifying needed restoration and mitigation actions to be utilized in the development of the program documents.

The final report to the Steering Committee of the EARIP was approved by consensus of all voting members of the Ecosystem Restoration Subcommittee.

	Restoration Action	Issue or Problem Addressed	Priority Ranking	Estimated Cost	Direct Benefit to Species	Potential Negative Impacts and Associated Concerns	Success Measures	Additional Comments
Recreation and Education	Determine current recreational practices and trends that would then be used to develop a Recreation Mgmt Plan that looks at public access points, erosion, vegetative denuding, litter and other recreational impacts.	The impacts of recreation are unquantified, but it is assumed that certain types of recreation in certain areas has impacts.	High to Med	$$	This action has the potential to benefit all endangered species and all other aquatic species. A written document would have to be funded and implemented before being a benefit to the species.	None	Implementation of the measures in the plan and if they achieved the associated objective.	Before a recreation plan can be designed and implemented, research needs to be conducted on the direct and indirect impacts of rec. Establish baseline, geographic scope, and limits. Establishment of what agency or entity has the legal authority to implement the Mgmt Strategies need to be determined before implementation.
	Installation of onsite education through interpretive signs and kiosks in public areas, that address: non-natives, endangered species, litter, access, springs, ecosystem as a whole, etc. Also educational brochures and maps located in city facilities addressing the same.	As a whole, the general public is not educated on the sensitivity of the Comal Ecosystem or the potential negative impacts of their actions.	Med to Low	$$	This action has the potential to benefit all endangered species and all other aquatic species, although impact most likely would be minimal. Education is an indirect benefit at best.	Sign Clutter	Change in park user's behavior.	Limited Educational Signage does exist in Landa Park; provided by EAA and the City of New Braunfels.
	Development of a Citizen Guide to properly functioning riparian zones and activities specific to the Comal River.	The general public is for the most part uneducated about BMP's for Riparian Management.	Med to Low	$$	All Species and Spring Ecosystems. Benefits may be direct or indirect, and most likely minimal.		Change in behavior of citizens.	Nueces River Authority has produced a good example for reference.
	Design of Springfed Pool inlet screen to reduce sedimentation in the pool and exclude biota from entering the pool.	Currently water enters into the Springfed Pool unfiltered, allowing sediment and biota to enter. The more sediment that enters the pool, the more frequent the cleaning of the pool and the associated negative effects with cleaning. Biota that enters the pool becomes trapped in the pool and their survival is unclear at that point.	Med to Low	$$	Fountain darter and aquatic organisms in the old channel. Improve old channel water quality and prevent fountain darters from becoming trapped in the Springfed Pool.	O/M of filter screen	Reduction of streamflow pulses to old channel from cleaning of the Springfed Pool and absence of fountain darters in pool.	There are contractors in NB that have looked at this project previously. Long lasting materials exist in small enough mesh to accomplish.
	Develop and implement a training class for City of New Braunfels seasonal and full-time staff that informs about the endangered species and habitat requirements of all.	Currently City of New Braunfels staff receive no training and for the most part are not educated about endangered species.	Med to Low	$	All species indirectly.	Cost to City to provide training	Educated Staff	

Estimated Cost Legend

$$$$ ≥ $1,000,000
$$$ ≥ $100,000
$$ ≥ $10,000
$ ≥ $1,000

	Restoration Action	Issue or Problem Addressed	Priority Ranking	Estimated Cost	Direct Benefit to Species	Potential Negative Impacts and Associated Concerns	Success Measures	Additional Comments
Bank Stabilization and Riparian Management	Establishment of riparian zones (park, public, private, golf course) - removing non-natives (lugustrum and cane/reed) planting natives, limiting access to reduce trampling, and establish no mow zones.	Current pedestrian traffic causes erosion and loss of natives; resulting in recolonization by non-natives.	High	$$$-$$$$	All species associated with the ecosystem; endangered species and others. Improves water quality of runoff entering system by capturing sediments, reducing pollutants, erosion, and turbidity. Riparian zones also work to increase aquifer recharge and reduce flood intensity.	Limit recreational access to water by the public. Limited visibility of dense vegetation creates security issues.	Amount of acres established and monitoring for success.	Design of this is underway by the City of New Braunfels at Landa Park and Landa Golf Course.
	Establishment of natural bank stabilization and reduced channelization consistent with the overall goals of the EARIP - Landa Lake and Island area.	Severe erosion is occurring in this area.	High to Med	$$$$	All species associated with the ecosystem; endangered species and others.	Future O/M; habitat destruction during construction.	Sedimentation abated.	City of New Braunfels has begun this independently already, is in design phase. Island area is private property.
	Erosion Control on Escarpment just Upstream of Spring Run 3 on Landa Lake, and steep hill along Spring Run 3.	This area is experiencing severe erosion and no preventive measures are in place. Where this water meets Landa Lake is known habitat for the beetles. Also sediment in this area is covering spring openings.	Med	$$$	Protect habitat of beetles that are found along this escarpment . Species that live near the spring openings, or are dependent on pristine water quality.		Installation of erosion control measures.	All property associated with this project is private.
	Establishment of natural bank stabilization and reduced channelization consistent with the overall goals of the EARIP - Landa Golf Course Area.	Severe erosion is occurring in this area.	Med	$$$$	All species associated with the ecosystem; endangered species and others.	Future O/M; habitat destruction during construction.	Sedimentation abated.	City of New Braunfels has begun this independently already, is in design phase.
	Implementation of Turf Establishment and Maintenance Program (native grasses, irrigation, and rotating relief from pedestrian traffic) in Landa Park, Prince Solms, and Hinman Island.	Severe erosion is occurring in this area. Currently pedestrian traffic in these areas denudes turf, especially during drought and hot summer months.	Med to Low	$$$$	All species associated with the ecosystem; endangered species and others.	Possible fertilization and water use.	Establishment of turf and decreased erosion.	City of New Braunfels has begun this independently already, is in design phase.
	Establishment of natural bank stabilization and reduced channelization consistent with the overall goals of the EARIP - Tube Chute Area.	Severe erosion is occurring in this area.	Med to Low	$$$$	The only endangered species would be the fountain darter; all other aquatic organisms in the area would benefit also.	Future O/M; habitat destruction during construction	Sedimentation abated.	Is badly needed, but is outside the distribution of all endangered species except the fountain darter.
	Establishment of natural bank stabilization and reduced channelization consistent with the overall goals of the EARIP - downstream private lands.	Erosion is occurring on private lands downstream of the Tube Chute.	Low	$$$$	The only endangered species would be the fountain darter; all other aquatic organisms in the area would benefit also.	Future O/M; habitat destruction during construction	Sedimentation abated.	Is badly needed, but is outside the distribution of all endangered species except the fountain darter. All on private lands.

	Restoration Action	Issue or Problem Addressed	Priority Ranking	Estimated Cost	Direct Benefit to Species	Potential Negative Impacts and Associated Concerns	Success Measures	Additional Comments
Dam Alteration and Water Control Structures	Manipulation of flows in the old and new channel using the gated culverts to benefit fountain darters and associated habitat in the old channel.	Currently the gated culverts to the old channel are set at a constant flow and never changed. A natural flow regime would be beneficial.	High	$ or $$	Fountain darters benefit because flow component of habitat is adjusted for total springflow, to help maintain spring ambient water quality including water temperature.	Some habitat may not be maintained to protect higher quality habitat.	Completion and implementation of MOU between City of New Braunfels and USFWS.	Draft MOU available; possible flow regime in the 2003 draft Mgmt Plan by Hardy et al. 1999; cost is determining flow regime, keeping gated culverts free of debris, O/M to set flows.
	Manipulation of streamflow at Clemens Dam and tube chute.	Current dam operation is determined by recreational needs, not species needs.	Med to Low	$ or $$	Fountain darter - And all species affected by backwater effect and retention time of Clemens Dam.	Managing for water quality may affect recreation and may increase water recreation impacts.	MOU to manage control structures in Clemens Dam to maintain water quality in river during low river flow.	Especially important during times of low flows. Range of control limited by three gates in Clemens Dam; Trade-off: during moderately low, average and high flows, tube chute operates normally with stage maintained for tube chute, (2) during stressful low flows Clemens Dam's gates are adjusted to lower retention time.
	NBU HydroPlant decommissioning should take into account the endangered species and O/M of the facility should not cause mortality or stress to the endangered species.	Hydroplants through turbine operation, intake, or pass through can cause mortality to fishes.	Low	$$ - $$$	Fountain darter - reduced mortality.			Hydroplant is inactive currently and water passes through.
	Develop a contingency plan that addresses how to proceed should there be a catastrophic dam failure on the Comal River or Landa Lake.	If dam should fail, there is no plan that addresses if or how to replace or rebuild the dam.	Low	$$	All Species.			This has happened on the San Marcos River and it was identified that a plan was needed rather than a decision on-site.
In-Stream Habitat Improvement and Species Management	Plecostomus (*Hypostomus spp* . and *Pterygoplichthys spp* .) and Tilapia (*Oreochromis aureus*) removal - concerted winter effort to remove these non-natives.	Numbers of these two non-natives are growing and both are detrimental to the habitat of all associated endangered species.	High	$-$$	Fountain darter mainly. non-native species compete with native species for resources and alter habitat among other issues. Specifically, tilapia and plecostomus destroy vegetation by consuming it and/or making bare ground nests.	Collection efforts may impact fountain darters or habitat.	Eradication of tilapia and/or plecostomus.	It is common for these tropical non-natives to congregate in spring runs on exceptionally cold days. This includes the Landa Lake spring runs and spring areas in the upstream reach of Landa lake. Areas could be boxed off and fish collected with seines. To be effective, this would require several collection efforts per year over several years and would only reduce numbers, not eradicate invasive species from system.
	Removal of the non-native Asian trematode, *Centrocestus formosanus.*	Gill parasite can cause stress to the fountain darter and eventually mortality.	High	$$ - $$$	Fountain darter.		Eradication of *Centrocestus formosanus.*	Two possible partial but untested control methods are physical removal of *M. tuberculatus* (by dredging) and water turbulence (dams, riffles, and air bubble) to kill drifting *C formosanus* cercaria. Cost determined by method chosen.
	Removal of Ramshorn (*Marisa cornuarietus*) and *Melanoides tuberculatus* snails.	The ramshorn during low flow is a threat to vegetation communities and *Melanoides* is the intermediate host for the gill parasite.	High	$$	Fountain darter. Ramshorn snail removes vegetation that may be used as habitat and *Melanoides tuberculatus* is part of life cycle of parasite that infects fountain darter.	May injure or "take" listed species during removal process.	Eradication of snails.	Requires annual efforts and therefore cost estimate is annual.

	Restoration Action	Issue or Problem Addressed	Priority Ranking	Estimated Cost	Direct Benefit to Species	Potential Negative Impacts and Associated Concerns	Success Measures	Additional Comments
In-Stream Habitat Improvement and Species Management	Elephant Ear (*Xanthosoma sagittifolium* and *Colocasia esculenta*) removal and replacement with native vegetation.	Spread of non-native species is causing a reduction in diversity and loss of natives. Elephant ears also contribute to increased evapotranspiration.	High to Med	$$	All four listed species and other species benefit from removal of elephant ears and establishment of native riparian vegetation that provides woody debris, shade, and habitat.	Temporarily increase of turbidity during removal.	Eradication of elephant ear.	Requires annual efforts and therefore cost estimate is annual.
	Stop or limit aquarium "dump" introductions.	Citizens often dump their entire aquarium into the river when they no longer can keep the aquarium.	High to Med	$$	All species associated with the ecosystem; endangered species and others. Regulating reduces the likelihood non-native or invasive species will be introduced to the system.		No new non-natives introduced to system.	One possible solution is an adopt a pet program like San Marcos has. Enforcement and education are key elements.
	Regulation of bait species used in Landa Lake - coordinating with local bait shops, kiosk signage, and enforcement.	Current practice allows for the use of any live bait species and can result in the introduction of non-natives.	High to Med	$$	All species associated with the ecosystem; endangered species and others by limiting the likelihood non-native or invasive species will be introduced to the system.	Reduces angler numbers.	No new non-natives introduced to system.	Actions could include the prohibition of live bait and allow for use of only artificial; or allow for only the use of native species as live bait. Enforcement and education are key elements.
	Nutria Removal.	Currently in the Landa Lake area Nutria cause erosion, the loss of old growth Cypress Trees along the banks, and destruction of beetle habitat.	Med	$	All species associated with the ecosystem; endangered species and others.	Possible negative PR associated with the killing of any species.	Eradication of Nutria population.	The City of New Braunfels currently has a program in cooperation with Texas Wildlife Services to remove Nutria every winter. However a more ramped up program would be useful.
	Allow fallen trees and coarse woody debris to remain in Landa Lake and the Comal River for the purpose of habitat.	Currently there is pressure to remove all trees and some trees are removed due to human safety concerns.	Med	$	Increases habitat complexity for fountain darter and riffle beetle. Fountain darter benefits from microhabitat alteration (streamflow alteration and structure) while riffle beetle larvae are found on woody debris (not as common as with other species, but still utilized). Also would benefit all other aquatic organisms in the area.	Aesthetic and/or recreational nuisance; Fallen trees can pose a safety threat to recreators.	Policy developed and implemented by the City of New Braunfels mandating trees remain in the water.	Current practices in 2003 management plan. Trees are currently removed based on human safety needs.
	Implementation of a Terrestrial Landscape and Green Waste Disposal Program: including increased enforcement, leave floating debris alone, shake out by hand to dislodge darters, and minimize vegetation put in system by private citizens (i.e. lawn clippings, etc.).	Some citizens currently use the Comal River and Landa Lake for disposal of household green waste.	Med	$	Primarily benefits fountain darter by minimizing take of individuals in debris.	Continual maintenance.	No darters taken by removal of debris.	Island area of Landa Lake should be focus and is private property. It is not uncommon for landowners to dispose of lawn clippings and other green waste by dumping into Landa Lake and the Comal River. Education and enforcement are key elements.
	Removal of Hyacinth, Hydrilla, and Hygrophila; replacing with natives.	Spread of non-native species is causing a reduction in diversity and loss of natives.	Med	$$	Removal of non-natives and reestablishment of native vegetation should create more usable and ideal habitat for the fountain darter.	May injure or "take" fountain darters during removal process.	Eradication of Hyacinth, Hydrilla, and Hygrophila	Requires annual efforts and therefore cost estimate is annual.

	Restoration Action	Issue or Problem Addressed	Priority Ranking	Estimated Cost	Direct Benefit to Species	Potential Negative Impacts and Associated Concerns	Success Measures	Additional Comments
Stormwater Management and Water Quality	Implementation of best management practices to address stormwater runoff in and around Landa Lake; could include stormwater retention ponds, rain gardens, wetlands, and storm sewer filters.	During rain events, surface runoff enters directly in to Landa Lake and the spring runs without filtration or settling.	High	$$$	All species. Water quality concerns from direct runoff can threaten endangered species habitat or if severe enough cause direct mortality.	Possible loss of usable park space.	Installation.	Expand efforts beyond TPDES and MS4 requirements. Hard to quantify positive effects.
	Increased prohibition of hazardous materials routes that cross the Comal River, watershed, or associated tributaries.	Roads that cross the Comal and recharge zone are not identified hazardous materials routes, but hazardous materials are allowed to cross. A spill could be catastrophic depending on location.	High	$ or $$	All species associated with the ecosystem; endangered species and others.	Could cause inconvenience through less direct routes.	No massive kill due to hazardous materials spill reaching the Comal Ecosystem.	Work with TXDoT, County, City of New Braunfels, and state agencies to establish restricted zones; cost is to install signage and designate alternative routes; City of New Braunfels has existing hazardous materials response plan.
	Development of household hazardous materials collection program and increased awareness about discarding household hazardous materials (including pharmaceuticals).	Often hazardous materials are discarded by pouring on the ground or in a storm sewer.	High	$ or $$	All species associated with the ecosystem; endangered species and others.		Receiving hazardous materials through program.	Work with state and local agencies to establish; City of New Braunfels does currently have a limited program and will increase as part of their upcoming MS4 compliance; cost is to establish a drop center and publicize.
	Implement an aerobic and anaerobic septic system registration, evaluation, and permitting program to prevent subsurface pollutant loadings from potentially being introduced to the spring ecosystem.	Potential leaking underground septic systems leaching nutrients (i.e. nitrates) and other constituents of concern into the springs ecosystem via groundwater transport pathways.	High	$ or $$$$	All Species and spring ecosystems.	Cost for cities to fully implement; politically challenging to determine what systems need to be upgraded.	All septic systems reevaluated and brought into TCEQ compliance with accepted best-maintenance standards with no new non-compliant systems installed.	The cost to identify, monitor, and impose construction specifications and retrofit standards for new and existing septic systems is relatively low. City Ordinances and Codes could be implemented to require the appropriate provisions. Costs to install new systems, or upgrade existing systems, could be seen to be onerous if it falls upon a single entity (i.e. a homeowner). Cost-assistance measures could be developed.
	Land acquisition throughout the watershed and recharge and contributing zones for conservation and green space; acquired land should fit the overall goals of the EARIP.	Land in the watershed, around Comal Springs, and the Comal River is being developed as pieces become available for acquisition. With no acquisition program, there will be minimal green space around the river or in the watershed.	High	$$$$	Depending on where conservation easement is located, could be direct or indirect impact to all species; endangered species and others.		Improved water quality and preserved green space.	Property could be above Landa Lake and Springs, at the Lake, or in the upstream watershed of Blieders Creek. Could also include development rights and conservation easements throughout the recharge and contributing zones.
	Conversion of impervious cover to pervious cover.	Impervious cover reduces aquifer recharge and contributes to stormwater pollution.	High	$$$$	All Species and spring ecosystems.	Loss of usable roads, extra expense during development.	Implementation of development codes that require conservation easements in lieu of development or require development to be no more than X% impervious.	One solution is watershed wide development restrictions and requirements.

	Restoration Action	Issue or Problem Addressed	Priority Ranking	Estimated Cost	Direct Benefit to Species	Potential Negative Impacts and Associated Concerns	Success Measures	Additional Comments
Stormwater Management and Water Quality	Restoration of riparian zones along tributaries (Blieders, Panther, Dry Comal) and entire watershed, including removing non-natives, planting native vegetation, bank stabilization, and possible wetland creation.	During runoff events the watershed and tributaries contribute to poor water quality in Landa Lake and the Comal River.	High	$$$	All species associated with the ecosystem; endangered species and others. Improves water quality from tributaries, Reduce runoff and erosion from tributaries as well as siltation and turbidity in Landa Lake associated with rainfall events.	private landowner cooperation required.	amount of riparian or wetland habitat created; water quality monitoring pre and post.	Primarily Private Lands. Priority should be focused on areas that contribute significantly to water quality concerns or areas closest to Landa Lake.
	Establishment of Aggressive and Frequent Water Quality Monitoring (surface and ground) that considers location, time of day, day of week, time of year, and all water quality parameters.	Efforts to monitor water quality around Landa Lake and the Comal Springs are minimal at best.	High	$$$	All species; endangered species and others. Can prevent future water quality problems by detecting early warning signs. Also useful in building baseline conditions.	None.	Success is preventative, there may be no direct measure.	Current sampling is per Clean Rivers Program, need to expand the frequency and scope.
	To evaluate and implement watershed wide regulations aimed at following Extension Service guidelines for pesticide, herbicide, and fertilizer applications. Environmentally safe alternatives could be used in order to reduce the potential of and/or prevent pollutant loadings from being introduced to the spring ecosystems.	Chemical applications leach into groundwater and/or storm water run-off being introduced to the spring ecosystems.	Med	$$	All species and spring ecosystems.	The cost to indentify monitor, educate and impose regulations that would require only organic compounds under certain conditions is a low cost.	Community embraces the concept and promotes all applications to be environmentally friendly. And an educational program or material is provided.	Organic alternatives should be considered. Refer to the U.S. Environmental Protection Agency (EPA) for alternatives.
	To evaluate and implement a program that would adhere to local City Codes and State regulations to reduce and/or prevent the potential for subsurface pollutant loadings from being introduced to the Spring Ecosystems through abandoned well systems.	Addressing the potential pollutant contamination of groundwater via a direct conduit through abandoned wells, which could adversely impact the springs ecosystem. Citizens often used abandoned wells as a way of disposing of hazardous materials.	Med	$$$	All species and spring ecosystems.	Limited number of locations - capping and registering all wells that could be a direct conduit to the water flowing to the springs is important.	All identified wells in a defined area have been registered, and if not approved for use are properly plugged or capped.	Spring communities may consider designating staff members to comply with State plugging regulations of abandoned wells. Potential for cooperative training and information sharing - both San Antonio and EAA have a program that consists of registering, inspecting and plugging wells if deemed appropriate. Partnering with or enforcement of TCEQ Regulations may be one solution.
	Prohibition of construction materials (dirt or mulch) storage in Landa Park or Landa Golf Course.	Piles of dirt and mulch stored in these areas washes in during rain events.	Med	$	All species associated with the ecosystem; endangered species and others.	None.	Create City of New Braunfels policy to prohibit construction materials to be stored in Landa Park	City of New Braunfels staff is currently working on establishing an internal City policy preventing.
	Evaluate current procedure and increase frequency or impose more stringent requirements on the construction and monitoring of NBU owned sanitary sewer mains in the vicinity of springs ecosystems.	Reduce or eliminate pollutant loadings from entering the Spring Ecosystems through leaking or poorly installed sanitary sewer mains.	Med	$$	All species and spring ecosystems.	CMOM program is moderately costly - repair and replacement of improperly installed or leaking infrastructure.	Capacity Management Operation and Maintenance Program implemented in vicinity of spring habitats.	Focus on areas closest to the springs.

	Restoration Action	Issue or Problem Addressed	Priority Ranking	Estimated Cost	Direct Benefit to Species	Potential Negative Impacts and Associated Concerns	Success Measures	Additional Comments
Stormwater Management and Water Quality	Conversion of impervious cover (roads, driveways, and rooftops) to pervious in public areas. Including no vehicular traffic or roads in Landa Park.	Impervious cover reduces aquifer recharge and contributes to stormwater pollution. Vehicles and roadways combined represent a direct pathway for pollutants to waterways during rain events.	Med	$$	All species; endangered species and others. Decreases input of sediment and other pollutants, also decreases rate and quantity of stormwater inflow.	None.	Measure water quality parameters before and after the implementation of these measures.	
	Installation of detention ponds, water quality measures, and riparian zones at the local Rock quarry operations and plant operations; possible consideration of stormwater and tributary filtration	Water quality impairments could be a result of runoff from these facilities.	Med to Low	$$$$	All species associated with the ecosystem; endangered species and others	Cost to quarries.	Implementation of measures.	Very little is known about this action; although it is generally agreed that this should be pursued as it could prove to be very significant.
	Prohibition of feeding all species in Landa Park.	Unnaturally large numbers of wildlife created by concentrated feeding can cause excessive buildup of feces; thus contributing to nutrient loading, ecoli concerns, D.O. fluctuations, and algae buildup.	Med to Low	$	Indirect benefit, omnivorous waterbirds may impact submergent plants.	None	Absence of non-native and nuisance waterbirds.	Non-native waterbirds should be excluded from Comal Springs invertebrate critical habitat; water quality impacts from waterbirds including nutrients are eliminated. Pay special attention to feral and non-native species.
	Evaluate current SOP's established by USFWS at the golf course in Landa Park. May include refinement and/or initiation of BMP's for turf which should include pesticide, fertilizer and irrigation water applications. Should identify the most environmentally-beneficial practices addressing over applications of fertilizers, irrigation waters and pesticides. One alternative could be to relocate golf course.	Golf course nutrient and pesticide stormwater run-off and groundwater has potential to leach into springs ecosystem via groundwater transport.	Med to Low	$$$	All species and spring ecosystems.	Portions of the golf course may have to be modified to provide buffers, and mitigate for ongoing operation of the course in a less-impactful manner.	Stormwater quality runoff is improved and buffers are provided that increase habitat quality for aquatic ecosystems.	One alternative could be to relocate the golf course. If the golf course is not relocated, the goal would be to protect the quality of run-off water and leachate to the Comal springs area; minimize erosion and transport of soil resulting from golf course activities and preserve and protect native plant and wildlife habitats to the greatest extent practicable. Development of an environmental management plan which should consist of the climate, irrigation, soils, geology, water resources, turf grass, and vegetation conditions at the golf course should be taken into consideration. Identify turf grass, soil, water quality risks an the development and implementation of an. If appropriate, identify specific alternate management practices and current Best Management Practices ("BMP's") for controlling runoff, site modifications, environmentally sound irrigation, soil and water conservation, fertilization and pest and disease control.
	To evaluate and implement a watershed wide program that could eliminate coal tar applications on roads that would reduce polycyclic aromatic hydrocarbons (PAH's) from entering the Spring Ecosystems.	Coal tar and Polycyclic Aromatic Hydrocarbons (PAH's) from roadway's enter the spring ecosystems and adversely impact the benthic ecosystem community.	Med to Low	$$	All species and spring ecosystems.	Should not be too controversial, secondary used park roads and walkways need not be asphalt, some sort of impervious cover could be used.	Other source pavement types such as crushed granite be utilized in close proximity to waterways and springs.	Recent studies by the USGS' National Water Quality Assessment have identified seal coating, which is the black, shiny surface often applied to asphalt pavement, as a significant and previously unrecognized source of extremely elevated concentrations of PAH's in streams. In one instance, runoff from parking lots sealed with a type of coal tar-based sealant had PAH concentrations of 65 times higher than concentrations from unsealed parking lots. PAH's are suspected human carcinogens and are toxic to aquatic life. Biological studies conducted by the City of Austin found a loss of species and decreased numbers of organisms at the PAH concentrations seen in Austin streams. Officials observed these effects at sites downstream from the points where sealed parking lot runoff enters the streams.

	Restoration Action	Issue or Problem Addressed	Priority Ranking	Estimated Cost	Direct Benefit to Species	Potential Negative Impacts and Associated Concerns	Success Measures	Additional Comments
Stormwater Management and Water Quality	Evaluate current SOP's recommended by the USFWS for the Springfed and Olympic Pool O/M; Update as needed for benefit of endangered species.	Current O/M uses small amounts of chemicals and neutralizers that eventually end up in the old channel of the Comal; current O/M also creates a weekly pulse in the old channel.	Med to Low	$	The only endangered species would be the fountain darter; all other aquatic organisms in the area would benefit also.	Use of small amounts of chemicals and water pulses.		There is the opportunity to evaluate the O/M form a habitat mgmt strategy: pulses, water flow, regime, etc. The City of New Braunfels currently follows USFWS recommendations from the 2003 Draft Comal Mgmt Plan.
	Installation of erosion and water quality BMP's on the old channel Schlitterbahn parking lot, including riparian and vegetative buffer zones. One alternative could be to relocate the parking lot.	All Schlitterbahn employees park on a gravel parking lot next to the old channel of the Comal River. Fluids and pollutants from the cars can directly enter the old channel.	Med to Low	$$$	The only endangered species would be the fountain darter; all other aquatic organisms in the area would benefit also.		Installation of any measures	Is on Schlitterbahn property.
	To evaluate and implement local City Codes or ordinances to control and/or eliminate domesticated pet-waste-induced bacterial loadings from entering the spring ecosystems.	To control and/or eliminate the bacterial loadings from entering the Spring Ecosystems via storm water run-off from pet waste. This waste contributes to nutrient loading and possible D.O. crashes.	Med to Low	$	All species and spring ecosystems.	The cost to educate, provide plastic bags, and signs along with the development of a City Ordinance is relative low.	Community embraces the concept and utilizes the Dog waste cleanup, construction of a designated Dog park with dedicated maintenance.	Dog waste often contains a variety of organisms, including bacteria and internal parasites, both of which may be communicable and harmful to humans, especially children. Fecal coli form bacteria, for example, can cause severe stomach illness and rashes. There also maybe a consideration of specifically designating a "Dog Park" area and no dogs are allowed outside this area. Currently there are pet waste stations in Landa Park.
	Relocation or upgrade of the railroad trestles over the new channel of the Comal River, for the purpose of minimizing habitat impacts from trestle, preventing hazardous material spills, and increasing the safety of railroad operations over Comal River.	Creosote bridge structure or spill from railroad can pollute the River.	Low	$$ or $$$	Fountain darter habitat would be less likely to receive pollution through rail accident. Also helps associated plants and invertebrates.	Some habitat disruption during construction.	Existence of railroad trestle that completely spans river; maximize safety of operations near and over Comal River; trestles over new and old channel currently are creosote treated timbers.	Union Pacific has replaced two trestles over San Marcos River.
	Litter removal from Landa Lake and islands.	Litter from stormwater events and the wind is currently allowed to collect in Landa Lake with limited removal.	Low	$$	All species associated with the ecosystem; endangered species and others.	Disturbance of habitat during collection of litter; or destruction of habitat.	Removal of all litter.	There are numerous contractors and companies that can perform this service.
	Installation of hot ash boxes in areas of public grilling throughout the parks system.	Ashes end up in the waterways and contribute to nutrient loading and turbidity.	Low	$	All species; endangered species and others. Increases water quality by containing charcoal remains.	Could increase/encourage the use of grills in the parks.	Reduced amount of charcoal emptied onto the ground.	

Appendix I

Additional Research Needed for Restoration of the Comal Ecosystem
Possible Components of the Adaptive Management Plan

Recreation and Education

- A determination of which agencies and entities have the authority to conduct activities or impose restrictions on the Comal River. This information will be important as the EARIP works to implement management strategies and restoration activities.

- Determine recreational baseline on Landa Lake, the old channel, the new channel, and the Comal River that includes, but is not limited to: user numbers, impacts to riparian and aquatic vegetation, impacts to the listed species and their associated habitats, geographical and spatial analysis, recreation types, seasonal and annual variations, and effects of varying springflows. This information could be used to develop and implement management strategies as relates to recreation.

- Revisit the management strategies recommended by USFWS (2003 Draft Comal Management Plan) and currently used by the City of New Braunfels in relation to the operation of the Springfed Pool in Landa Park. Looking specifically at updating procedures to develop management strategies that promote habitat for Fountain Darters and improve water quality.

Bank Stabilization and Riparian Management

No research items were identified in this category. Although many of the other identified research items apply indirectly.

Dam Alteration and Water Control Structures

- Research impacts associated with a catastrophic dam failure on the Comal River. Plan should address questions such as: should the dam be fixed, what are the potential impacts to the threatened and endangered species and what to do with species to ameliorate impacts.

- Identify appropriate flow regime to maximize fountain darter habitat in the old channel of Comal River.

In-stream Habitat Improvement and Species Management

- Determine areas on the Comal River and in Landa Lake that have experienced heavy sedimentation; and determine positive effects or potential concerns from dredging those identified locations. Could be done in conjunction with dredging for snail removal.

- Monitoring and modeling of *Centrocestus formosanus*, an exotic fish gill parasite, in the Comal River. Correlations among spring flow, *Melanoides tuberculatus* (snail host of *C. formosanus)* numbers, and parasite numbers need to be established. Determination of correlations among flow, snail host, parasite, and fountain darter will permit the development of a model to predict future effects of the parasite on fountain darter survival.

- Management of *Centrocestus formosanus*, an exotic fish gill parasite, in the Comal River. Elimination of the parasite from the rivers is not likely. Physical removal of the parasite's host snail, *Melanoides tuberculatus*, by dredging and using turbulence (dams, riffles, and air bubbles) to kill drifting parasites are possible methods to manage the effects of the parasite on the fountain darter. Removal of snails by dredging could be done in conjunction with sediment removal.

- Monitoring and modeling of the effects of cumulative spring discharge on the fountain darter and Comal Springs riffle beetle populations in the Comal River need to be determined. Also, the effects of the proposed springflow regime on the listed species needs to be monitored, evaluated, and a predictive model developed accordingly.

- Monitoring of the Comal River to detect newly introduced species before they become problematic needs to be conducted. Bi-annual surveys of the plants, invertebrates, and fishes should be done to identify newly introduced species and to determine if significant changes in native species have occurred. Non-native species need to be removed immediately. Causes of significant changes in native species numbers or distributions need to be determined and addressed.

- Determination of the best methods to remove non-native, such as plecostomus, tilapia, giant cane, elephant ear, ramshorn, melanoides, and others.

- Determine effects of introduced non-native species from all sources: live bait, aquarium dumps, storm events, etc.

- Determination of all life history characteristics of the endangered invertebrate species associated with the Comal Springs ecosystem. This should include the endangered species, karst species, and the undescribed species of salamander.

- Survey pertinent springs in the region for the purpose of identifying new locations and populations of the endangered species. These efforts could also focus on the karts species and undescribed species of salamander.

Stormwater Management and Water Quality

- Design and implement an aggressive water quality and quantity monitoring program on Landa Lake, the Comal River, and associated tributaries. Taking into account differences between days of the week, stormwater events, metals and PAH's, nutrient loading,

turbidity, seasonal variations, springflow effects, point source discharge effects (golf course), etc.

- Determination of hydrologic features and flow paths; especially major conduits and recharge features that relate to Comal Springs. This information could be used to determine priority of which recharge areas to protect first, relocation of hazardous material routes away from direct recharge areas, and development decisions.

- Evaluate management strategies and current practices used by the City of New Braunfels in relation to the operation of the golf course. Implementation of an aggressive water quality monitoring of leachate and stormwater runoff to determine the quality of the water potentially leaving the site and entering the spring system via groundwater and/or stormwater run-off. Monitoring efforts could include analysis of plant tissue, soil, and irrigation water, as well as pesticide and nutrient applications to develop management strategies that promote habitat for fountain darters and improve water quality.

- Determination and location of abandoned water wells. This information could be used to enforce the capping of these wells but should also determine priority based on proximity to spring openings and direct recharge conduits.

- Establish effects, if any, caused by the presence of *Thompsodinium*, the dinoflagellate plume discovered in the Blieders Creek area of the Comal River during the summer of 2009.

- Evaluation of need and feasibility of a real time flow gauge on Landa Lake above Spring Run 3. This gauge could be used to establish flows and water quality during storm events and to determine the contribution from springs in the upper end of Landa Lake during normal and low flow periods.

- Identify leaking aerobic and anaerobic septic systems in the vicinity of Landa Lake and the recharge and contributing zones of the Edwards Aquifer. This information would also be useful in prioritization of which septic systems to address first. Determine if a more aggressive program is needed.

- Determine effects to the Comal Springs ecosystem caused by local rock quarries and cement plants. Develop and design BMP's to mitigate.

- Evaluate the existing CMOM program and upgrade if needed.

Report on Restoration Options for the San Marcos River

The San Marcos River (River) is home to six federally protected species. The River has many invasive plant and animal species that compete with and disrupt the habitat for the River's native species. The growing human population within the watershed is also constantly changing the River (e.g., pollution, sedimentation, the building of dams, etc.). This report on restoration options (in tabular form) for the River includes pursuits to restore every aspect of the River, comprising: activities that enhance value, use, appearance, access, safety, and knowledge; practices designed to reduce/eliminate erosion or slumping of bank material into the river channel; alteration of dams to reduce negative ecological impacts; removal of barriers to upstream/downstream migration of fishes, including the physical removal of barriers and also construction of alternative pathways; altering structural complexity to increase habitat availability and diversity for target organisms and provisions of breeding habitat and refugia from disturbances and predation; practices that directly alter aquatic native species distribution and abundance through the addition or translocation of animal and plant species and removal of exotics; revegetation of riparian zone and removal of exotic species; and flow modifications that include the construction and management of structures (ponds, wetlands, and flow regulators) in urban areas to modify the release of storm run-off into waterways.

In order to put together such a comprehensive report, a team of experts, stakeholders, and all interested parties joined together. Representatives from state agencies, federal agencies, local government, landowners, NGOs, and multiple Texas universities have been attending each meeting. We worked together to create a report that encompasses all goals and objectives for the future of the river. The restoration actions we recommend are broken into five main goals/categories:

1. Aesthetics/Recreation/Education
2. Bank Stabilization and Riparian Management
3. Dam Alteration and Aquatic Organism Passage
4. In-stream Habitat Improvement and Species Management
5. Stormwater Management

All actions identified were given a priority level (H = High, MH = Moderate to High, M = Moderate, LM = Low to Moderate, and L = Low) and an estimate of cost ($ = < $10,000, $$ = $10,000 - $100,000, $$$ = $100,000 - $1 million, $$$$ = >$1 million); both decided by majority vote. The geographic scope of actions considered included the San Marcos River from the headwaters in Spring Lake down to the first low water crossing after the confluence with the Blanco River, and the entire watershed that surrounds this portion of the river and its tributaries.

The report matrix is followed by a glossary which describes in more detail what each restoration action item entails.

While creating the matrix, we found that some of the action items we suggest would benefit from research projects done prior to the described actions. Many of these research topics apply to multiple actions and would be beneficial to the overall management of the San Marcos River restoration efforts. These research items are listed in Appendix I and are intended to be used in the development of future activities and/or the ongoing adaptive management process. As in the report matrix, we also gave each research question a priority level (following the same designations as described above) and an estimate of cost (following the same designations as described above); both decided by majority vote.

The information included in the following report is intended to assist the EARIP Steering Committee and contractors in identifying needed restoration and mitigation actions to be utilized in the development of the program documents.

Restoration Plan Goal	Restoration Action	Issue or Problem Addressed	Priority Ranking	Estimated Cost	Species Benefited	Potential Negative Impacts Associated	Success Measures	Additional Comments
1	Develop educational publications	Educate river-users on the importance of the river ecosystem and ways to protect it including the negative impacts of invasive species	**MH**	**$**	All	None	Less polluting and releasing invasive species into the river	
1	Develop an internet presence to market existing and upcoming educational materials	Educate river-users on the importance of the river ecosystem and ways to protect it including the negative impacts of invasive species	**M**	**$**	All	None	Less polluting and releasing invasive species into the river	
1	Develop travelling exhibits and demonstration sites	Educate river-users on the importance of the river ecosystem and ways to protect it including the negative impacts of invasive species	**LM**	**$**	All	None	Less polluting and releasing invasive species into the river	
1	Increase enforcement of park/city rules re: polluting and aquarium dumping	Trash in the river and invasive species introductions	**H**	**$$**	All	None	Less polluting and releasing invasive species into the river	
1	Remove Floating debris from Texas wild-rice stands	Trash in the river, low light levels and inhibition of flowering for Texas wild-rice	**H**	**$**	Texas wild-rice	None	Larger Texas wild-rice stands with a higher percent cover	

1	Relocate Texas State University watercraft classes to Spring Lake	Texas wild-rice damage	**M**	**$**	Texas wild-rice	None	Less damage to Texas wild-rice stands from watercraft	
2	Create pre-determined access points into the river	Unstabilized banks	**H**	**$$$**	All	None	Less sedimentation in the river, better riparian buffer zones, less trampling of native aquatic vegetation	$$$ is assuming construction material will be needed (i.e. stacked rock, pathways, etc.)
2	Create non-access points in sensitive areas	Unstabilized banks and trampling of native aquatic vegetation	**H**	$$	All	None	Less sedimentation in the river, better riparian buffer zones, less trampling of native aquatic vegetation	Non-access points = bank stabilization using prohibitive (thorny) plants
2	In-stream barriers as needed to protect habitat	Protection of endangered species from trampling	**M**	**$$**	All	Flooding could move barriers to undesired locations	An increase in endangered species population counts in the fenced-off areas	
2	Involve riverside landowners in riparian management	Buffer zones, pollution, invasive species	**MH**	**$**	All	None	Adequate buffer zones, less pollution and invasive species in the river	
2	Remove elephant ear from the river	Invasive species competition with native plants	**M**	**$$**	Texas wild-rice	Bank destabilization	Less elephant ear in the river and more native river-edge species	Has to include planting natives in its place for bank stabilization
2	Remove invasive trees from the river's riparian zone	Invasive species competition with native plants	**M**	**$$**	Terrestrial vegetation and animals	None	Less invasive species along banks of the river	These two actions items need to be done together
2	Reintroduce native riparian vegetation	Invasive species competition with native plants	**MH**	**$$**	Terrestrial vegetation and animals	None	Less invasive species along banks of the river	

2	Prune riparian vegetation	Watercraft movement being pushed over Texas wild-rice stands	**L**	**$**	Texas wild-rice	None	Less damage to Texas wild-rice stands from watercraft and more robust stands (higher percent cover) under pruned areas	This needs to be approved by authorized state and/or federal agencies per pruning event
2	Relocate coarse woody debris (CWD) from areas immediately upstream of Texas wild-rice	CWD scours Texas wild-rice plants out of the river during flooding events	**M**	**$**	Texas wild-rice	Loss of fish and invertebrate habitat	No scouring of Texas wild-rice stands during flooding events	Only **DIRECT** threats to Texas wild-rice
2	Create a buffer zone along the river's edge and tributaries where possible	Runoff, pollution and sedimentation	**H**	**$$**	All	None	Less pollution and sedimentation in the river.	
3	Create Fish Passage Structures in Spring lake Dam and Rio Vista Dam	Natural migration patterns of fish in the river are currently obstructed	**M**	**$$$$**	Fountain darters and potentially all spp. due to return of natural conditions	None	Higher genetic flow between sections of the river for fountain darters and return of American Eel and Macrobrachium	
3	Create an emergency plan for the possible case of dam failure	Sudden loss of habitat for Texas wild-rice and other native aquatic vegetation	**H**	**$**	Texas wild-rice	None	The saving of Texas wild-rice stands in times of sudden dam failure	
3	Cummings Dam and Capes Dam alteration	Texas wild-rice and fountain darter limited habitat availability	**M**	**$$$$**	Potentially Texas wild-rice and fountain darters	Research needed (see below)	Dam alteration allowing for an increase in potential Texas wild-rice and fountain darter habitat	Research needed prior
3	Create/Fulfill a landscaping plan if dam alteration will be put forward	Bank stabilization and fulfilling landowners needs for access for cattle and recreation.	**M**	**$$**	Potentially Texas wild-rice and fountain darters	None	Dam alteration allowing for an increase in potential Texas wild-rice and fountain darter habitat	Research needed prior

4	Annual monitoring of in-stream biota	Not knowing when and where species are changing (in terms of presence or coverage) within the river	**H**	**$$**	All	None	Understanding of aquatic ecosystem trends	Estimated cost is per year
4	Remove invasive plant species that negatively affect native species	Non-native species out-competing native species in the river for space and resources	**H**	**$$$**	All	None	Higher population numbers for all native species including all federally-listed species	This most likely will be an on-going process- but needs a big jump start. These two actions need to be done together.
4	Reintroduce native aquatic plants	Non-native species out-competing native species in the river for space and resources	**H**	**$$**	All	None	Higher population numbers for all native species including all federally-listed species	
4	Remove invasive animal species that negatively affect native species	Non-native species out-competing native species in the river for space and resources	**H**	**$$$**	All	None	Higher population numbers for all native species including all federally-listed species	This most likely will be an on-going process- but needs a big jump start
4	Control of non-migratory waterfowl	Water chemistry and a lack of a Texas wild-rice seed bank in the wild	**H**	**$**	All	None	Cleaner parks, an increase in the Texas wild-rice seed bank in the wild, and cleaner water	
4	Dredge fine sediment from specific areas of the river	Shallowing of the river	**M**	**$$**	All	Accidental removal of organisms during dredging	Less turbidity, more available habitat for native aquatic species	Designed to replace missing natural river processes due to flood control structures
4	Remove structures that create channelization of river and affect natural flow regimes	Channelization of the river and non-natural flow regimes	**MH**	**$$$**	All	Possible negative ecological impacts during construction	Natural bank species return and natural flow regimes return	
4	Emergency planning for drought, floods and spills	Loss of habitat for native aquatic species	**MH**	**$**	All	None	The saving of native species in times of drought, floods and catastrophic spills	

5	Build wetlands and wetponds	Sedimentation and pollution in the river	**M**	**$$$**	All	Land availability	Less sedimentation and better water quality	
5	Acquire land for retrofitting developed areas to follow better watershed protection	Sedimentation and pollution in the river	**M**	**$$$$**	All	Land availability	Less sedimentation and better water quality	
5	Acquire land for conservation purposes	Sedimentation and pollution in the river	**M**	**$$$$**	All	Land availability	Less sedimentation and better water quality	
5	Create a zoning and management plan for the San Marcos River watershed	Sedimentation and pollution in the river	**MH**	**$$**	All	None	Less sedimentation and better water quality	
5	Create watershed stewardship programs	Sedimentation and pollution in the river	**M**	**$**	All	None	Less sedimentation and better water quality	
5	Create more stringent Structural and Non-structural BMPs	Sedimentation and pollution in the river	**H**	**$**	All	None	Less sedimentation and better water quality	
5	Better/More enforcement of BMPs	Sedimentation and pollution in the river	**H**	**$**	All	None	Less sedimentation and better water quality	
5	Rebuild streets near river for better water quality control	Toxic materials associated with coal tar in the river ecosystem	**M**	**$$$$**	All	None	Reduction of toxic hydrocarbon derivatives	
5	Create low-cost loan programs for rain collection	Water quantity	**L**	**$$$**	All	None	More water in the river	

1. **Develop educational publications:** A comprehensive education plan will be developed to educate river users and other stakeholders on the importance of the San Marcos River ecosystem and teach them how to protect it. Educational tools to be developed will include but not be limited to an educational website targeting teachers, publications such as brochures and factsheets, traveling exhibits, demonstration sites, media releases, and community talks. Topics addressed will include the impact of invasive species, conservation of rare and endangered species, effects of aquarium dumping, trash input into the river, and maintenance of riparian habitats.
2. **Develop an internet presence to market existing and upcoming education materials:** self-explanatory.
3. **Develop travelling exhibits and demonstration sites:** See description of Develop education publications.
4. **Increase enforcement of park/city rules re: polluting and aquarium dumping:** Self explanatory
5. **Remove floating debris from Texas wild-rice stands:** Periodically, floating mats of dead and non-rooted vegetation along with garbage get trapped on top of Texas wild-rice stands. These mats inhibit light from getting to the plants for photosynthesis. The mats need to be removed from the stands on a consistent basis. The mats need to be taken out of the river and not pushed downstream. The floating plant debris can be composted. Vegetation clippings floating downstream, originating from the maintenance of Spring Lake via Texas State University's cutter boat, needs to be eliminated.
6. **Relocate Texas State University watercraft classes to Spring Lake:** Currently, Texas State University watercraft classes are given in areas near Texas wild-rice, and new boaters tend to trample of the endangered plant when falling out of their watercraft. The classes need to be moved to an area without Texas wild-rice nearby such as Spring Lake.
7. **Create pre-determined access points into the river:** Permanent access points will be combined with bank stabilization for the locations designated which avoids Texas wild-rice areas. They will serve as entry and exit ways that could be used by canoeists, tubers, swimmers, etc., while stabilizing highly eroded banks. In these areas, the bank is eroding due to natural river dynamics in combination with intense recreational use. The City plans to stabilize banks in at least six areas (City Park, Hopkins Street Underpass, Bicentennial Park, Rio Vista Park, Ramon Lucio Park and Cheatham Street underpass). The City Park project will be 370 m^2, and the remaining projects will measure about 100 m^2. Terrestrial and aquatic vegetation in the vicinity of these sites will be monitored pre- and post-construction to determine the effects.
8. **Create non-access points in sensitive areas:** Banks will be stabilized using prohibitive (thorny, sharp, etc.) plants, so that recreationists will be deterred from entering the river in those areas. Terrestrial and aquatic vegetation in the vicinity of these sites will be monitored pre- and post-construction to determine the effects.
9. **In-stream barriers as needed to protect habitat:** During low flow periods or during occasions of high recreational traffic (e.g., Texas Water Safari), place

buoys or another form of barrier in the water, protecting sections of the river that provide habitat for federally-listed and state-listed aquatic species.

10. **Involve riverside landowners in riparian management:** Educate riverside landowners on the importance of riparian buffer zones and possibly create other incentives that will increase the implementation of better riparian management practices.
11. **Remove elephant ear from the river:** The aquatic plant known as elephant ear (*Colocasia esculenta*) is considered an invasive species that directly competes with a number of native species along the banks of the San Marcos River, including Texas wild-rice. Elephant ear will be systematically removed in order to increase available habitat for native plant and fish species. Removal of this species should occur methodically and in tandem with the planting of native species so as not to encourage destabilization of the river's bed and banks.
12. **Remove invasive trees from the river's riparian zone:** Invasive plant species have increased in number and distribution within the river's riparian zone, competing directly with beneficial native species and altering wildlife habitat. Removal of invasive species should occur methodically and in tandem with the planting of native species so as not to encourage erosion or bank destabilization. Control of invasive species will require continuous monitoring in order to prevent re-establishment.
13. **Reintroduce native riparian vegetation:** Vegetated riparian zones provide a number of critical functions within a watershed. Acting as an interface between uplands and the river, these zones stabilize river banks, prevent erosion, protect water quality by filtering runoff and pollution, provide habitat for terrestrial wildlife, and provide canopy cover critical to fish habitat. The reintroduction of native riparian vegetation should occur in tandem with the previous action item, as well as independently throughout the river corridor where the riparian zone is absent or impaired.
14. **Prune riparian vegetation:** In some areas of the river, specifically near the I-35 bridge, riparian vegetation forces watercraft users to canoe/kayak over Texas wild-rice stands due to low-hanging branches. At low flows, the movement of the paddles can do damage to the plants. During low flows, a plan needs to be in place in order to create alternate pathways for watercraft so as not to disturb the Texas wild-rice. One easy way to do this is to prune the riparian vegetation that would normally block pathways over deeper water.
15. **Relocate coarse woody debris (CWD) from areas immediately upstream of Texas wild-rice:** When CWD is located within a meter upstream of Texas wild-rice or is on top of a Texas wild-rice stand, a plan needs to be put in place to relocate the debris downstream of the stand(s).
16. **Create a riparian buffer zone along the river's edge and tributaries:** Riparian buffer zones are important natural biofilters, protecting aquatic environments from excessive sedimentation, polluted surface runoff and erosion. These zones need to be present along the entire river's edge, including tributaries.
17. **Create Fish Passage Structures in Spring Lake Dam and Rio Vista Dam:** Install structures such as a fish ladder or bridge within the dams that are already in place to allow for fish migration upstream.

18. **Create an emergency plan for the possible case of dam failure:** Put together a plan that describes what actions need to take place and in what order, in case of dam failure in order to protect aquatic vegetation from becoming dewatered.
19. **Cummings Dam and Capes Dam alteration:** Alter these two dams in such a way that will allow for more potential fountain darter and Texas wild-rice habitat, both upstream and downstream of the dams (e.g., removal or lowering of the dams).
20. **Create/Fulfill a landscaping plan if dam alteration will be put forward:** This ties together with the previous action item. If dam alteration is a viable option to increase potential Texas wild-rice and fountain darter habitat, in order to stabilize banks as well as make the alteration a smooth process for the landowners that would be affected by the alteration, a landscaping plan must be put into place. The landowners will require access to the river for both their livestock as well as their own recreation.
21. **Annual monitoring of in-stream biota:** Surveys of all native and invasive plants and animals need to performed on an annual basis in order to learn how the ecosystem is changing and what species are being introduced into the river.
22. **Remove invasive plant species that negatively affect native species:** Invasive plants, particularly hydrilla and hygrophila, will be removed in phases beginning in Spring Lake and working downstream to the Blanco confluence. The removal method has not yet been determined. The area of removal will be replanted with native aquatic plants and weeded until the reintroduced plants can outcompete the invasives. Removed plants will be composted in an area outside of the floodplain.
23. **Reintroduce native aquatic plants:** Native plants, such as *Zizania texana*, *Sagittaria* sp., *Ludwigia repens*, *Potamogeton illinoisensis*, *Heteranthera dubia*, and *Cabomba caroliniana*, will be planted in the main corridor. Edges will be planted with *Zizaniopsis* sp. as well as other edge species. Exotics will be continually removed from the sites until the native plantings are established. The replacement plants will come from the Aquatic Nursery at Aquarena Center in San Marcos, TX and the San Marcos National Fish Hatchery and Technology Center to ensure no introductions of associated biota. These greenhouses propagate aquatic plants taken only from the San Marcos River.
24. **Remove invasive animal species that negatively affect native species:** Invasive animals will be removed (either on a continuous basis or as opportunities arise) by physical or other means as necessary to control the species.
25. **Control non-migratory waterfowl:** self-explanatory
26. **Dredge fine sediment from specific areas of the river:** Fine sediment will be removed from the river bottom at various locations within the San Marcos River. Sediment has accumulated due to the urbanization of the watershed and the installation of five flood control dams. As a result, the river is losing depth and width. Hydrosuction is a possible method to remove accumulations of sediment, but care would need to be taken to not remove biota. Although landscape controls need to be established on the various sources of sediment in the watershed, this project would remain long-term. Modeling could be done to decide how often the dredging should occur in order to make up for the loss of natural processes due to flood control structures.

27. **Remove structures that create channelization of river and affect natural flow regimes:** Natural banks and shorelines are significant features of a stable functioning riverine ecosystem, providing access and habitat for fish, wildlife, and plant species. Additionally, natural banks are more adept in absorbing hydraulic energy during flood events and allow the channel to adjust itself appropriately to changes in flow regime. Structures creating channelization and/or affecting the natural flow regime will be removed in order to enhance stream stability and increase available habitat.
28. **Emergency planning for drought, floods and spills:** Put together a plan that describes what actions need to take place and in what order, if the San Marcos River experiences drought, floods and catastrophic spills in order to protect the river ecosystem and its federally-listed and state-listed species, including limiting recreational access.
29. **Build wetlands and wetponds:** Wetlands and wetponds will be created within the San Marcos River watershed in order to decrease the amount of pollutants and sediment entering the river.
30. **Acquire land for retrofitting developed areas to follow better watershed protection:** The San Marcos area has undergone rapid development for over two decades without consideration for preserving the water quality of the San Marcos River. The areas that have already been developed can be retrofitted with various BMPs that work to reduce the pollutant concentration in stormwater runoff. A master plan would be developed to meet this goal with the pollutant loading standards based (at a minimum) on TCEQs water quality standards.
31. **Acquire land for conservation purposes:** For areas not yet developed or sparsely developed, land needs to be acquired through fee simple acquisition, conservation easement, purchase of development rights, or other means. A master plan needs to be developed (as part of the urban area masterplan above) to designate areas that have the highest potential for water quality improvement. Some of these properties need to be considered for regional wetland development.
32. **Create a zoning and management plan for the San Marcos River watershed:** Zoning determines land use and is therefore a critical tool in watershed management. An overall watershed management plan needs to be developed that will incorporate zoning and all other actions taken to improve water quality for the San Marcos River, including those previously mentioned in this matrix. A watershed plan addresses the entire area that affects a water body and thus is the beginning point for planning for water quality enhancement. A small group of stakeholders in San Marcos has begun working toward this goal, beginning with the Sessom Creek watershed. Grants are being researched to help fund the development of an overall plan.
33. **Create watershed stewardship programs:** Interested citizens from throughout the watershed will learn how to protect the San Marcos River. A Watershed Stewardship Manual would be developed to accompany these classes and would include materials on each of the class topics. Classes would consist of presentations, activities, and hands-on training led by experts in each field. Topics could include:

- Introduction to Watershed Hydrology
- Wetland Plant Identification (FIELD)
- Water Quality Monitoring
- Water Quality Monitoring (FIELD)
- Drinking Water (with tour of water supply facility)
- Waste Water (with tour of wastewater facility)
- Conservation Development
- Policy & Community Involvement

Several types of volunteer programs could be developed, such as watershed monitoring, school outreach programs, community ecology programs, community partners for a healthy stream; associated activities would be storm drain marking, waterway cleanups, creation of neighborhood rain gardens, pet waste education, etc.

Stewardship groups could advance into taking the lead in developing restoration strategies and implementing solutions. It would be important to involve a variety of stakeholders including developers and conservationists; as well as state and federal agencies for technical assistance with projects. Additionally, financial resources from state and federal agencies with private funds, foundations, local businesses and corporations could be leveraged more easily with such a group.

34. **Create more stringent Structural and Non-structural BMPs:** Best Management Practices are required by the City for developments, but are primarily limited to silt fences and detention ponds. There is a diversity of practices in the market of BMPs that are more effective than silt fences or in combination with silt fences. Additionally, detention ponds do not address water quality, only quantity. The Center for Watershed Protection has a plethora of detailed guidance for municipalities addressing this issue. The City has begun looking at these ideas and should adopt more stringent practices. Also, in the near future, TCEQ will require the City to comply with its water quality practices requirements for cities with a population of 50,000 or greater.
35. **Better/More enforcement of BMPs:** A regulation is only as good as its enforcement.
36. **Rebuild streets near river for better water quality control:** No coal tar derivatives in street materials within the San Marcos River watershed.
37. **Create low-cost loan programs for rain collection:** Offering low-cost loans to homeowners to install rainwater collection systems (potable and/or non-potable) would allow for the installation of rainwater collection systems on all new construction, retrofitting existing structures to capture rainwater where possible, the development of stormwater capture reservoirs (a form of rainwater collection), and would in turn reduce demand on the Edwards Aquifer, and reduce stormwater runoff.

Appendix I

Goal #	**Research Needs** *** = currently being conducted**	**Priority Ranking**	**Estimated Cost**
2	Where are people entering the river and what size area is affected per access point?	**H**	**$**
2	What is the best width and slope of proposed access areas?	**M**	**$**
2	What is the projected growth for the region?	**M**	**$**
2	Where do river-users park and what route do they take into the river?	**L**	**$**
2	What size buffer is needed around Texas wild-rice stands?	**H**	**$$**
2	What is the minimum riparian buffer zone needed for benefit to the river?	**H**	**$$$**
2	What is the current riparian vegetation? *	**M**	**$$**
3	What would altering Capes and Cummings Dam do to Texas wild-rice and fountain darter potential habitat? *	**H**	**$$**
4	What are *Protoptila arca* (San Marcos Saddle-case Caddisfly) habitat requirements and population estimates?	**M**	**$$**
4	How has the San Marcos River changed in bathymetry over a 10 year period? *	**H**	**$$$**
4	How has the macrophyte community of the San Marcos River changed in over a 10 year period? *	**M**	**$$**
4	How do CO2 levels and temperature change with changing spring flows? *	**M**	**$$**
4	What are the affects of CWD on the river bottom during flood events?	**M**	**$$**
4	Is water clarity or CO2 the reason behind low numbers of Texas wild-rice in the lower part of the upper San Marcos River?	**H**	**$$**
4	What are San Marcos River native mussel habitat requirements and population estimates?	**MH**	**$$**
5	How would the river and its banks change if large sediment islands that have formed due to poor stormwater management were removed? (Just upstream and just down stream of the University Dr. Bridge)	**H**	**$$**
5	What is the percent impervious cover in the San Marcos River watershed?	**M**	**$**
5	What are the maintenance requirements for detention/retention ponds? How long before they no longer function?	**M**	**$**
5	What areas do not have but need detention ponds?	**M**	**$**

APPENDIX H:

DR. THOMAS B. HARDY, "TECHNICAL ASSESSMENTS IN SUPPORT OF THE EDWARDS AQUIFER SCIENCE COMMITTEE "J CHARGE" FLOW REGIME EVALUATION FOR COMAL AND SAN MARCOS RIVER SYSTEMS," DECEMBER 29, 2009

Technical Assessments in Support of the Edwards Aquifer Science Committee "J Charge" Flow Regime Evaluation for the Comal and San Marcos River Systems

Prepared for:

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Executive Summary

This report summarizes the technical analysis of the flow dependent characteristics of physical habitat for target aquatic species within the Comal and San Marcos Rivers to support the Science Committee of the Edwards Aquifer Recovery Implementation Program in development of their recommendations for flow regimes under Senate Bill 2 'J Charges'. Target species were fountain darter (*Etheostoma fonticola*), Texas wild rice (*Zizania texana*), and the Comal Springs riffle beetle (*Heterelmis comalensis*). In addition, qualitative assessments of other native and non-native species as well as recreation were considered.

A team of private, state, federal, and university researchers knowledgeable with the target species and in particular, the Comal and San Marcos River systems were used to develop influence diagrams for the three target species to aid the evaluation of both intrinsic and extrinsic factors that affect the persistence of these target species. The team also used these diagrams to evaluate existing data and specific modeling approaches to aid in their evaluations of flow regimes for each river system. As part of this process, the team considered other factors such as non-native species of plants and animals, parasites, recreation, and anthropogenic impacts due to watershed development.

Historical research and existing physical, chemical, and biological monitoring data collected through 2009 from both the Comal and San Marcos Rivers were integrated to develop biological response functions for factors such as depth, velocity, substrate/vegetation use, water temperatures, etc. Habitat suitability curves were reviewed for fountain darters, Texas wild rice, and Comal Springs riffle beetles based on new data collected over the past eight years. Existing monitoring data were used to update the fountain darter habitat suitability curves for depth and velocity. No modifications were made to the Texas wild rice habitat suitability curves and as noted below, simulations of available habitat for the Comal Springs riffle beetle relied on a simplified surface area analysis as well as an alternative analysis based on data collected during the original Comal River studies. Vegetation maps relied upon those derived from the original studies conducted in the Comal and San Marcos due to lack of system-wide revised vegetation mapping data being available. These existing or revised habitat suitability curves for the target species, in conjunction with the two-dimensional hydrodynamic models for each river and associated one-dimensional water quality/temperature models for the Comal and San Marcos Rivers were used to predict the location and quality of wild rice, fountain darter, and riffle beetle habitat as a function of different flow ranges in each river system. No new water quality modeling was undertaken and the report relied upon the previous modeling results for both river systems. Model sensitivity to changes in channel topographies and habitat suitability curves for depth and velocity for fountain darters were also explored.

Updated modeling results show that the largest difference in the habitat versus flow relationships for fountain darters were attributed to differences in habitat suitability curves. Modeling of fountain darter habitat for pre versus post 1998 flood induced channel changes in the San Marcos River primarily resulted in a scaling of the magnitude of predicted available habitat rather than a substantive change in the functional relationship. In both the San Marcos and Comal River systems, potentially adverse thermal conditions may begin to limit darter larval survival under very low flow conditions.

Modeling results for Texas wild rice in the San Marcos River suggest that habitat availability begins to

decline below about 65 cfs with increasing risk to physical disturbance and drying, especially at and below 30 cfs. The modeling results also suggest that protection of Texas wild rice would likely ensure protection for the other target species such as fountain darters.

Modeling results for the Comal Springs riffle beetle based on total surface area in the main spring runs (i.e, 1,2, and3) were somewhat insensitive to modeled total Comal flow rates as low as 30 cfs. However, maintaining spring run flows provides the most conservative strategy as it provides the best overall protection for the other flow dependent aquatic resources such as fountain darters and other native species.

Based on modeling results and analysis, recommendations are made for future work in light of the on-going data collection and modeling in support of the Edward Aquifer Habitat Conservation Plan.

Although this report provides the technical documentation on modeling approaches and summary results, no specific flow recommendations are made. The Science Committee of the Edwards Aquifer Recovery Implementation Program will recommend target flow regimes for each river system.

Introduction

The primary modeling approaches adapted for this report were originally reported in Hardy et al (1998) for the Comal River, and from Bartsch et al. (2000), INSE (2004), and Saunders et al. (2001) for the San Marcos River. Additional data, analysis, and published research were also relied upon as noted throughout the report. The work reported here includes both quantitative and qualitative assessments of flow regimes on the target aquatic species; fountain darters, Texas wild rice, Comal Springs riffle beetle as well as other flow dependent aquatic resources.
The focus of this report is to provide technical analysis in support to the Expert Science Subcommittee of the Edwards Aquifer Recovery Implementation Program to evaluate flow regimes for each river system required under Senate Bill 3 "J" charges. To that end, the original technical work cited above was reanalyzed using updated biological information to examine the quantity and quality of available habitat for Texas wild rice, Comal Springs riffle beetle, and fountain darters. These assessments include a quantitative evaluation of water quality and temperature as well as the qualitative evaluation of other factors such as recreation, parasites, and non-native species.

To accomplish this effort, a team of knowledgeable scientists with specific experience in the Comal and San Marcos rivers as well as research on the primary target species were brought together to review the existing biological data and updated modeling results based on refined habitat suitability information for the three target species (i.e., Texas wild rice, Comal Riffle beetle, and fountain darter).

Study Areas

Physical, chemical, and biological data were available for each river system from a variety of research efforts. Collection of physical, chemical, and biological data was undertaken from their respective spring sources downstream to their confluence with the next river junction as part of the original work by Hardy et al. (1998) for the Comal River, and by Bartsch et al. (2000), INSE (2004), and Saunders et al. (2001) for the San Marcos River. Additional biological monitoring data has also been collected as noted below.

Comal

The Comal River is a 3.2 mile long system located in New Braunfels, Texas (Figure 1). Flow enters Landa Lake from fissures in the Edwards Aquifer. A prominent feature of the park is the three main spring runs which contribute between 22.9 to 30 percent of the total spring flow with a median value of 23.8 percent (McKinney et al. 1995; USU measurements, 1998; BioWest 2003 – 2008). The rest of the water enters the lake via various seeps and spring runs. A fairly constant flow of 30 cfs exits the lake by the old channel outlets at the golf course tee box and at the spring fed pool while the rest of the flow exits the bottom of Landa Lake down the new channel. Historically, the old channel bypass was constrained to approximately 40 cfs before small, low lying areas of the golf course adjacent to the old channel become inundated. Upgrades to the culvert system can now accommodate up to approximately 100 cfs. The old channel and new channel join just above Clemmen's Dam and flow another 1.2 miles downstream to the confluence with the Guadalupe River. An analysis was undertaken to examine the relationship between flow and the quantity and quality of available habitat for several flow split scenarios between the old and new channels as noted below.

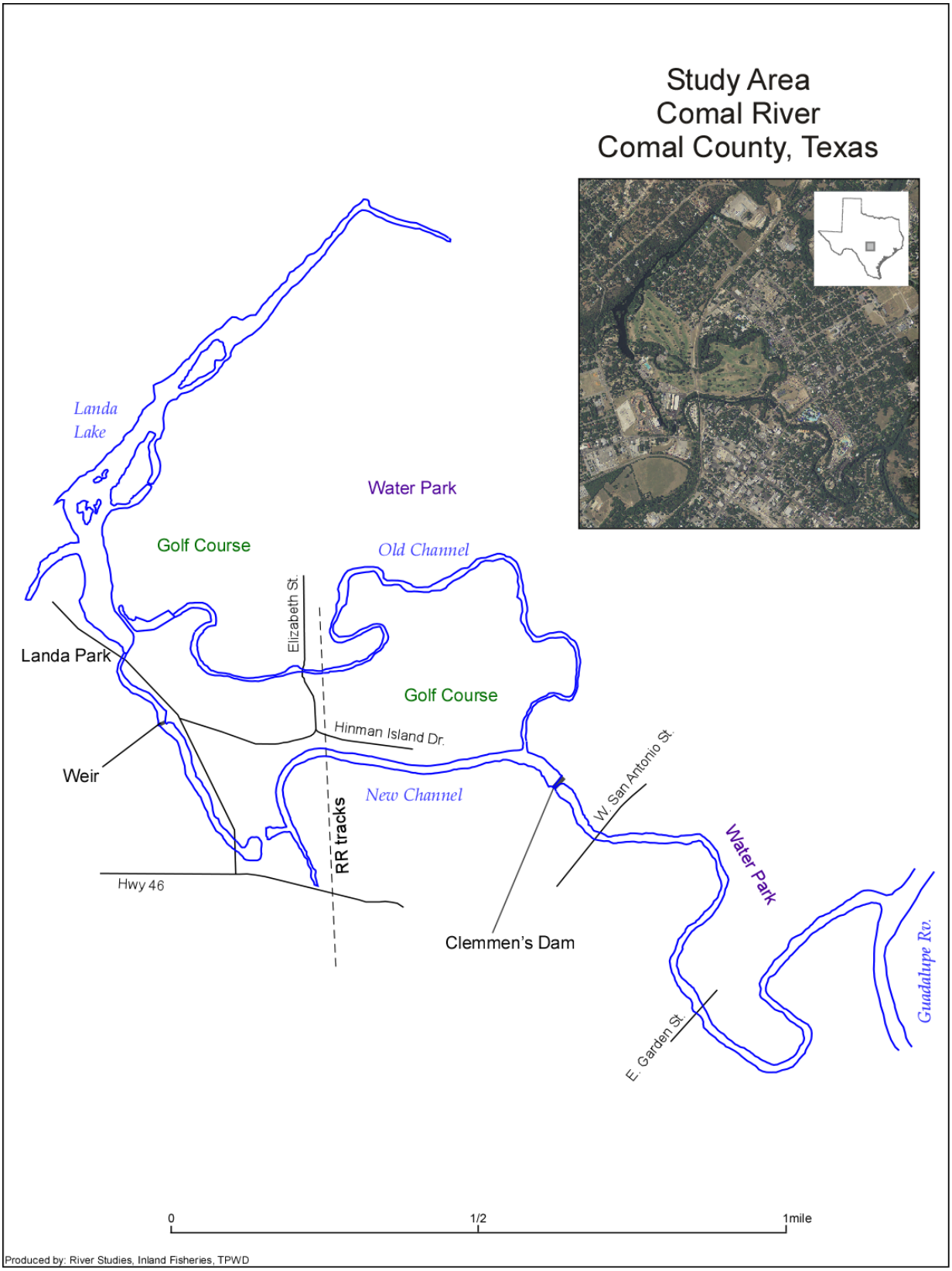


Figure 1. Comal River study area.

San Marcos

The San Marcos River originates from San Marcos Springs in Spring Lake, San Marcos, Hays County, Texas. The river flows 4.6 miles downstream to a confluence with the Blanco River (Figure 2) and continues for another 71.5 miles where it joins the Guadalupe River. This report focuses on the first 4.6 miles of river starting at Spring Lake and continuing downstream just past its confluence with the Blanco River to Cumming's Dam as shown in Figure 2. However, as noted later, analysis included an evaluation of the Cape's Dam area where river flow was split in two, partitioning flow down the mill race and the main San Marcos river channels.

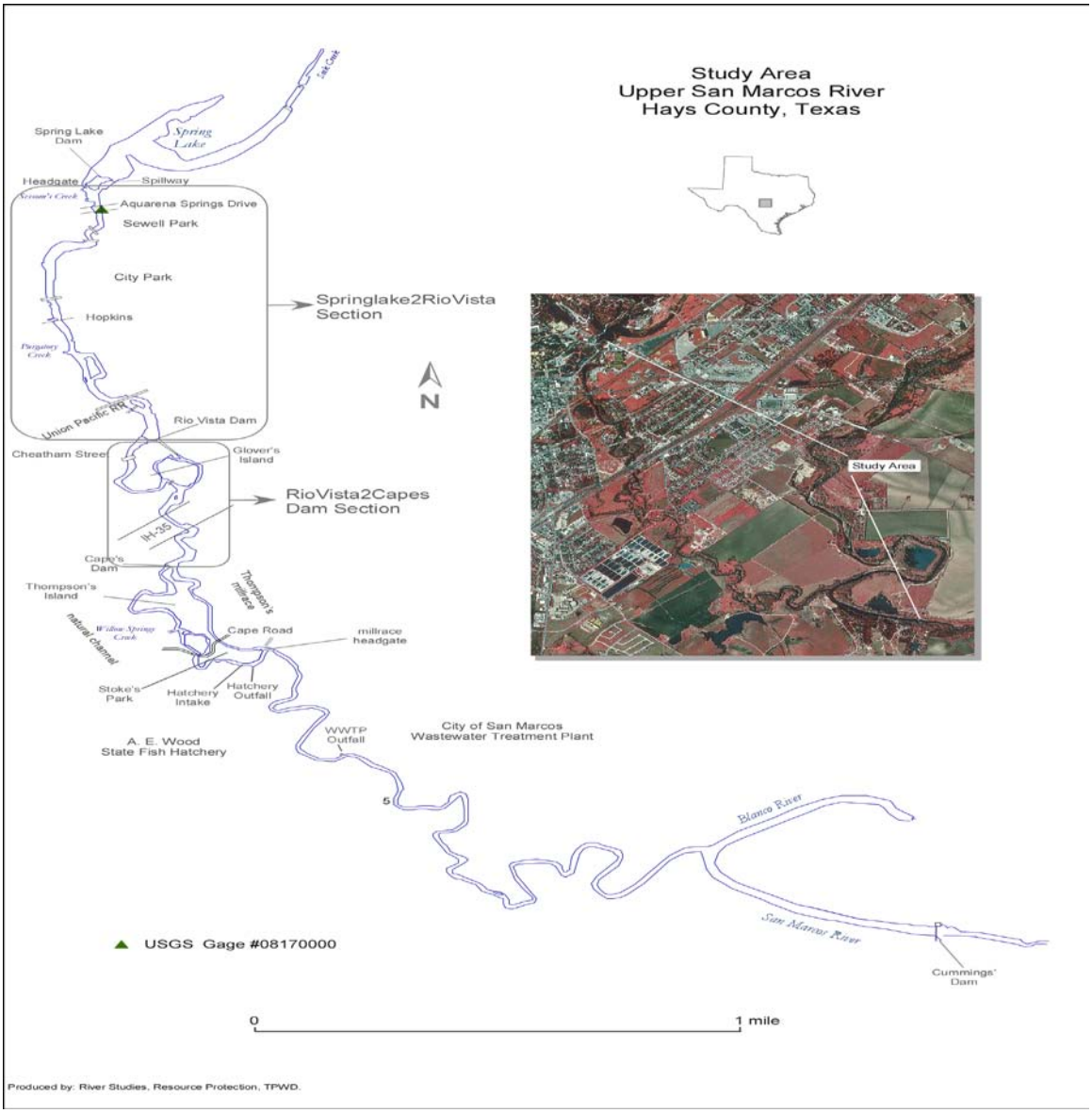


Figure 2. San Marcos study area.

Influence Diagrams for Target Species

As an initial step in support of the anticipated U.S. Fish and Wildlife analysis of the Habitat Conservation Plan (HCP) for the Edwards Aquifer Recovery and Implementation Plan, Ms. Jean Cochrane (USGS) facilitated a series of workshops involving a multidisciplinary team of biologists familiar with the primary target species, namely Texas wild rice, Comal Springs riffle beetle, and the fountain darter. These workshops were held to develop influence diagrams which relate cause and effect pathways between physical, chemical, and biological characteristics of these systems and their potential affects on various target species life stages. They specifically were utilized for the following purposes:

- Help identify where existing modeling efforts could inform key influence diagram linkages
- Direct modifications and/or analysis of the existing modeling work on behalf of Science Subcommittee
- Help identify the potential needs of existing and future biological modeling efforts to best support future Habitat Conservation Plan (HCP) analysis (to extent feasible)
- To help conceptualize and illustrate how spatial, flow-dependent biological modeling inter-relates with other factors
- Provide a framework for use by other EARIP teams in HCP development, and the U.S. Fish and Wildlife Service (FWS) in Endangered Species Act (ESA) analysis
    - e.g., linking potential management actions to biological outcomes to be evaluated under the HCP process

Influence diagrams were developed by consideration of both intrinsic and extrinsic factors affecting the three target species and providing definitions of specific intrinsic and extrinsic factors. The influence diagrams helped identify where existing biological or modeling results used in this study support the knowledge base for each species. Given this linkage between the existing modeling efforts and the influence diagrams, it is intended to inform the Science Committee (and others) where strategic research will be needed during implementation of the HCP. In addition, the influence diagrams show where the existing modeling can be used to inform potential benefits of planned restoration actions that may directly or indirectly affect either physical habitat or water quality parameters. These could include such factors such as changes in channel topography or changes in vegetation due to non-native plant removal. In the later case for example, vegetation polygons could be updated to reflect the changes in the spatial distribution or composition due to vegetation management and the changes in fountain darter habitat areas could be simulated under these revised conditions. It is however, beyond the scope of this report to examine these alternatives, which will be undertaken in support of the HCP development.

The draft influence diagrams and associated definitions were provided to the EARIP for review and comment. The comments were passed onto the UWFWS/USGS for their review and consideration. If and when, the decision is made to utilize these tools within the HCP analysis framework, it will be undertaken via the HCP stakeholder process. Appendix A provides a listing of all comments and submitted influence diagram revisions. It is however, beyond the scope of this report to respond to the provided comments or make any of the suggested revisions. Appendix A also provides definitions supporting the following influence diagrams for the three target species. Figure 3 provides a key the overall format or design of the influence diagrams reported below for the three target species.

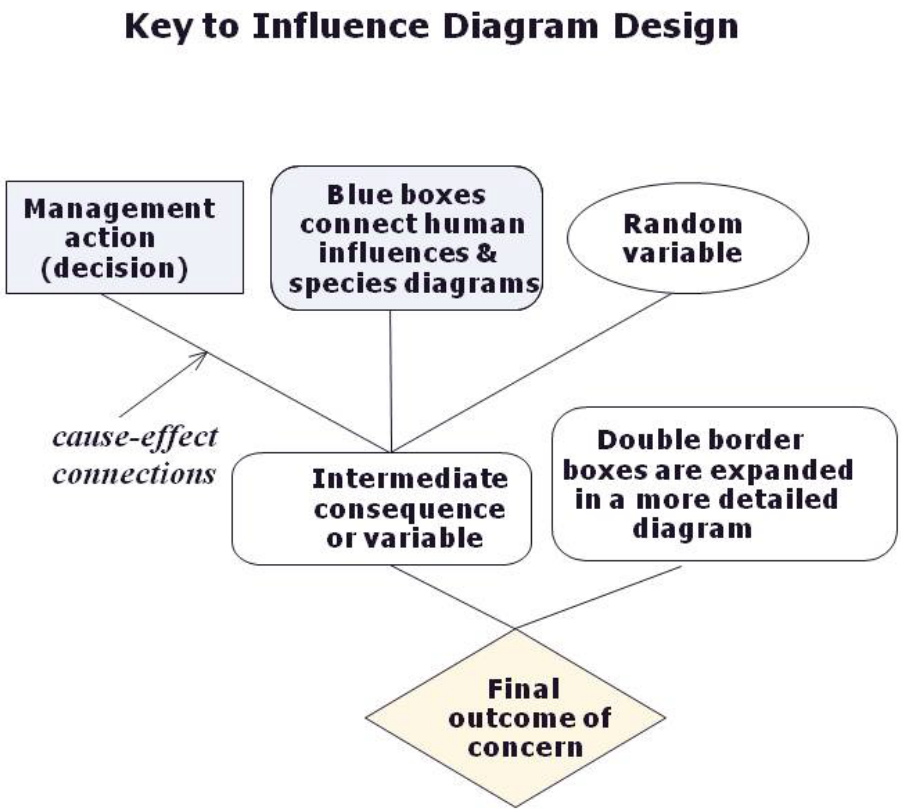


Figure 3. Key to influence diagram designs.

Comal Springs Riffle Beetle

Figure 4 provides the 'Big Picture' influence diagram for the Comal Springs riffle beetle. This figure illustrates the larger scale factors that were identified by the species experts as potentially affecting persistence of this species. It also illustrates the primary portion of the influence diagram that can be addressed with the existing models. Figure 5 shows the expanded influence diagram for Water Quantity, which includes contributing elements of overall habitat suitability and where the existing modeling will inform the scientific evaluation process. It should be noted that additional components of the influence diagram will be needed to show the cause-effect relationships between potential management actions of the HCP and the factors that are influencing the Comal Springs riffle beetle (e.g., water quantity and quality, recreation, disturbance, fine sediment, etc.). The team did not develop specific influence diagrams for management actions. Figures 6 and 7, however, illustrate examples of potential human influences on water quantity and quality and fine sediment inputs.

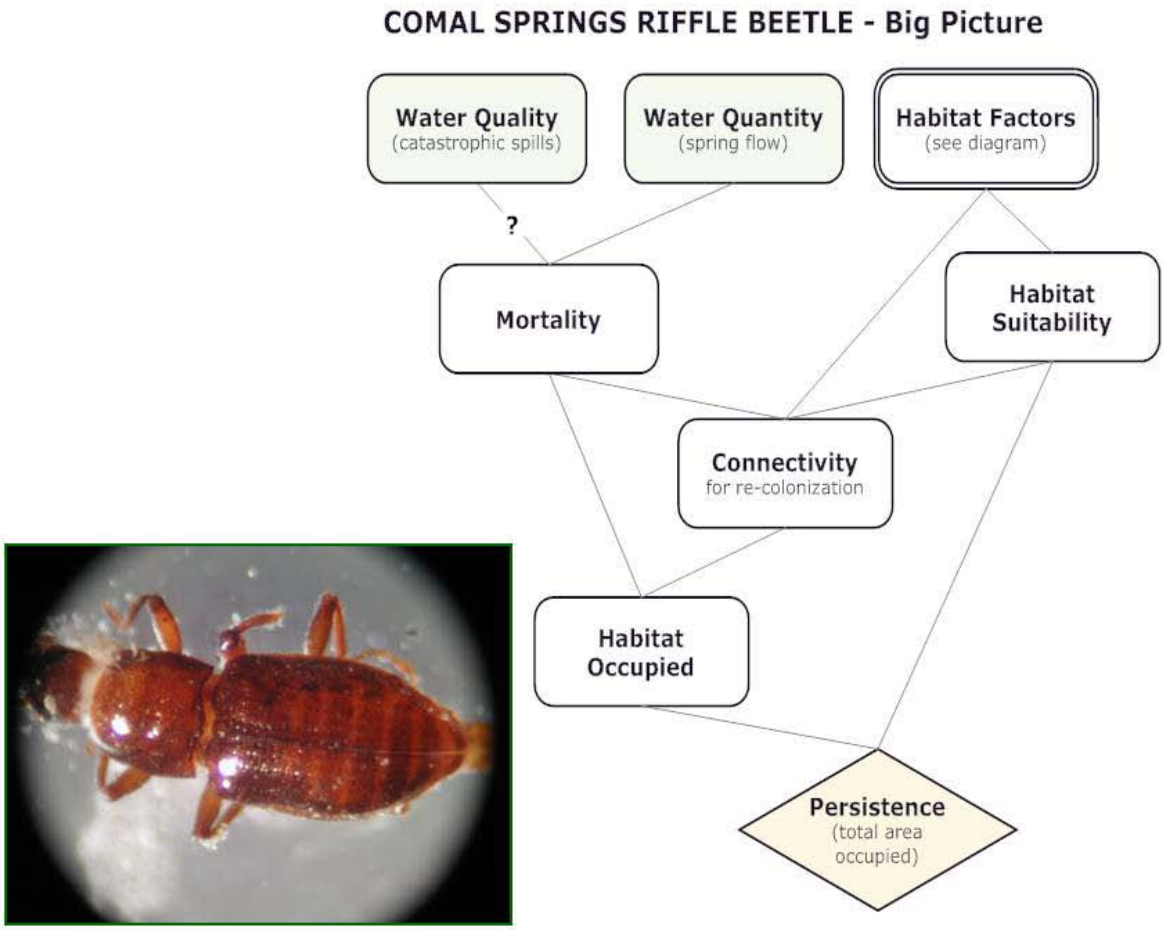


Figure 4. Comal Springs riffle beetle overall influence diagram.

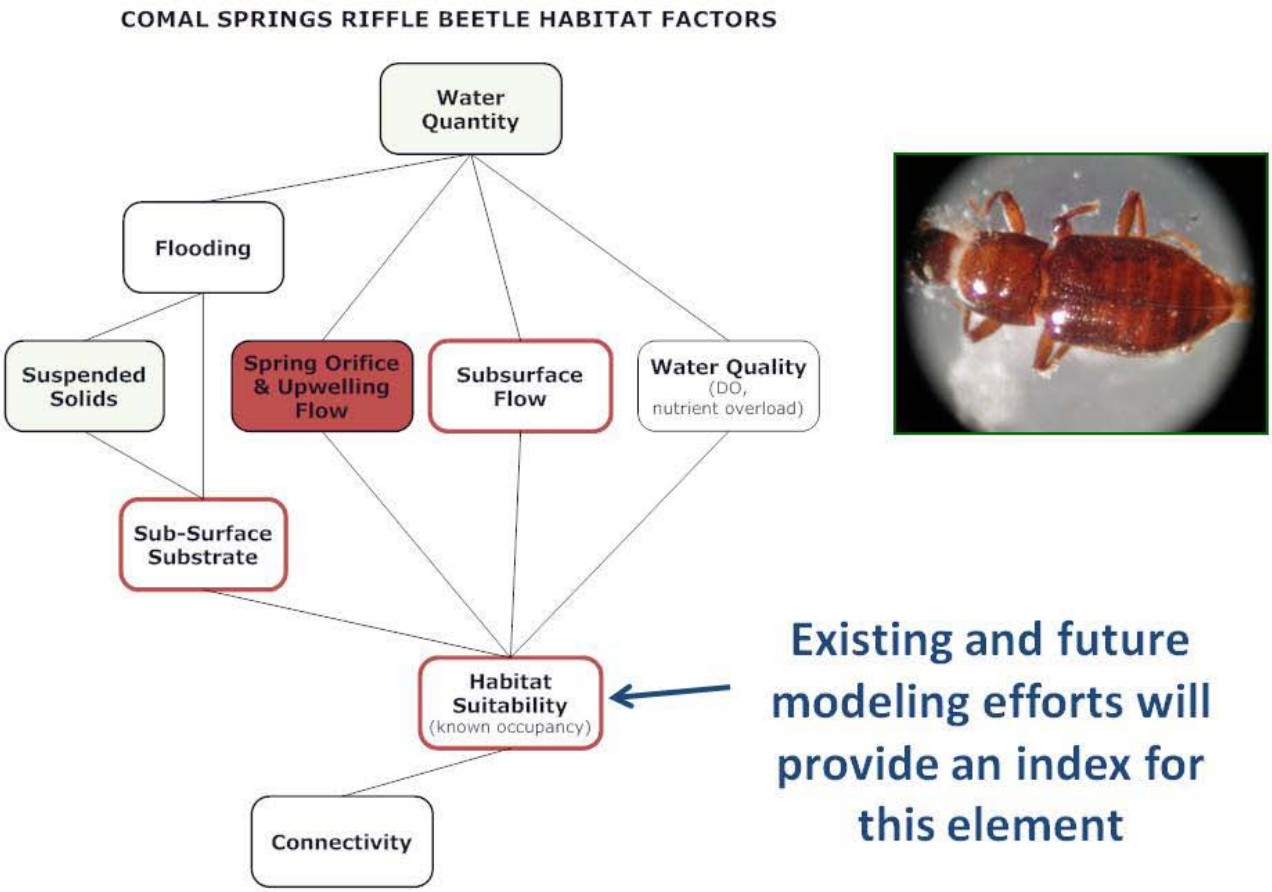


Figure 5. Habitat factors specific to water quantity for the Comal Springs riffle beetle.

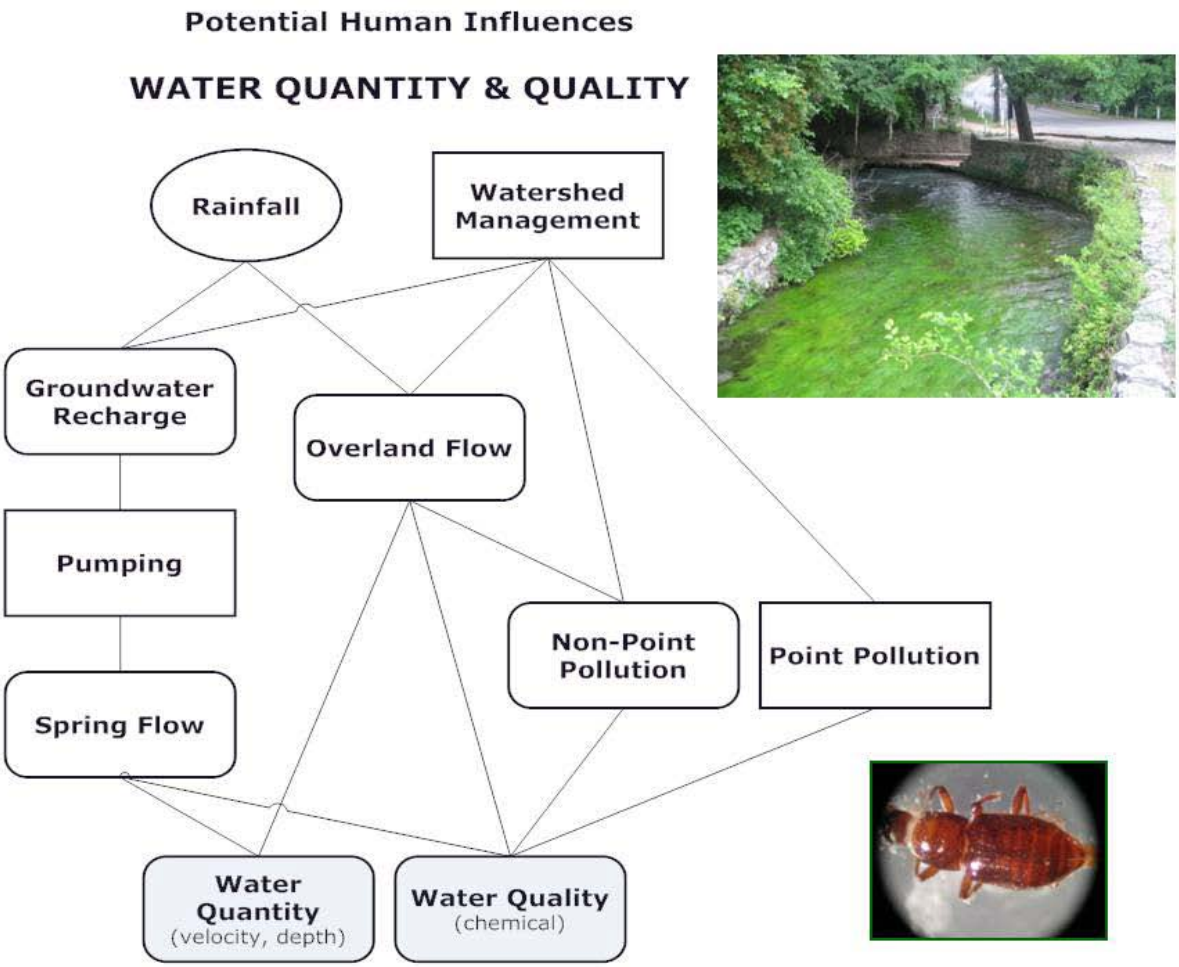


Figure 6. Example of potential human influences on water quantity and quality for the Comal Springs riffle beetle.

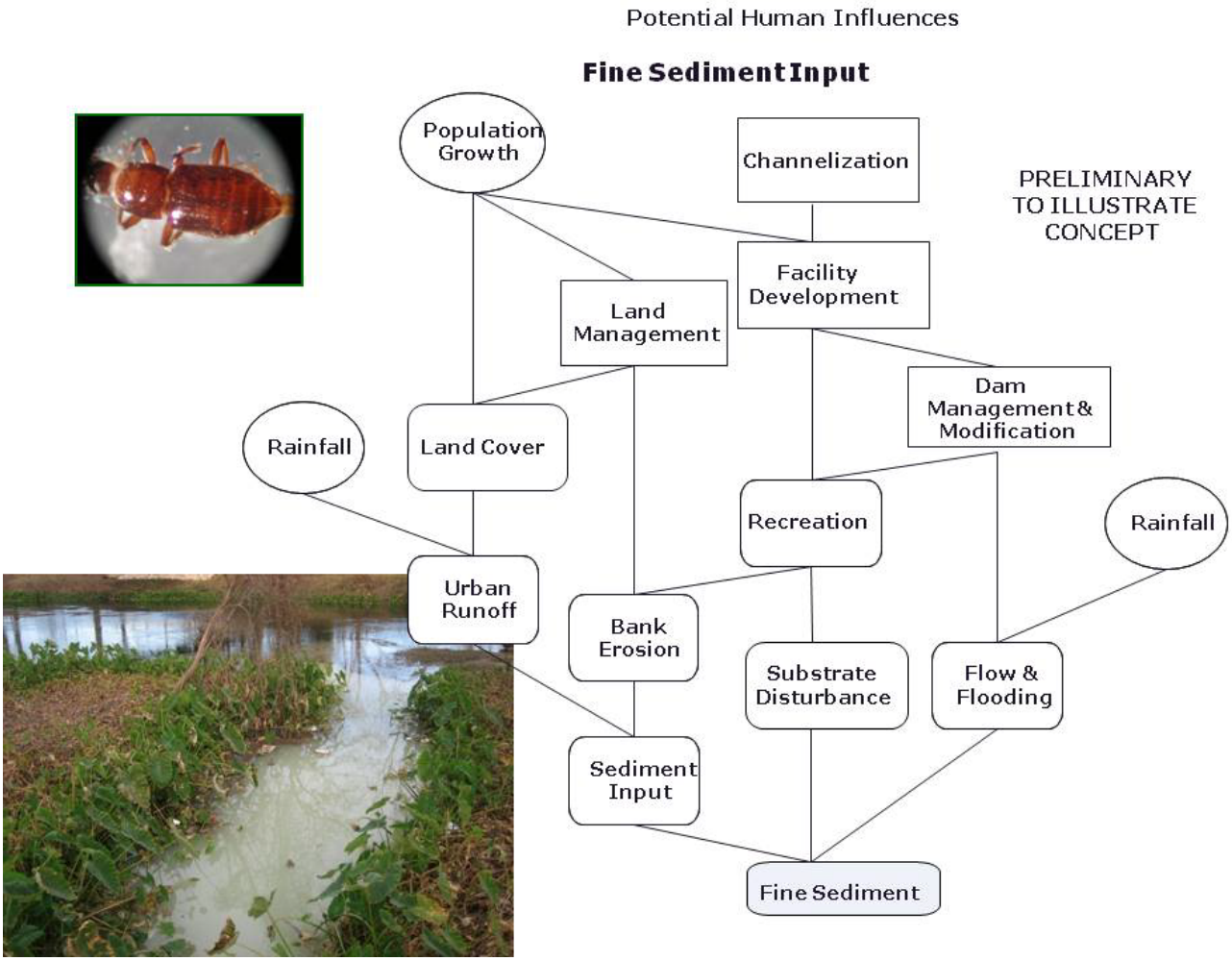


Figure 7. Example of potential human influences on fine sediment input for the Comal Springs riffle beetle.

Texas Wild Rice

Figure 8 provides the 'Big Picture' influence diagram for Texas wild rice. This figure illustrates the larger scale factors that were identified by the species experts as potentially affecting persistence of this species. It also illustrates the primary portion of the influence diagram that can be addressed with the existing models. Figure 9 shows the expanded influence diagram for Water Quantity, which includes contributing elements of overall habitat suitability for water quantity and quality and where the existing modeling will inform the scientific evaluation process. As noted for the Comal Springs riffle beetle, Texas wild rice will also need to have additional components of the influence diagram developed to show the cause-effect relationships between potential management actions of the HCP and the factors. Figure 10 is provided to show an example of an expanded influence diagram component related to direct mortality factors on Texas wild rice.

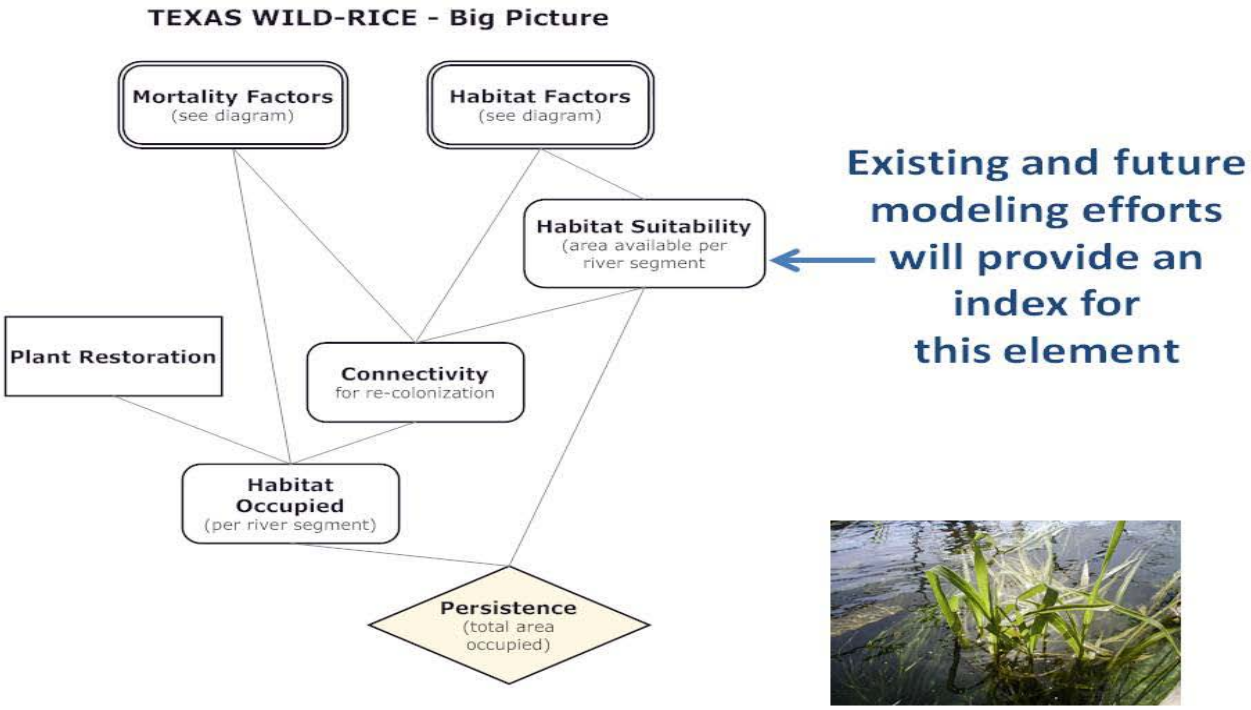


Figure 8. Texas wild rice overall influence diagram.

Fountain Darters

Figure 11 provides the 'Big Picture' influence diagram for fountain darters. This figure illustrates the larger scale factors that were identified by the species experts as potentially affecting persistence of this species. Figure 12 shows the expanded influence diagram for Habitat Factors that include both water quantity and quality and where the existing modeling will inform the scientific evaluation process. As noted previously, additional components of the influence diagram will need to be developed to show the cause-effect relationships between potential management actions of the HCP and their factors. Figure 13 is provided to show an example of an expanded influence diagram component related to direct mortality factors on fountain darters.

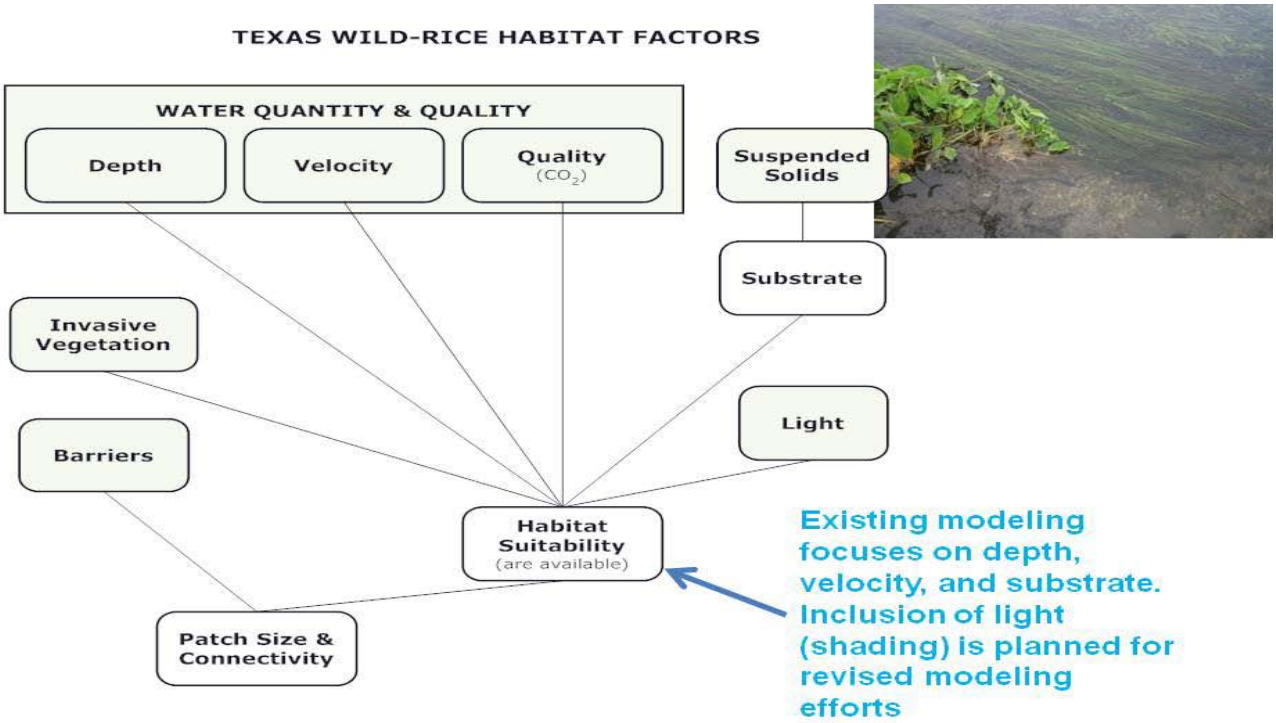


Figure 9. Habitat factors potentially affecting Texas wild rice.

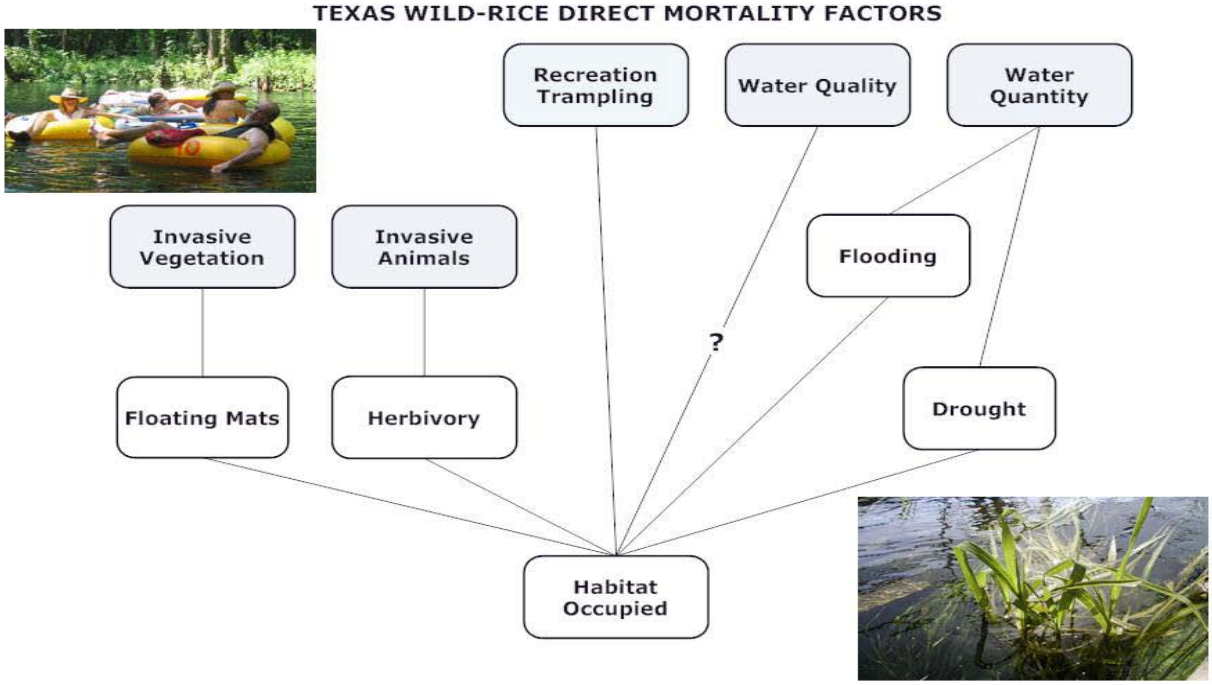


Figure 10. Example of direct mortality factors influence diagram for Texas wild rice.

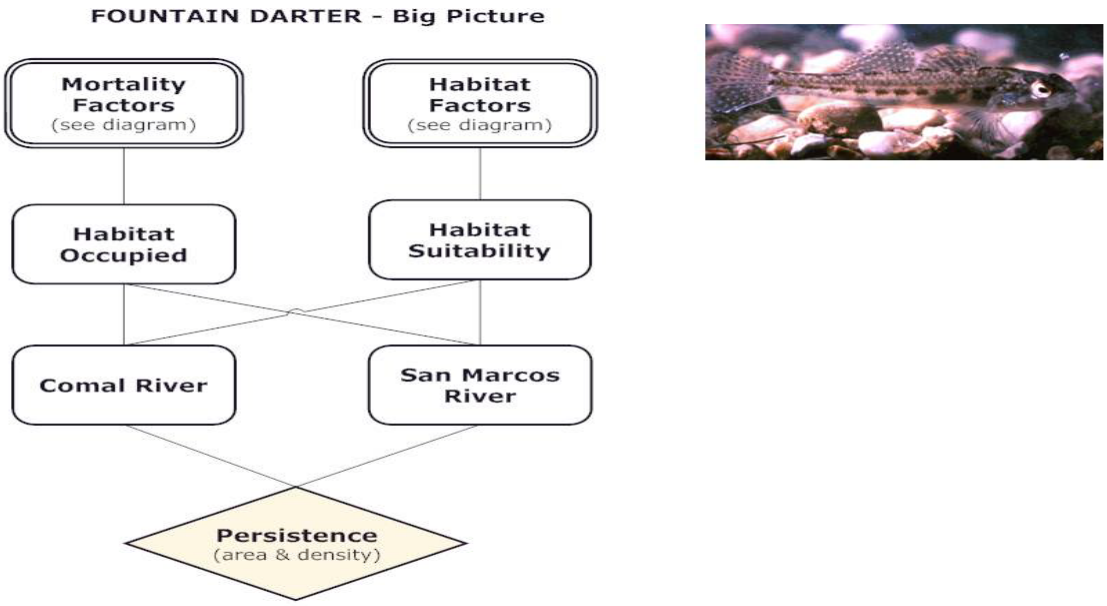


Figure 11. Fountain darter overall influence diagram.

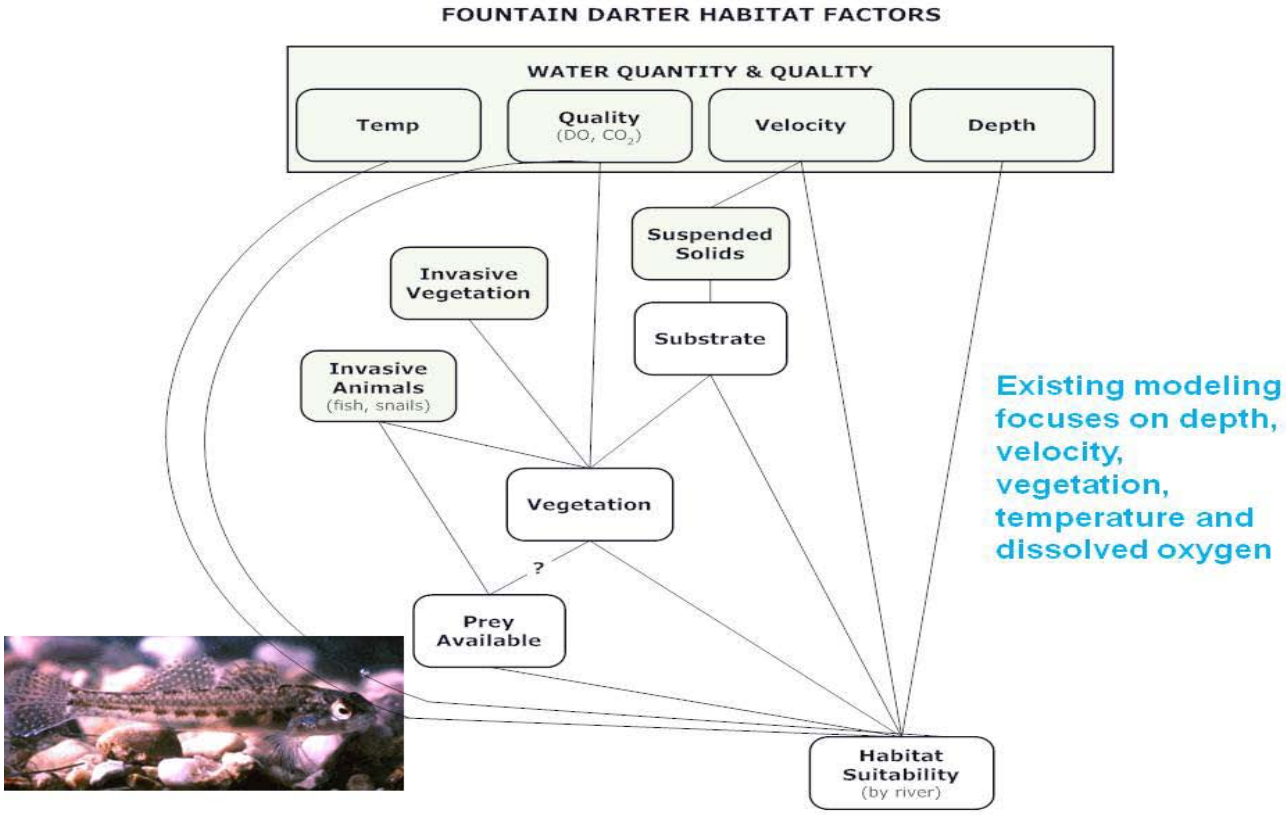


Figure 12. Habitat factors potentially affecting fountain darters.

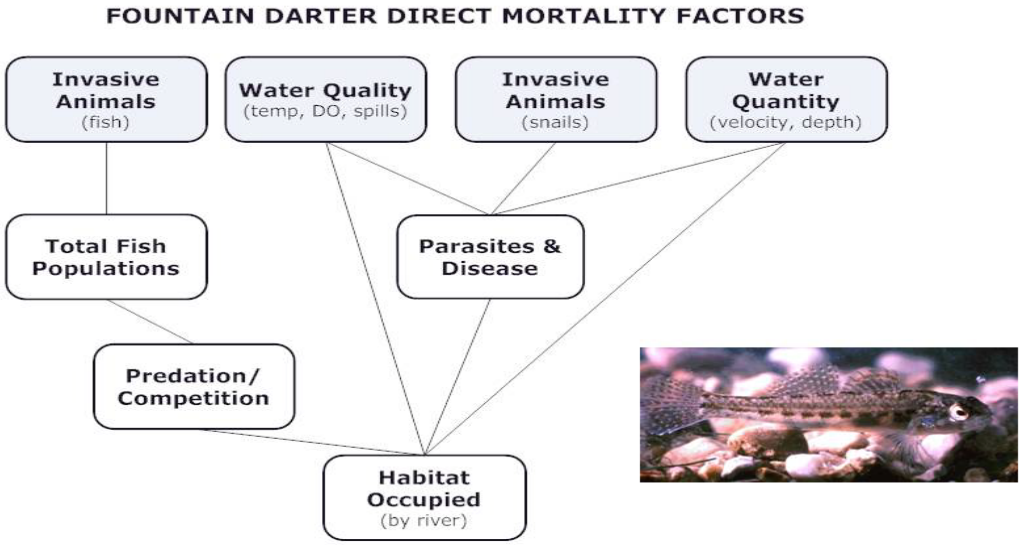


Figure 13. Example of direct mortality factors influence diagram for fountain darters.

As noted previously, these influence diagrams were developed to support the analysis needs identified by the USFWS as part of the HCP process. The material provided above is also used to inform the reader where the existing modeling tools can be used to provide quantitative input to the identified key influences between physical, chemical, and biological processes affecting these target species in the Comal and San Marcos Rivers. These influence diagrams will need to be further refined and modified not only based on the comments provided to date, but also on broader input through the HCP process. At this juncture, no decision by the Edwards Aquifer and Recovery Program or the HCP has been made on whether to use or refine these influence diagrams, not in what specific capacity these diagrams may be utilized in support of HCP development and evaluation.

Hydrodynamic Modeling

Physical Characterization

For each river system, the bottom topography was delineated using a variety of survey equipment. Where water depths were too shallow for the acoustic bottom tracking unit, depths at each location were obtained using a topset wading rod. In some instances where thick aquatic vegetation stands interfered with the acoustic sounding device, bottom depths were also obtained using a topset wading rod. Where water depths permitted, bottom profiles were obtained using a hydroacoustic array linked to a GPS unit. Above water surface elevations along the channel margins were obtained using either a standard survey level or total station in conjunction with a GPS. More detailed descriptions of the survey techniques can be found in Hardy et al. (1998) for the Comal and Bartsch et al. (2000) for the San Marcos.

On October 17th and 18th 1998, torrential rains dropped 22.5 inches of rain on the San Marcos, Texas area resulting in what could be the 500-year flood in the San Marcos River. Actual flood discharge is unknown, as the flood rendered the USGS San Marcos gage inoperable. Damages in San Marcos exceeded twelve million dollars. The 1998 flood greatly affected the vegetation and morphology of the San Marcos River. Whole stands of vegetation were torn up from the river bottom during the flood. Stands of Texas wild rice, in particular, disappeared from the stretch of river near the state fish hatchery and areas downstream of that location. Deposition and removal of bed material occurred throughout the system including new gravel deposits above the University Drive Bridge in an area near Texas wild rice stands. Introduction of sediment was aggravated due to upstream construction activities within the Sessoms Creek drainage.

Additionally, Cape's (Thornton's) Dam in the San Marcos River failed in December 1999. Temporary repairs of bags of concrete reinforced with rebar were made to the dam. In April 2001 personnel from INSE and the Ecological Services Office of the USFWS collected cross-section information at select locations in the Rio Vista section (Spring Lake dam to Rio Vista dam) and the Cape's Dam section (Rio Vista dam to Cape's or Thornton's dam). Based on these cross sections INSE and USFWS judged the channel change could potentially impact modeling results enough to warrant remapping of channel topographies at that time. The updated channel topographies collected during 2001 in the San Marcos River were utilized in this report.

It should be noted that continued channel topography changes associated with sedimentation has continued through the present. This has been contributed by increased sedimentation from the Sessoms Creek watershed due to on-going construction activities and has resulted in a gravel bar island at the confluence of Sessoms Creek and the San Marcos River just downstream from the outfall of Spring Lake. Movement of these sediments downstream has also altered channel topography and bed material composition in the Sewell Park and City Park areas. Additional alterations since the revised topography of 2001 was obtained include alterations to the channel structure to improve safety at the tube chute. Some sensitivity analysis has been conducted on the impact of measured channel changes (i.e. the pre-flood versus post-flood topography) within the San Marcos and indicates that the primary effect has been scaling the magnitude of the habitat versus flow relationships rather than changing the underlying relationship between flow and available habitat. It should be cautioned however, that modeling does not reflect changes in the aquatic vegetation community, which has a higher potential for impacting predictions of suitable darter habitat for example, than the observed/modeled channel changes.

Development of Computational Meshes

Computational meshes were developed from the raw topography data for each river system based on evaluation of several standardized grid generation techniques. This process required the translation of the irregularly spaced raw data sets into regularly spaced finite difference or finite element grids depending on the specific grid generation technique. The specific algorithms evaluated were linear krigging, inverse distance weighting, Clogh-Tocher and natural neighbor. General gridding procedures entailed an iterative application of each method until the most representative surface (MRS) had been created for a particular algorithm. The MRS was defined as the interpolated grid that least deviates

from the raw data. The lowest MRS of the various algorithms was then selected for use in the generation of the final computational meshes. The final MRS was generated as a 3 x 3 foot grid for use with the 2-dimensional hydraulic and habitat modeling programs. The natural neighbor algorithm was selected for use in both the Comal and San Marcos Rivers for all river sections modeled. Figure 14 shows an example of the three dimensional computational mesh for a section of the San Marcos River. Detailed methods are provided in Hardy et al. (1998), Bartsch et al. (2000) and INSE (2004).

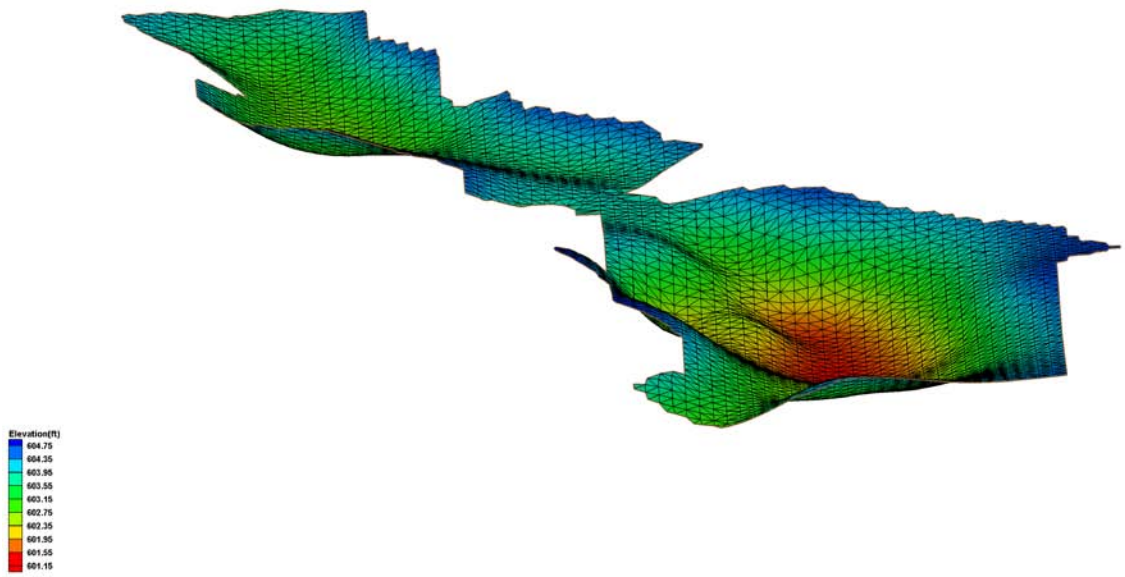


Figure 14. Example of a three dimensional computational mesh from a section of the San Marcos River.

Two-dimensional Hydraulic Models

Hydrodynamic modeling was undertaken in both river systems using the Surface-Water Modeling System (SWMS). SWMS is a comprehensive environment for 1D, 2D, and 3D hydrodynamic modeling. SWMS includes 2D finite-element, 2D finite-difference, 3D finite-element and 1D backwater modeling tools. Primary applications of the models include calculation of water surface elevations and flow velocities for shallow water flow problems for both steady-state or dynamic conditions. As noted below, different hydrodynamic models were originally applied within the Comal and San Marcos River systems. The differences were driven by the desire to assign spatially explicit inflow locations associated with spring orifices within Landa Lake of the Comal River system.

At the time that the original modeling was undertaken, the SWMS modeling system was chosen given the ability to integrate both the 1-dimensional water surface profile modeling capabilities needed to derive the longitudinal water surfaces needed by the 2-dimensional hydrodynamic models within a standardized user interface. The choice of the SWMS modeling system was also made based on its use of well documented and accepted analytical models for the various hydrodynamic model developed by the U.S. Army Corp of Engineers modeling group.

Water Surface Elevation Modeling

During the original studies on the Comal and San Marcos Rivers, discharge and water surface elevation data were collected throughout the study sites. These data were used on conjunction with the calibration and application of 1-dimensional water surface profile models (HEC-RAS) in order to obtain the boundary conditions for use in the 2-dimensional hydraulic models. The 1-dimensional models were developed for 'computational sections' within each river system. These sections were delineated based on physical features such as dams, weirs, confluence of channels, etc., and at the time, computational limitations of the computer systems. These computational segments were retained in the current modeling efforts.

Within each computational section, the 3x3 foot MRS grid was used to create one-dimensional cross section geometries approximately every 10 ft along the longitudinal profile of channel length. An automated system was developed to derive these cross sections from the 3-dimensional topographies based on a line drawn perpendicular to the channel. Control structures, such as weirs and sluice gates, were modeled where they existed in the system. Cross sections were calibrated to observed WSEL-discharge data by manipulation of the cross section's Manning's n value within HEC-RAS. Weir and sluice gate configurations were calibrated by the use of submerged inlet and outlet coefficients of discharge in the 1-D hydraulic model. Figure 15 illustrates an example from Landa Lake in the Comal River where 1-dimensional cross section locations are extracted from the computational mesh.

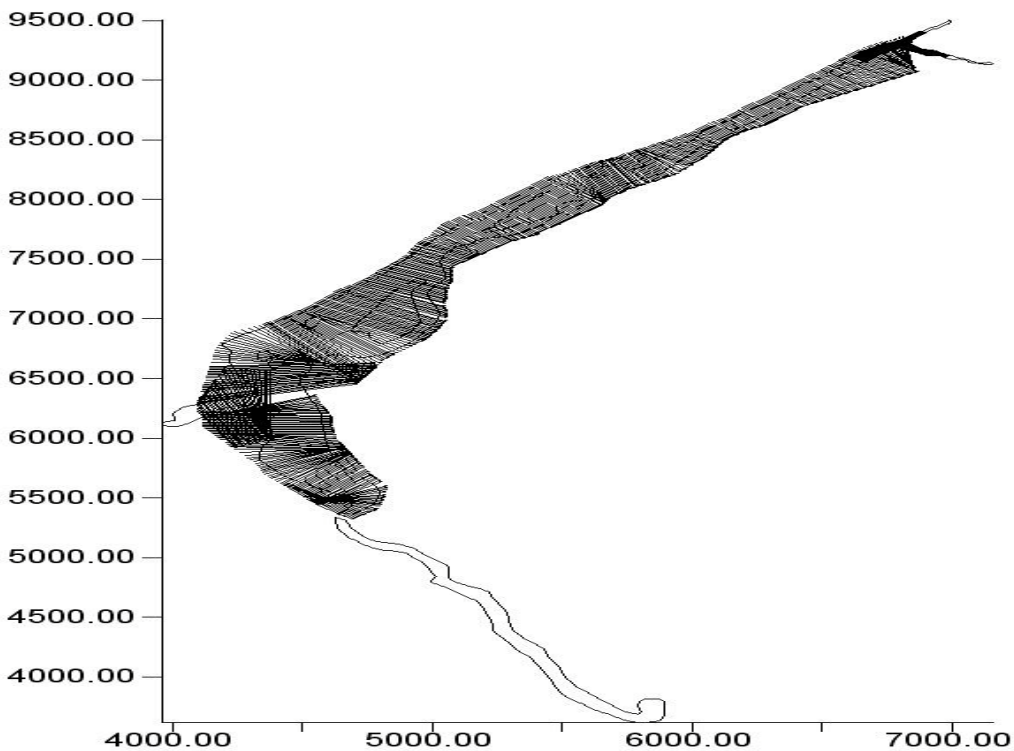


Figure 15. Example of 1-dimensional cross sections extracted from the three-dimensional computational mesh for a section of the Comal River. X and Y axes are UTM Coordinates (in meters).

Comal River

The Comal River was modeled using SWMS (7.2) with the RMA-2 hydrodynamic model. RMA2 is a two-dimensional depth averaged finite element hydrodynamic numerical model. It computes water surface elevations and horizontal velocity components for subcritical, free-surface flow in two-dimensional flow fields. RMA2 computes a finite element solution of the Reynolds form of the Navier-Stokes equations for turbulent flows. Friction is calculated with the Manning's or Chezy equation, and eddy viscosity coefficients are used to define turbulence characteristics. The model input data was updated to SWMS (9.2) using RMA-2 for potential use in future modeling efforts.

As noted above, the HEC-RAS calibrated 1-dimensional hydraulic model results were used to set the boundary conditions for the water surface elevation at each modeled flow rate for each computational section required by the RMA-2 model. Figure 16 shows the location of each computational section used within the Comal River system. In addition, data reported in Brune (1981) on spring locations and approximate discharges were used to assign inflow nodes to specific computational nodes as illustrated in Figure 17.

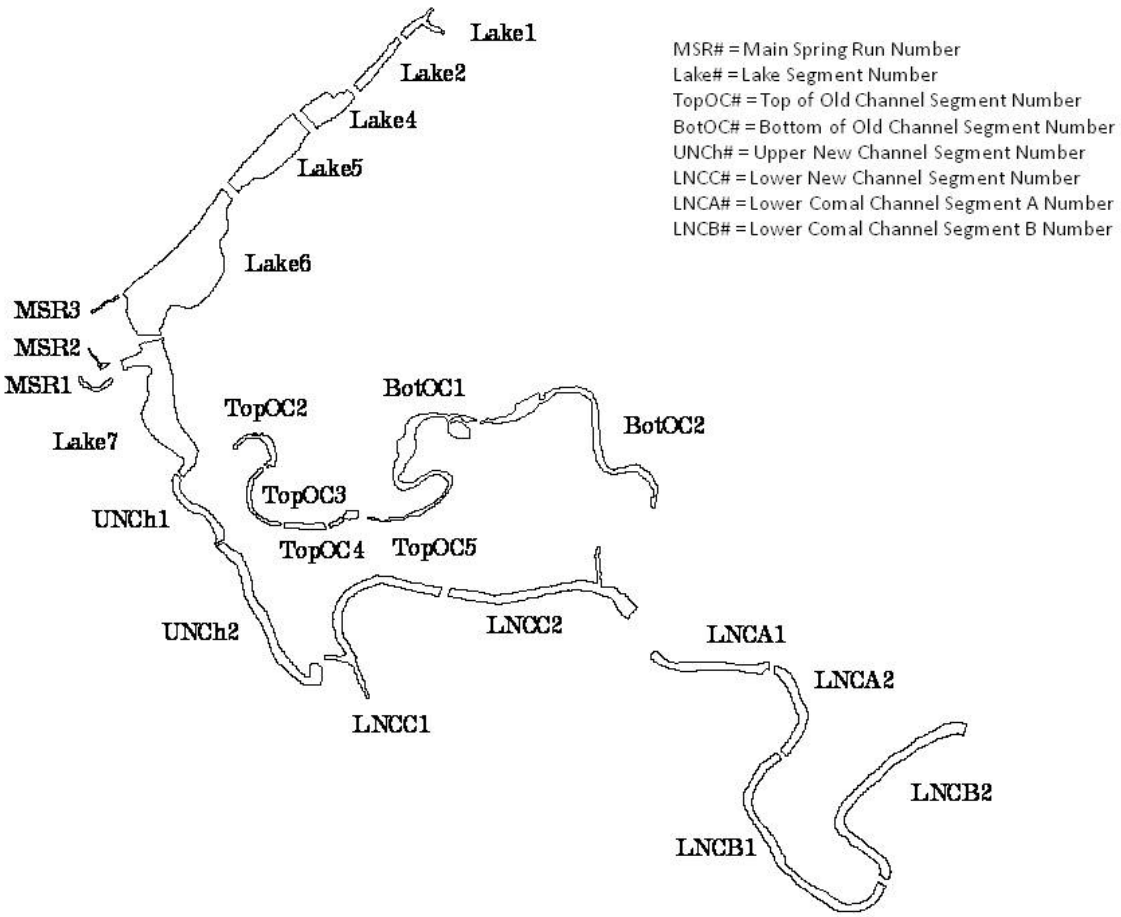


Figure 16. Hydrodynamic computational sections for the Comal River system used in the RMA-2 modeling.

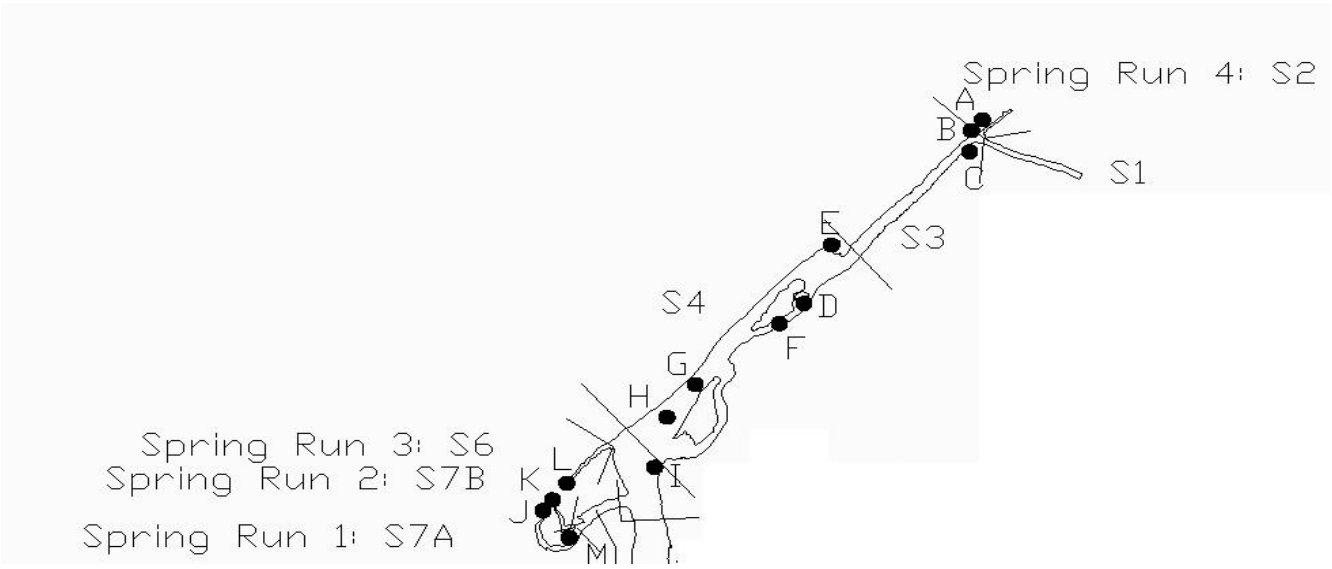


Figure 17. Spatial location of spring inflow nodes within Landa Lake of the Comal River system used in the hydrodynamic modeling.

Based on Brune's (1981) classification of spring size (i.e., Large, Moderately Large, and Medium), it was assumed that at total Comal River flow rates greater than 225 cfs that flows would be partitioned by a 3:2:1 ratio for Large:Moderately Large:Medium springs. At total Comal River flow rates less than 225 cfs, it was assumed that springs G through L would contribute 90 percent of the total river discharge. Table 1 provides the Brune (1981) spring designations (see Figure 17), their size classification, the assumed flow contributions for each spring source, and the modeled flow split between the Old and New Channels. This table also indicates the Segment location for each spring source (see Figure 16 for Segment locations). Table 2 shows the corresponding total discharge entering each Segment location within Landa Lake for the assumed distribution of flows for the indicated total discharge of the Comal River. The contribution of specific spring flow rates at total spring flows between these values was based on a simple linear interpolation between the values in Table 1. The incremental contribution of each Lake Segment was determined from the data in Brune (1981) and synoptic flow measurements taken within Landa Lake as part of the original studies conducted by Hardy et al. (1998).

The existing spring and total flow rate dependent discharge for the specific springs and Landa Lake segments (Tables 1 and 2) were provided for review to the RIP, but no comments were received. Therefore the existing assumed flow rates (and hydraulic existing simulations) were used in all analyses in this report. Additional work has been undertaken by the Edwards Aquifer Authority over the past 10 years based on synoptic flow measurements and dye tracer studies which are being evaluated to update these inputs for use in the on-going hydrodynamic model development which will include updated channel topography and vegetation distributions.

Table 1. Spring name (see Figure 17), size, model segment in Landa Lake, assumed flow rates for each modeled discharge, and associated flow splits between the old and new channels in the Comal River.

		Spring Flow					
Total Comal River Discharge (cfs)		**300**	**150**	**100**	**60**	**30**	
Flow split New Channel/Old Channel (cfs)		**225/75**	**100/50**	**75/25**	**50/10**	**25/5**	
Spring	**Size**	**(cfs)**	**(cfs)**	**(cfs)**	**(cfs)**	**(cfs)**	**Segment**
A	Medium	14.3	7.1	1	0.6	0.3	LAKE1C
B	Large	42.9	21.4	2.9	1.7	0.9	LAKE1C
C	Moderately Large	28.6	14.3	1.9	1.1	0.6	LAKE1C
E	Medium	14.3	7.1	1	0.6	0.3	LAKE4C
D	Medium	14.3	7.1	1	0.6	0.3	LAKE5C
F	Medium	14.3	7.1	1	0.6	0.3	LAKE5C
G	Moderately Large	28.6	14.3	11.4	6.9	3.4	LAKE6C
H	Moderately Large	28.6	14.3	11.4	6.9	3.4	LAKE6C
I	Medium	14.3	7.1	14.3	8.6	4.3	LAKE6C
J	Medium	14.3	7.1	12.4	7.4	3.7	LAKE6C
K	Large	42.9	21.4	4.8	2.9	1.4	LAKE6C
L	Large	42.9	21.4	37.1	22.3	11.1	LAKE7C

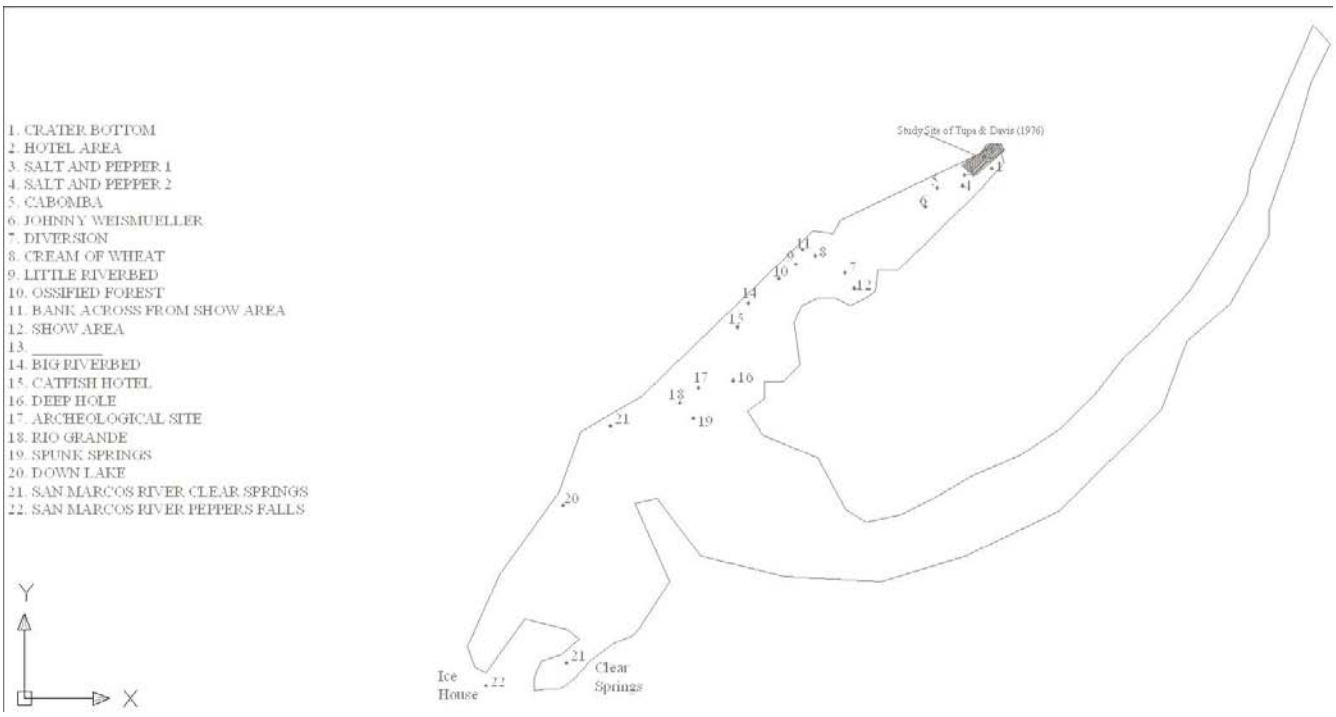
Table 2. Incremental discharge accretions by Landa Lake model Segments used in the hydrodynamic modeling of the Comal River.

Water Entering at the Head of Segment					
Segment	**225/75 cfs**	**100/50 cfs**	**75/25 cfs**	**50/10 cfs**	**25/5 cfs**
LAKE1D	7.00	6.00	5.00	2.00	1.00
LAKE2D	85.70	42.90	5.70	3.40	1.70
LAKE4D	85.70	42.90	5.70	3.40	1.70
LAKE5D	100.00	45.00	1.70	1.50	2.00
LAKE6D	128.60	54.30	3.60	0.10	0.60
LAKE7D	167.90	71.40	62.90	39.70	19.90
UNCH1	225.00	100.00	80.00	50.00	25.00
UNCH2	225.00	100.00	80.00	50.00	25.00

San Marcos River

The San Marcos System was originally modeled in SWMS (8.0) using the FESWMS 2-dimensional hydrodynamic model FESWMS. FESWMS is a hydrodynamic model that supports both super and subcritical flow analysis including area wetting and drying. The FESWMS model allows users to include weirs, culverts, drop inlets, and bridge piers in a standard two-dimensional finite element model. FESWMS is used to compute water surface elevations and flow velocities at nodes in a finite element mesh representing a body of water such as a river, harbor, or estuary. Although the model input data was updated to SWMS (9.2), the existing hydraulic simulations utilize the SWMS (8.0) model results from FESWMS for this report. As noted above, the HEC-RAS calibrated 1-dimensional hydraulic model results were used to set the boundary conditions for the water surface elevation at each modeled flow rate for each computational section required by the 2-dimensional hydrodynamic model.

INSE/USFWS field discharge measurements in the summer of 1997 showed that the Sink Creek flow rate to be extremely small at 1.8 cfs (October 1, 1997). For the 2-D hydraulic model, up to five cfs was added in the entire slough area at medium to high modeled flow rates in order to simulate discharge accretions through this area. These flow contributions were intended to account for all unmeasured sources contributing to this section of the lake using professional judgment based on our synoptic flow measurements. With up to two hundred individual springs in Spring Lake (Brune, 1981), modeling springs input in the lake was simplified. A map of the eighteen largest springs in Spring Lake oriented to North American Datum (NAD) 83 coordinates to match the system GIS coordinate system was



obtained from the USFWS (Figure 18).

Figure 18. Location of 18 springs used in the hydrodynamic modeling of Spring Lake in the San Marcos River.

This data was then overlain on the 2-D hydraulic mesh and at each hydraulic cell containing a spring, a source input was created in the hydraulic model. Total modeled San Marcos Springs flow was divided by twenty-one (the eighteen largest springs with three springs at double the flow rate) and the resulting discharge assigned to each spring (plus double the flow for the three largest springs) as shown in Table 3. The values in Table 3 were used to interpolate values at other discharges based on a simple linear interpolation to derive the specific contribution of spring areas given a total San Marcos discharge. The original modeling also included the A.E. Woods state fish hatchery 5 Million Gallon per Day (MGD) discharge permit. A standard wastewater treatment discharge curve was taken from Tchobanoglous (1991) and scaled up to match this 5 MGD rate. The maximum discharge during the day was assumed to be 23.2 cfs and this flow rate was added to the 2-D hydraulic model at the appropriate location at all modeled flow rates.

In addition, the original modeling assumed that the City of San Marcos wastewater treatment plant was to be upgraded to a 9 MGD discharge. A standard daily wastewater discharge curve was scaled to 9 MGD and the maximum instantaneous discharge (assumed to 41.8 cfs) was taken from this curve and applied to the 2-D hydraulic model at this location at all modeled discharges.

Table 3. Assumed spring flow contributions for various spring sources in Spring Lake of the San Marcos River.

Total San Marcos Discharge (cfs)			**170 cfs**	**135 cfs**	**100 cfs**	**65 cfs**	**30 cfs**	**15 cfs**
Node	**USFWS Designation**	**Spring Name**	**Srpring Flow cfs**					
14630	1	Crater Bottom	8.95	7.11	5.26	3.42	1.58	0.79
14585	2	Hotel Area	8.95	7.11	5.26	3.42	1.58	0.79
14375	3	Salt and Pepper 1	8.95	7.11	5.26	3.42	1.58	0.79
14322	4	Salt and Pepper 2	8.95	7.11	5.26	3.42	1.58	0.79
14076	5	Cabomba	8.95	7.11	5.26	3.42	1.58	0.79
13943	6	Johny Weismueller	8.95	7.11	5.26	3.42	1.58	0.79
11549	8	Cream of Wheat	8.95	7.11	5.26	3.42	1.58	0.79
11549	9	Little Riverbed	8.95	7.11	5.26	3.42	1.58	0.79
10522	10	Ossified Forest	8.95	7.11	5.26	3.42	1.58	0.79
11549	11	Bank across from show area	8.95	7.11	5.26	3.42	1.58	0.79
12417	12	Show Area	8.95	7.11	5.26	3.42	1.58	0.79
	13	Not Used	na	na	na	na	na	na
9326	14	Big Riverbed	17.89	14.21	10.53	6.84	3.16	1.58
8592	15	Catfish Hotel	17.89	14.21	10.53	6.84	3.16	1.58
7441	16	Deep Hole	17.89	14.21	10.53	6.84	3.16	1.58
6298	18	Rio Grande	8.95	7.11	5.26	3.42	1.58	0.79
5441	19	Spunk Springs	8.95	7.11	5.26	3.42	1.58	0.79

No new water quality simulations were conducted as part of this existing effort. Updated water quality/temperatures models are currently being developed and will include updated boundary conditions for known point source inflows associated with data for the hatchery and waste water treatment plants from compliance monitoring data.

San Marcos No Cape's Dam Alternative Modeling Scenario

The model was also calibrated for an alternative scenario in the Cape's Dam section. Specifically the model was calibrated for the absence of Cape's Dam. The 2001 mesh geometry was altered using Terramodel to reflect the removal of the dam and the channel upstream of the dam was modified for approximately 100 feet to a roughly trapezoidal shape. Due to the heavy sediment deposition in this part of the channel the resulting geometry should only be considered hypothetical. From the resulting channel cross section the HEC-RAS software was used to develop a discharge curve. The model was calibrated to the flows above and the downstream water surface elevations predicted by the curve shown in Figure 19.

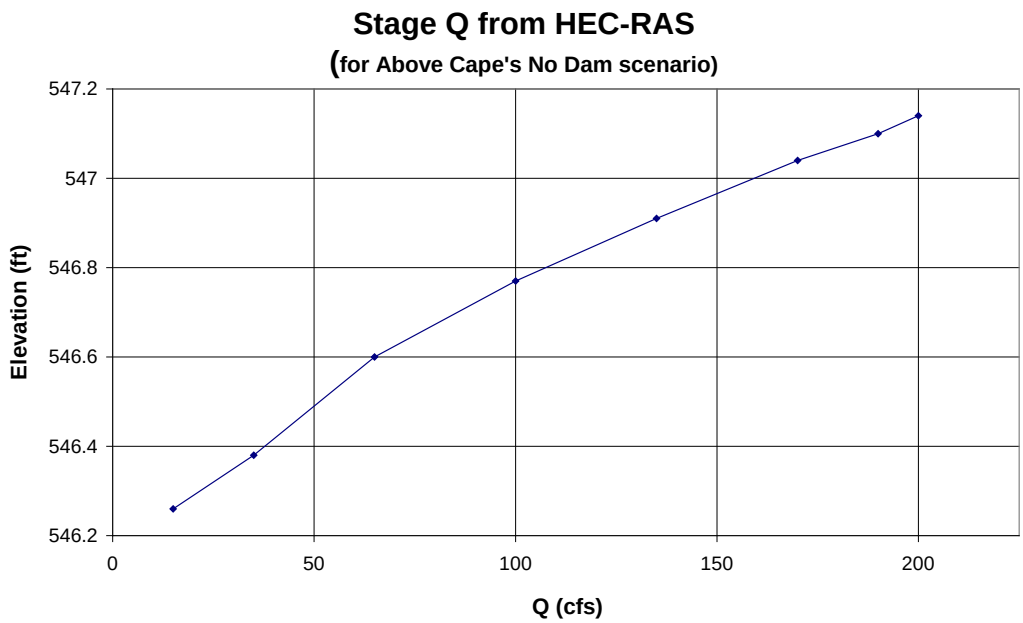


Figure 19. Stage discharge relationship from HEC-RAS used to calibrate the Above Cape's section No Dam scenario.

Vegetation Mapping

Vegetation distributions were surveyed using GPS by the USFWS and Texas State University personnel (Roland Roberts, David Lemke) for the Comal. Additional work was undertaken by Jonathan Beale, an Americorps student working for/with USFWS, who mapped Comal vegetation from March-June 1996. Some patches were mapped using a GPS-determined centroid with notes on length, width, and height. Other larger patches were mapped using GPS points along the patch boundary. Field notes based on GPS locations and size of vegetation patches were entered into a GPS data recorder and then redrawn

in AutoCAD format. In general, patches of vegetation less than 10 feet in diameter were not mapped. Updated macrophyte survey data completed in 2001 by Dr. Robert Doyle, Baylor University was used for the San Marcos River system. The distribution of elephant ears were not resurveyed after the 1989 flood, but had their polygons updated from the 2001 field notes. Vegetation polygons were then integrated over the 3-dimensional channel geometry grid for each river system used in the 2-D hydraulic model by rectification of these data to the same coordinate system. An example of the vegetation mapping results for a section of the Comal River is provided in Figure 20.

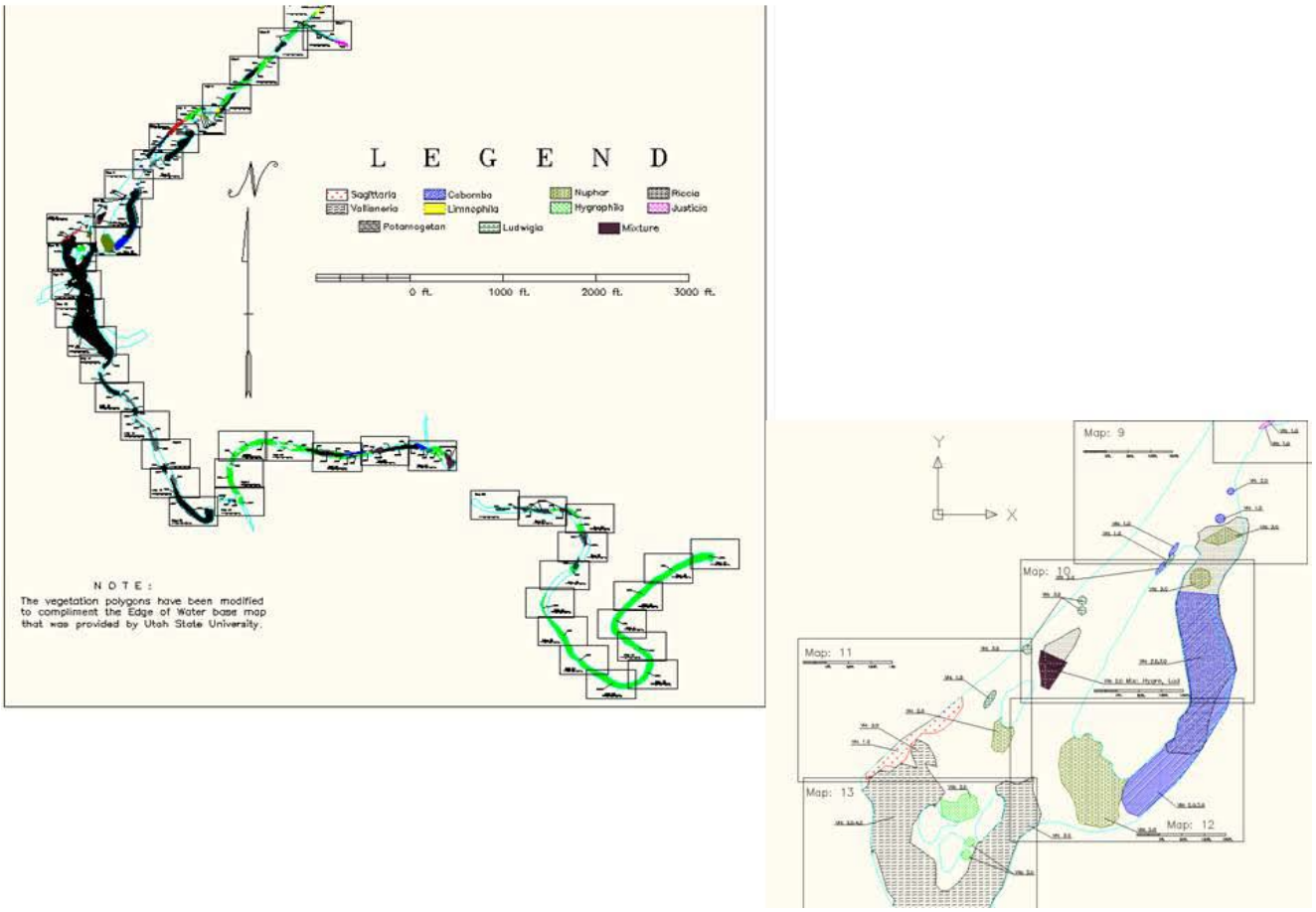


Figure 20. Example of vegetation mapping polygons from the Comal River.

Vegetation Dependent Hydraulic Roughness

The vegetation maps were overlain on each 2-D hydraulic section and each cell within the mesh was assigned a material type based on vegetation species. Each vegetation species except Texas wild rice was assigned a unique hydraulic roughness value based on vegetation/vertical velocity profile data from collections in the Comal River system. No data was collected from Texas wild rice stands in the San Marcos River to avoid direct disturbance of the plants at the request of the USFWS. Vegetation specific velocity profiles and depth data collected during the vegetation survey in the Comal River were used in the hydraulic models to include the effect of the various vegetative stands and their

characteristic roughness for velocity modeling within the 2-dimensional hydrodynamic model as noted below. The associated roughness for each vegetation type was approximated from the measured vertical velocity distributions using the average velocities and depths based on a unit width modified form of Manning's Equation to determine an equivalent roughness. The modified form of Manning's Equation that was developed is:

$$\overline{V} = \frac{C}{n}\left(\frac{A}{P}\right)^{\frac{2}{3}}\sqrt{S_0}$$

where:

V = mean velocity (ft/s)
C = 1.486 for English units
n = roughness
A = area (ft^2), which was represented by average depth multiplied by a unit width (1 ft)
P = wetted perimeter, two times the average depth added to the unit width (ft)
S_0 = energy slope (ft/ft)

Since the energy slopes and characteristics of the surrounding area for the provided velocity profiles by vegetation types were not collected, an iterative procedure that varied slope, roughness and unit width was used to approximate comparative roughness from the data. The roughness determined from the above equation can not be called a true Manning's n roughness but is treated as an apparent roughness in this application. The calculated roughness was then iteratively scaled during 2-D hydraulic calibration to known water surface elevations in conjunction with eddy viscosity coefficient changes. Vegetation type and resulting roughness are shown in Table 4.

Table 4. Vegetation class and roughness assignments for 2-D hydraulic boundary condition files.

Vegetation Class	Roughness	Vegetation Class	Roughness
No vegetation	0.049	*Limnophila sessiflora*	0.103
Hygrophila polysperma	0.07	*Potamogeton illinoensis*	0.078
Riccia fluitans	0.035*	*Ludwigia repens*	0.05
Cabomba caroliniana	0.058	*Nuphar luteum*	0.09
Vallisneria americana	0.026	*Justicia americana*	0.035*
Sagittaria platyphylla	0.02		

** As no vertical velocity distribution or roughness data was available for these plant types, they were assigned a generic roughness value.*

As noted in Table 4, several species were assigned 'generic roughness' values since no data was available for these species from the field investigations but were delineated during the vegetation mapping. Ongoing vegetation mapping for both the Comal and San Marcos River systems will be used in updated modeling and assignment of generic roughness values will be reviewed and revised as necessary.

Vertical Velocity Distributions in Vegetation

Due to the extensive aquatic vegetation in both the Comal and San Marcos River systems, it was recognized that the mean column velocity predictions from the hydrodynamic models would need to be modified to predict the hydraulic conditions within vegetation beds as well as 'near the bed' to represent conditions where fountain darters were known to inhabit. This was accomplished by collection of vertical velocity distributions in most vegetation types within the Comal River in order to provide data for vertical velocity curve development. These curves were used in conjunction with the 2-D hydraulic model output in determining velocity at 0.5 feet (15 centimeters) above the channel bottom for input into the habitat suitability equations used by fountain darters. For each point evaluated in the system, the ratio of 0.5 foot to total depth was input into the vertical velocity distribution curve developed for that particular vegetation type present, when available, in order to produce the corresponding adjusted velocity values. The velocity/mean velocity ratio value was then multiplied by the mean velocity at each location, as predicted by the 2-D hydraulic tool, in order to produce actual velocities for input into the fountain darter habitat suitability equations. A detailed description of the methodology and results can be found in Bartsch (1996). This adjustment in the velocity values was only applied when modeling fountain darter habitat.

Water Quality and Temperature Modeling

Water Quality and temperature modeling in the Comal and San Marcos River systems was undertaken using the QUAL2E water quality model (Brown and Barnwell, 1987). The Enhanced Stream Water Quality Model (QUAL2E) is a steady state model for conventional pollutants in branching streams and well mixed lakes. It can be operated either as a steady state or dynamic model and is intended for use as a water quality planning tool. The model can be used to study impact of waste loads on in-stream water quality and identify magnitude and quality characteristics of non-point waste loads. In this study, the model was used under steady state conditions for the whole river system but subsequently used to simulate maximum daily water temperatures over a 48 hour period associated with the hottest meteorological conditions as a worse case scenario. The maximum daily simulations of temperature and dissolved oxygen were used for all simulated flows when assessing fountain darter habitat.

Water quality/temperature modeling relied on the original simulations in the Comal and San Marcos River systems as this provided a consistent linkage between the conditions used to collect and calibrate the models that best matched the topography and vegetation conditions used in the habitat simulations. At this time, there is now more extensive water quality monitoring data available that has been collected by the Edwards Aquifer Authority over the past nine years as part of their variable flow study in both river systems. These data will be used to calibrate/validate updated water quality/temperature models in the Comal and San Marcos Rivers that also reflect updated channel geometries and updated vegetation mapping in support of the HCP.

Comal River

The Comal River was divided into 18 computational reaches containing a variable number or computational segments that were 100 feet in length as illustrated in Figure 21. Selection of these computational segments were based on channel features (hydraulic control structures) and

computational limitations (size of meshes) of the hydrodynamic models. Table 5 provides a description of the reaches, segments, and boundary descriptions.

Temperature calibration and verification data were gathered by placing temperature recording devices on each major branch of the Comal River system. Locations were simultaneously monitored at the bottom of Landa Lake, near the bottom of the old channel, middle of the new channel, and near the confluence with the Guadalupe River at the bottom of the system (Figure 22). Data were recorded on a 15 minute interval beginning in August, 1997.

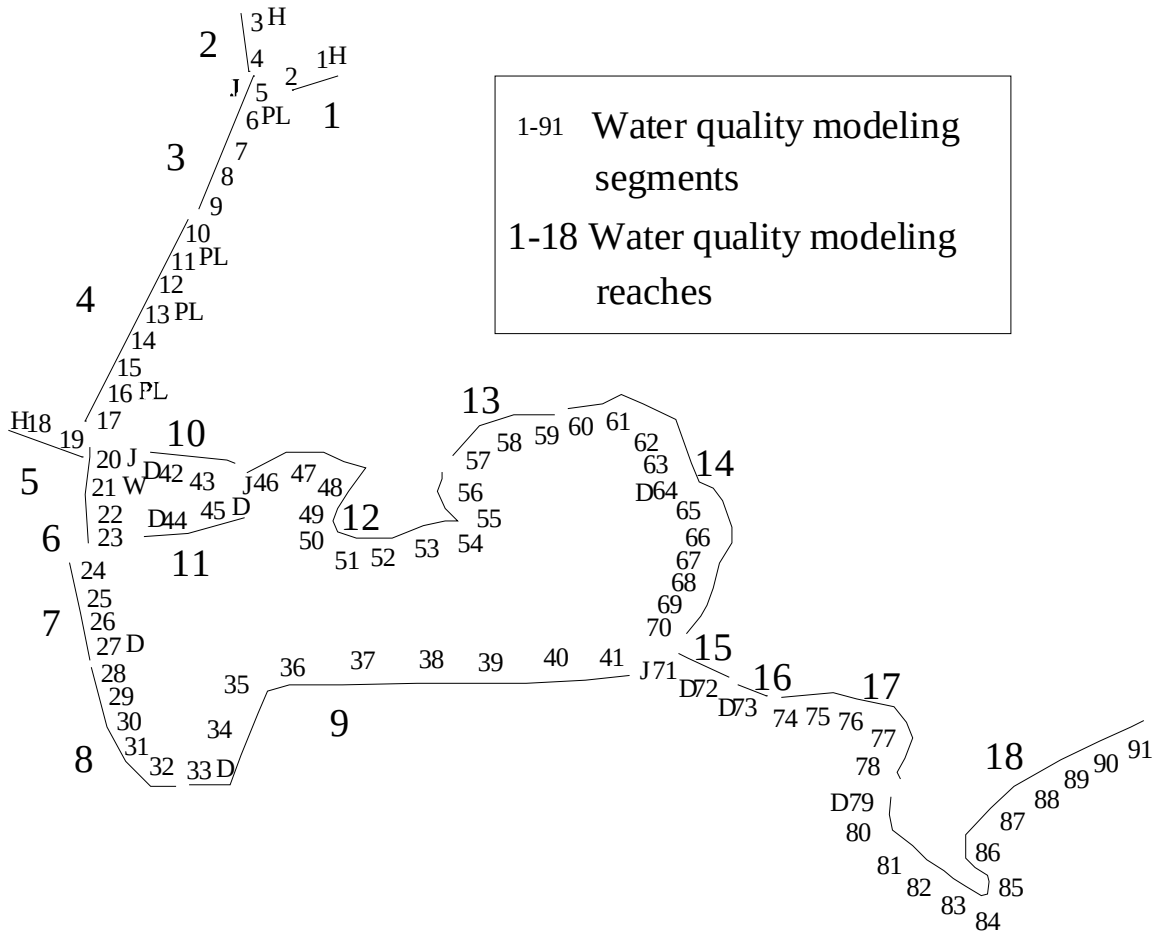


Figure 21. Computational segments and computational cells for use in water temperature and dissolved oxygen modeling in the Comal River System.

Table 5. QUAL2E water quality modeling reaches and segment physical descriptions for the Comal River.

Reach	Segments	Boundary descriptions	Reach	Segments	Boundary descriptions
1	1-2	Northeast headwaters of Landa Lake	10	42-43	Woods section of upper old channel
2	3-4	Northwest headwaters of Landa Lake	11	44-45	Spring fed pool and small section below pool
3	5-9	Shallow stretch of upper Landa Lake	12	46-56	Old channel past golf course
4	10-17	Landa Lake widens out to include islands	13	57-59	Upper Schlitterbahn old channel section
5	18-19	Main spring runs	14	60-70	Lower old channel.
6	21-23	Deep lower end of Landa Lake	15	71-72	Below junction of old and new channels
7	24-27	Narrow, fast moving upper stretch of new channel	16	73	Below Clemens Dam
8	28-32	New channel below LCRA weir	17	74-78	Below USGS weir
9	33-41	Below power plant outfall. Highly aerated	18	79-91	River below USGS weir, above Guadalupe River

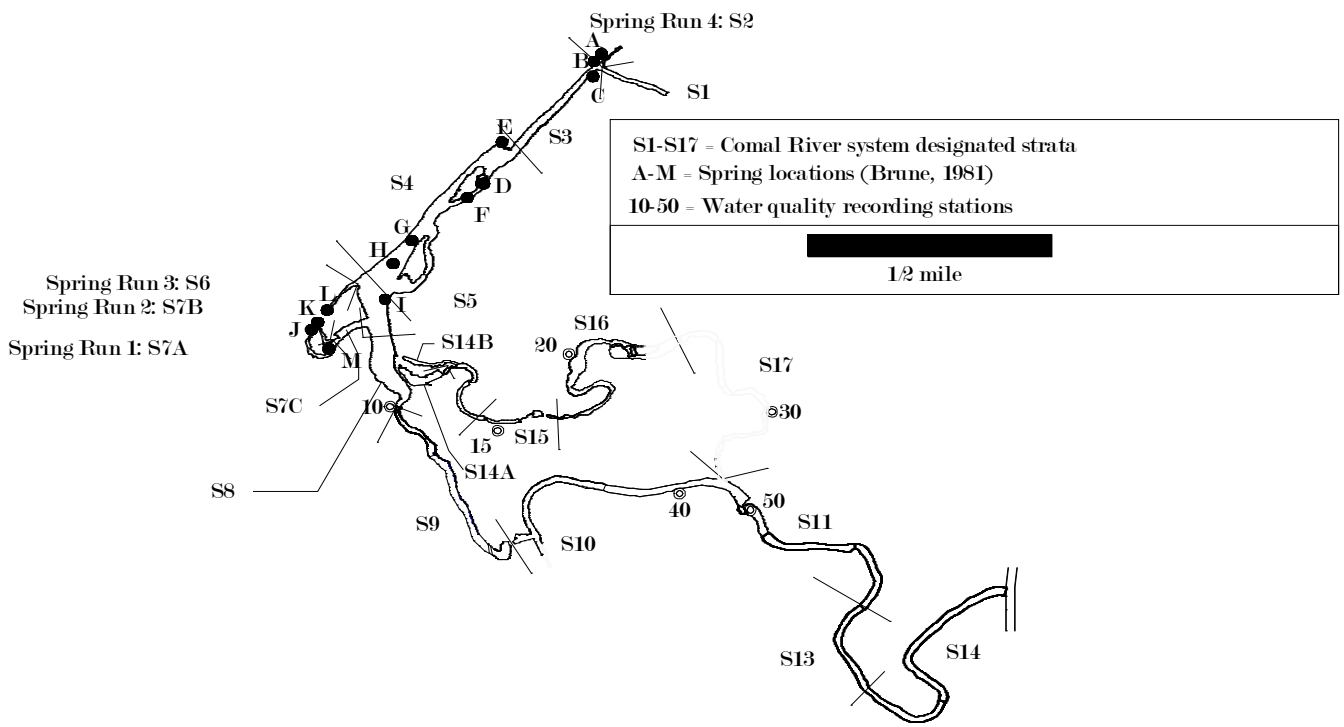


Figure 22. Water temperature monitoring stations in the Comal River used for model calibration.

Boundary Conditions

For a given total Comal River discharge, flow and temperature values for either headwaters (H) or point loads (PL) associated with specific springs or the new/old channels were estimated from the data provided in Brune (1981). Mean spring water temperature in Comal Springs is 73.4^{0}F (23^{0}C) (George et. al 1952), which is very close to the average annual air temperature of about 69^{0}F (20.6^{0}C) in New Braunfels (Brune 1981). An example of the linkage between a specific flow rate (150 cfs) and the assumed spring flow, spring orifice temperatures, and dissolved oxygen are provided in Table 6.

Table 6. Example of boundary conditions of spatially distributed flow, temperature, and dissolved oxygen for the Comal River at a flow of 150 cfs.

Point Loads						Headwater onditions					
Reach	**Segment**	**H or PL**	**Volume (CFS)**	**Notes**	**Cumulative Flow**	**Reach**	**Segment**	**Type**	**FLOW cfs**	**Temp F**	**DO mg/l**
1	1	H	0.15	NE Branch headwater of Landa Lake	0.15	2	2	Point Source	3.75	74.4	4.5
2	1	H	6	NW Branch of Landa Lake, Spring run 4 headwater.	6.15	2	3	Point Source	2.253	74.4	4.5
2	2	PL	3.75	Along bluff	9.9	3	2	Point Source	2.253	74.4	4.5
2	3	PL	3.75	Along bluff	13.65	3	3	Point Source	0.468675	74.4	4.5
3	2	PL	2.253	Along bluff	15.9	3	4	Point Source	2.253	74.4	4.5
3	3	PL	0.468675	Spring run 5 headwater	16.37	3	5	Point Source	2.253	74.4	4.5
3	4	PL	2.253	Along bluff	18.62	3	6	Point Source	2.253	74.4	4.5
3	5	PL	2.253	Along bluff	20.88	3	7	Point Source	2.253	74.4	4.5
3	6	PL	2.253	Along bluff	23.13	3	8	Point Source	2.253	74.4	4.5
3	7	PL	2.253	Along bluff	25.38	3	9	Point Source	2.253	74.4	4.5
3	8	PL	2.253	Along bluff	27.64	3	0	Point Source	2.253	74.4	4.5
3	9	PL	2.253	Along bluff	29.89	3	11	Point Source	2.253	74.4	4.5
3	10	PL	2.253	Along bluff	32.14	3	12	Point Source	2.253	74.4	4.5
3	11	PL	2.253	Along bluff	34.4	3	13	Point Source	2.253	74.4	4.5
3	12	PL	2.253	Along bluff	36.65	3	14	Point Source	2.253	74.4	4.5
3	13	PL	2.253	Along bluff	38.9	4	1	Point Source	2.253	74.4	4.5
3	14	PL	2.253	Along bluff	41.15	4	2	Point Source	2.253	74.4	4.5
4	1	PL	2.253	Along bluff	43.41	4	3	Point Source	0.15	74.4	4.5
4	2	PL	2.253	Along bluff	45.66	4	4	Point Source	0.15	74.4	4.5
4	3	PL	0.15	Along bluff	45.81	4	5	Point Source	0.4	74.4	4.5
4	4	PL	0.15	Along bluff	45.96	4	6	Point Source	0.15	74.4	4.5

4	5	PL	0.4	Spring Island spring	46.36	4	7	Point Source	0.15	74.4	4.5
4	6	PL	0.15	Along bluff	46.51	4	8	Point Source	0.15	74.4	4.5
4	7	PL	0.15	Along bluff	46.66	4	9	Point Source	2.5	74.4	4.5
4	8	PL	0.15	Along bluff	46.81	4	10	Point Source	2.5	74.4	4.5
4	9	PL	2.5	Along bluff	49.31	4	11	Point Source	2.5	74.4	4.5
4	10	PL	2.5	Along bluff	51.81	4	12	Point Source	2.5	74.4	4.5
4	11	PL	2.5	Along bluff	54.31	4	13	Point Source	2.5	74.4	4.5
4	12	PL	2.5	Along bluff	56.81	4	14	Point Source	2.5	74.4	4.5
4	13	PL	2.5	Along bluff	59.31	4	15	Point Source	2.5	74.4	4.5
4	14	PL	2.5	Along bluff	61.81	4	16	Point Source	2.5	74.4	4.5
4	15	PL	2.5	Along bluff	64.31	4	17	Point Source	2.5	74.4	4.5
4	16	PL	2.5	Along bluff	66.81	4	18	Point Source	2.5	74.4	4.5
4	17	PL	2.5	Along bluff	69.31	4	19	Point Source	2.5	74.4	4.5
4	18	PL	2.5	Along bluff	71.81	4	20	Point Source	2.5	74.4	4.5
4	19	PL	2.5	Along bluff	74.31	5	1	Point Source	2.5	74.4	4.5
4	20	PL	2.5	Along bluff	76.81	6	2	Point Source	2.5	74.4	4.5
5	1	PL	2.5	Along bluff	79.31	6	3	Point Source	2.5	74.4	4.5
6	1	H	18.6	Spring run 3 headwater	97.91	7	2	Point Source	9	74.4	4.5
6	2	PL	2.5	Spring run 3 seep	100.41	9	2	Point Source	3	74.4	4.5
6	3	PL	2.5	Spring run 3 seep	102.91	10	2	Point Source	4.5	74.4	4.5
7	2	PL	9	Along bluff	111.91	10	3	Point Source	4.5	74.4	4.5
8	1	H	14.85	Spring run 1 head	126.76	10	4	Point Source	4.5	74.4	4.5
9	1	H	2.1	Spring run 2 head	128.86	10	5	Point Source	4.5	74.4	4.5
9	2	PL	3	Spring run 2 seep	131.86	11	4	Withdrawal	-20	75	6
10	2	PL	4.5	SR 1 below SR2 inflow	136.36	11	5	Withdrawal	-10	75	6
10	3	PL	4.5	SR 1 below SR2 inflow	140.86						
10	4	PL	4.5	SR 1 below SR2 inflow	145.36						
10	5	PL	4.5	SR 1 below SR2 inflow	149.86						
16	1	H	20	OC-Woods headwater							
17	1	H	10	OC-Spring fed pool headwater							

It was further assumed that at total spring flow rate less than 150 CFS, spring flow in the upper part of the Landa Lake was reduced to 5% of the total combined overall flow rate. This adjustment was made based on field observations of velocities and temperature by the USFWS in the summer of 1996, wherein a backwater was created in upper Landa Lake during low spring flows.

Model Calibration and Verification

The steady state simulations of water quality were calibrated for up to three locations at a time (Figure 22) within the system during several short time periods in 1993. This data consisted of data logging pH, specific conductivity, temperature and DO concentrations on a 30 minute basis when monitoring stations were functioning. Specific calibration dates were July 10-16, 1993 (average water temperature of 85.4), August 21-27, 1993 (average water temperature of 87.0), and September 14-20, 1993 (average water temperature of 80.4).

Temperature model calibration for the dynamic maximum daily temperature simulations, the National Climatic Data Center weather data from August 1997 to May 1998 for the base sation at Randolph Air Force Base was analyzed to isolate the hottest 48 hour period. This base was the closest available weather center (approximately 16 miles distant) to the site at the time of the original report. Weather information used in calibration, verification and analysis consisted of dry bulb temperatures, wet bulb temperature (calculated from dry bulb and humidity), cloud cover, wind speed and barometric pressure. The hottest 48 hour period with available water temperature data was identified as occurring on August 15-16, 1997. Average channel width and length, depth, and stage/discharge relationships based on field measured values were utilized.

The wind speed and cloud cover were adjusted to calibrate the temperature model. Figure 23 shows the measured and modeled water temperature near the bottom of the old channel for the calibration model run. Once the model was calibrated, a verification run was conducted to determine the accuracy of the model under different flow and weather conditions. A second hot period for which water temperature and climate data existed was found for August 21-23, 1997 and the results of verification runs are shown in Figure 23. Subsequently, the August 15th-16th climatic data were used as the input for all the flow rates simulated for evaluation of temperature impacts on darter habitat.

Dissolved oxygen (DO) modeling was performed without considering the effect of ammonia or nitrate nitrogen oxidation, sediment oxygen demand, phytoplanktonic algae/macrophytes and associated respiration, growth, nutrient effects, nitrification biological oxygen demand (BOD) due to lack of available calibration data. Only temperature, reaeration and dam reaeration were considered for the DO analysis. Calibrating DO concentrations to known values relied heavily on the use of dam reaeration coefficients (Brown and Barnwell 1987).

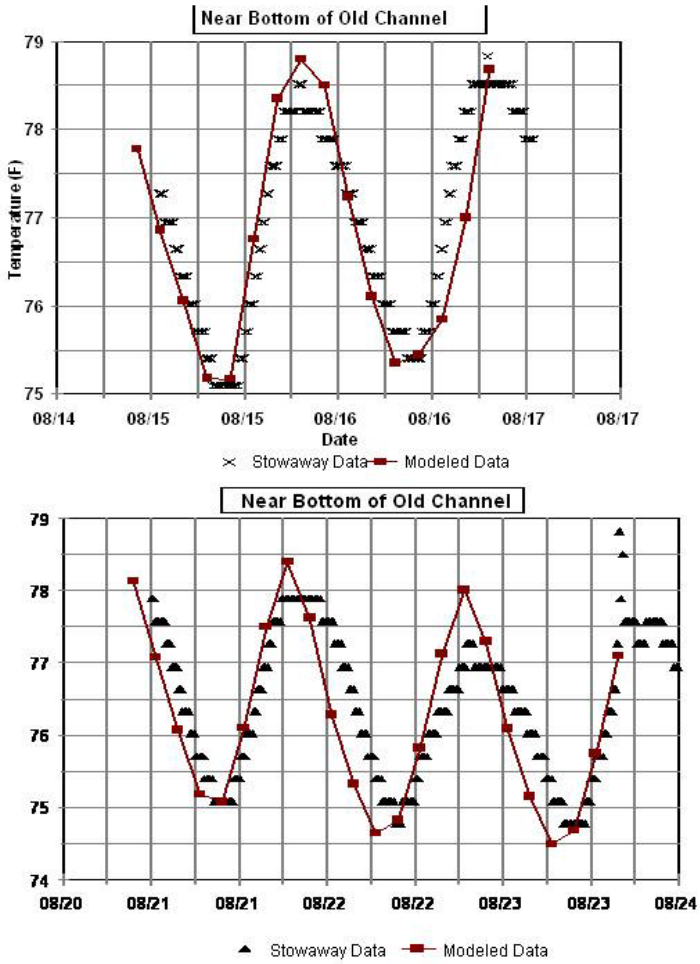


Figure 23. Calibration data for the bottom of the old channel. Run is for 48 hours. (b) Verification data for the old channel. Run is for 48 hours.

San Marcos River

The San Marcos River system was split into twenty-one separate sections based on in-reach similarities (Figure 24). Each section was divided into elements 100 feet long. Table 7 provides a listing of the twenty-one computational reaches and number of computational elements contained in each.

Boundary Conditions

Flow was input into the model in the Spring Lake slough area, main San Marcos Springs area in Spring Lake, from the A.E. Woods State Fish Hatchery and the City of San Marcos wastewater treatment plant as noted previously. An example of the linkage between a specific flow rate (110 cfs) and the assumed spring flow, spring orifice temperatures, and dissolved oxygen are provided in Table 8.

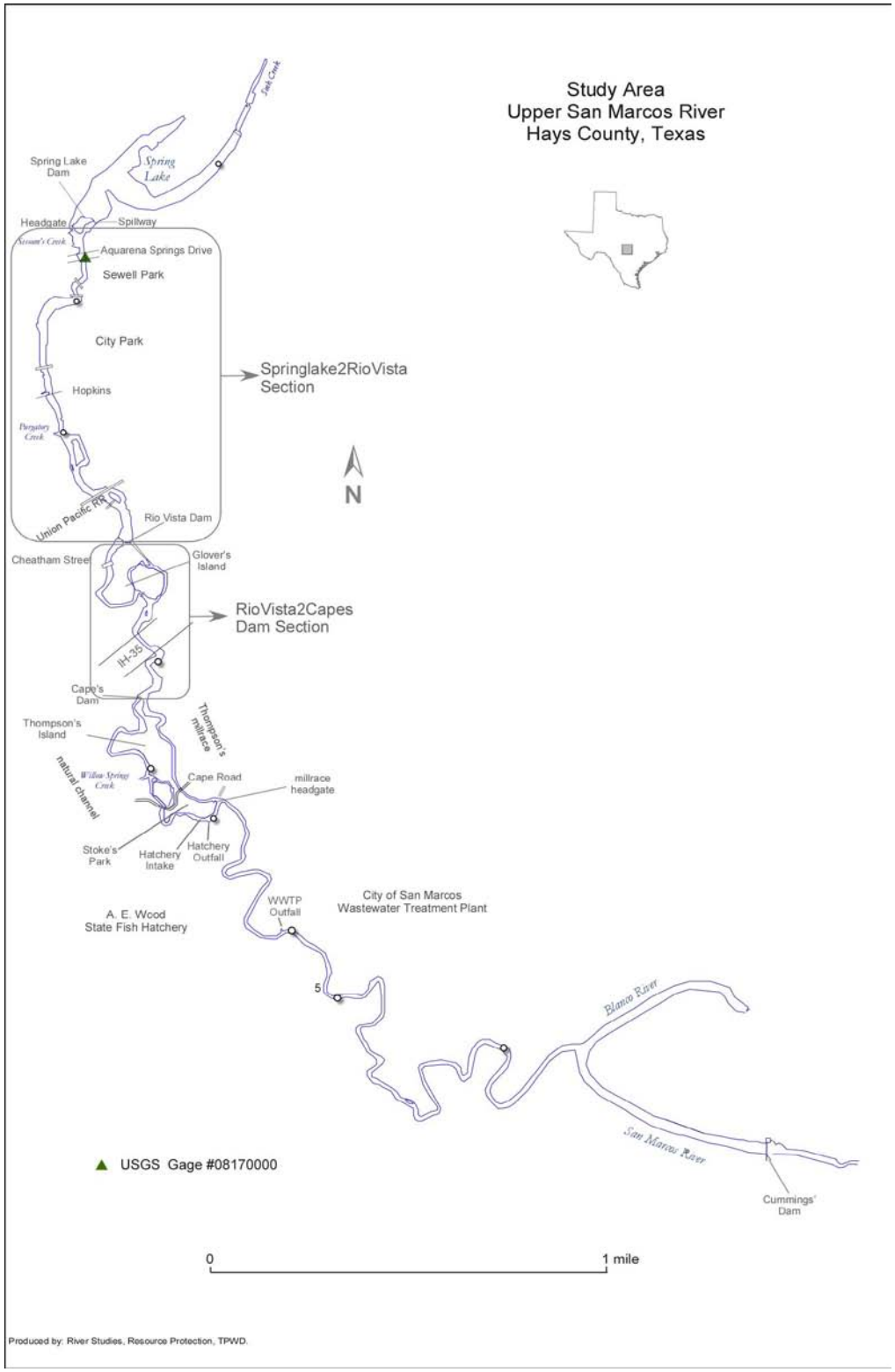


Figure 24. Water quality computational reaches for the San Marcos River with water temperature monitoring stations indicated by open circles.

Table 7. QUAL2E water quality modeling reach and segment physical descriptions for the San Marcos River.

Section	Number of Elements	Reach	End (mile)	Start (mile)
Upper Main Spring Lake	13	1	5.11	4.87
Upper Spring Lake Slough	7	2	0.61	0.47
Mid Spring Lake Slough	17	3	0.47	0.15
Lower Spring Lake Slough	8	4	0.15	0.00
Lower Spring Lake	8	5	4.87	4.72
University Drive	10	6	4.72	4.53
City Park	20	7	4.53	4.15
Above Rio Vista Dam	20	8	4.15	3.77
Below Rio Vista	18	9	3.77	3.43
Glover's Ditch	11	10	0.21	0.00
Above Cape's Dam	18	11	3.43	3.09
Below Cape's Dam	20	12	3.09	2.71
State Hatchery	17	13	2.71	2.39
Mill Race	19	14	0.36	0.00
Lower San Marcos A	6	15	2.39	2.27
Lower San Marcos B	20	16	2.27	1.89
Lower San Marcos C	20	17	1.89	1.52
Lower San Marcos D	20	18	1.52	1.14
Lower San Marcos E	20	19	1.14	0.76
Lower San Marcos F	20	20	0.76	0.38
Lower San Marcos G	20	21	0.38	0.00

Table 8. Example of boundary conditions of spatially distributed flow, temperature, and dissolved oxygen for the San Marcos River at a flow of 110 cfs.

Reach	Segment	H or Volume PL (cfs)	Notes	Cumulative Flow (cfs)	
1	1	H	Upper Spring Lake	0.5	
2	2	H	Upper Slough	0.6	
3	3	H	Glover's Ditch	2.8	
4	4	H	Mill Race Head	112.8	
Headwater Conditions					
Reach	**Segment**	**Type**	**Flow (cfs)**	**Temp (F)**	**DO (mg/L)**
1	1	Head Water	0.5	73.5	4.9
2	2	Head Water	0.1	80.5	4.9
3	3	Head Water	2.2	74.5	4.9
4	4	Head Water	110	74.2	4.9
H = Headwater; PL = Point Load					

Model Calibration and Verification

Weather data from the National Climatic Data Center for Randolph Air Force Base for the dates from October 1st, 1997 through February 28th, 1998 were used for calibrating and verifying the water quality model. USFWS stowaway temperature logger data had been gathered from nine separate locations within the San Marcos River system (Figure 24) . Data were available from September 5th, 1997 through September 29th, 1998. The two hottest two day periods for which suitable NOAA and USFWS data existed were then chosen for use in model calibration and verification for simulations of maximum daily temperatures. Only maximum daily temperatures were analyzed based on the previous modeling efforts in the Comal River system which indicated that maximum daily temperature was a better indicator of limiting thermal conditions compared to mean daily temperatures. These periods were identified as hot summer days with corresponding low San Marcos Springs flows and high state fish hatchery and City of San Marcos wastewater treatment plant input flow rates. The days chosen for calibration and verification were September 8th and 9th, 1997 and October 1st and 2nd, 1997. The maximum daily temperature in each section was the temperature used in habitat analysis.

In order to achieve a representative 24 hour temperature range, the model was calibrated, verified, and run for 48 hours with the second 24 hour period being used for temperature analysis while the first 24 hour period was used as a model spin-up period only and was not considered for actual habitat analysis. Model calibration and verification runs were re-run until modeled data matched observed hourly data to within 2EF. Figure 25 provides examples of the calibration and verification results for the City Park and Confluence with the Blanco River monitoring stations. Simulations for each flow rate was then accomplished by setting the appropriate San Marcos Springs and Sink Creek flow rates adjusted accordingly. A.E. Woods State Fish Hatchery and City of San Marcos wastewater treatment plant flows were held constant at their maximum levels of 5 MGD (75EF) and 9 MGD (78EF) respectively.

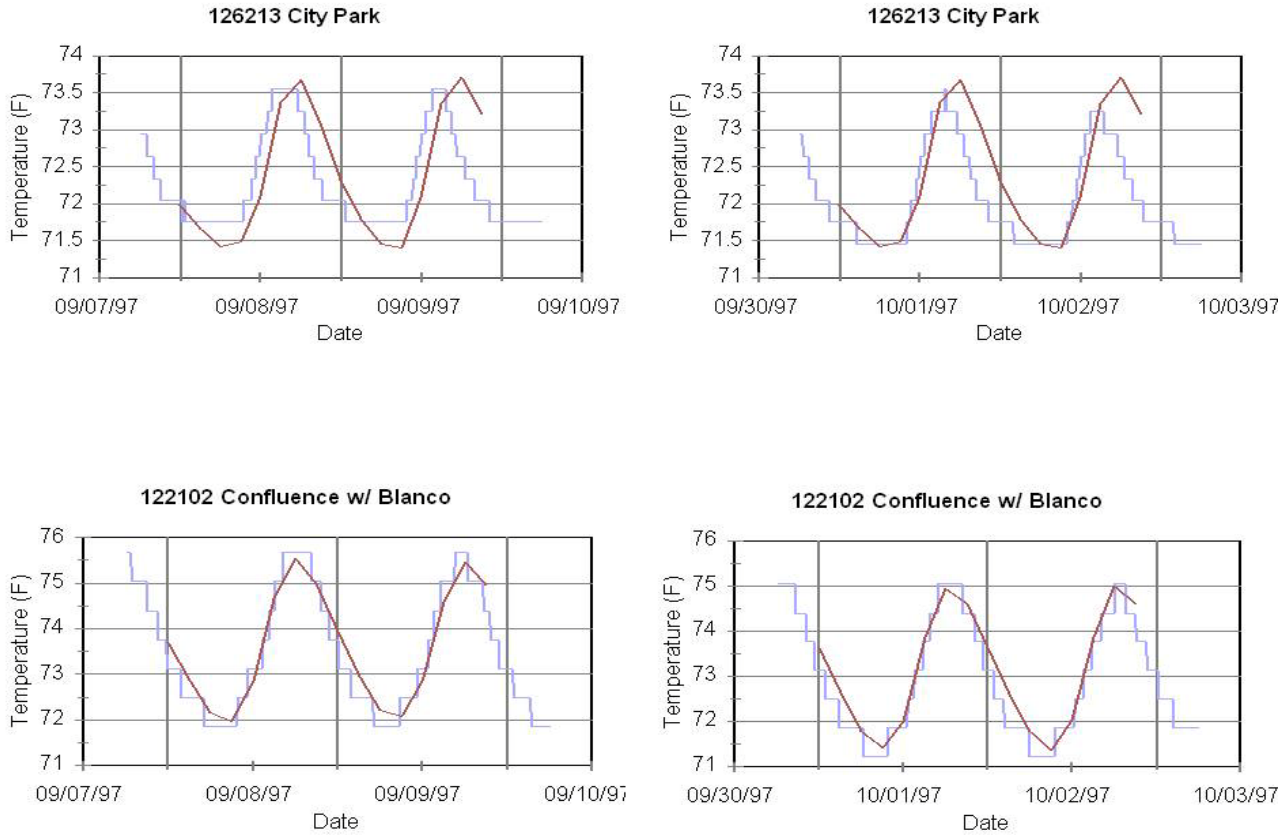


Figure 25. Examples of the water temperature model calibration and verification runs for the San Marcos River at the City Park and confluence with the Blanco River monitoring stations. Stowaway data (blue) and modeled values (red).

Habitat Suitability Curves

The original work by Hardy et al. (1998), Bartsch et al. (2000) and INSE (2004) relied on habitat suitability index relationships for depth, velocity, and vegetation type for fountain darters from collection data over a two year period in the Comal River system and additional work by Saunders et al. (2001) in the San Marcos River. The habitat suitability index curves for Texas wild rice were based on the work reported in Saunders et al. (2001). Long-term fisheries monitoring data collected by the Edwards Aquifer Authority over the past 8 years in the Comal and San Marcos River systems using the basic sampling protocol developed by Hardy et al. (1998) was utilized to develop updated habitat suitability curves for depth and velocity for fountain darters. Although additional data on vegetation use was available from the monitoring data, the vegetation curves were not modified due to incompatibility in the vegetation coding scheme used by EAA and the historical vegetation maps for both river systems. This is being addressed through the on-going vegetation mapping for both river systems that will permit use of the long-term monitoring data to update the fountain darter vegetation suitability curves. In addition, the annual Texas wild rice monitoring data collected collaboratively by the Texas Parks and Wildlife Department and USFWS were used to evaluate the existing Texas wild rice habitat suitability curves. Based on this review, the original depth and velocity habitat suitability curves for Texas wild rice were not modified.

As highlighted above in the influence diagrams, the purpose of these effort is to establish quantitative relationships between flow dependent attributes of depth, velocity, substrate, vegetation, temperature, and dissolved oxygen for target species that can be used to assess available habitat within the river systems.

The most common approach is to utilize Habitat Suitability Curves (HSC) which parametrize the relative suitability of a factor (e.g., depth) on a scale between 0.0 and 1.0 over the range of potentially useable values. These relationships, when combined with the hydraulic and water quality simulations produce relationships between flow and the quantity and quality of available habitat.

Comal Springs Riffle Beetle

The Comal Springs riffle beetle (*Heterelmis comalensis*), is a small, aquatic beetle from the family Elmidae known from Comal Springs and San Marcos Springs. It was first collected by Bosse in 1976 and was described in 1988 by Bosse et al. (1988). Adult Comal Springs riffle beetles are about 2 mm (1/10 inch) long, with females slightly larger than males. The Comal Springs riffle beetle occurs in the gravel substrate and shallow riffles in spring runs and upwelling spring orifices. Very little detailed information is available for the Comal Springs riffle beetle. In many Elmid species, larvae undergo 6-8 instars, requiring anywhere from 6 months to 3 years to complete a life cycle from egg to adult. Growth and development times can be temperature dependent and are faster at higher temperatures. In other riffle beetle species, larvae crawl out of the water to construct terrestrial pupal chambers, adults emerge and undergo a short flight period, after which they reenter the water and are incapable of further aerial activity. However, the hind wings of *Heterelmis comalensis* are short and almost certainly non-functional, making the species incapable of this mode of dispersal (Bosse et al. 1988).

Heterelmis comalensis larvae have been collected with adults in the gravel substrate of the spring headwaters and not on submerged wood as typical of most *Heterelmis* species (Brown and Barr 1988). Usual water depth in occupied habitat is 2 to 10 cm (1 to 4 inches) although the beetle may also occur in slightly deeper areas within the spring runs. Populations are reported to reach their greatest densities from February to April (Bosse et al. 1988). The Comal Springs riffle beetle has been collected from spring runs 1, 2, 3, and 6 at Comal Springs in Landa Park (Bosse et al. 1988, Barr 1993) as well as the spring orifices along the western margin of Landa Lake in the vicinity of Pecan and Spring Islands. A single specimen was also collected from San Marcos Springs (Barr 1993). *H. comalensis* may have the ability to burrow into substrate in order to avoid or tolerate environmental stress; if so, this may explain how *H. comalensis* was able to survive the drought of the 1950s, when Comal Springs ceased flowing for up to six months (Arsuffi 1993). However, genetic analysis suggests that this may have invoked a genetic bottleneck as the genetic makeup of the recovered spring run populations differ from populations associated with spring orifices within the bottom of Landa Lake.

The populations found in the higher elevation springs (spring runs 1, 2, and 3) of the Comal River system contained the lowest amount of genetic variation and contained no unique haplotypes as compared to the West Shoreline and Spring Island populations. This and the fact that the beetles are not found in the higher elevation headwater springs (spring run 4 and 5 near Blieders Creek) could be the result of beetle population reductions (due to bottleneck effects) in these areas due to historical prolonged drought conditions (Gonzales 2008).

Stagnation of water or drying of the spring runs may be limiting conditions for the Comal Springs riffle beetle. Flowing water is considered important to the respiration and therefore survival of these invertebrate species. Elmid beetles have a mass of tiny, hydrophobic (unwettable) hairs on their underside where they maintain a thin bubble of air through which gas exchange occurs. This method of respiration loses its effectiveness as the level of dissolved oxygen in the water decreases. A number of aquatic insects that use dissolved oxygen rely on flowing water to obtain oxygen from the water.

The technical team evaluated historical and existing distribution data for the Comal Springs riffle beetle and believed that given the available data, the most pragmatic modeling approach was to use the total surface area of the main spring runs (i.e., spring runs 1, 2 and 3). This was considered the most conservative approach given the fact that they have recolonized springs that have previously gone dry. The mechanism of recolonization (i.e., migration into the substrata or migration from other spring sources) is not known. Modeling for the Comal Springs riffle beetle was accomplished by use of the hydraulic model outputs within the three main spring runs of Landa Lake by summing surface areas that were at least 0.02 feet deep. The 0.02 foot depth threshold was utilized since this is the analytical default for the hydraulic models in the wetting and drying algorithm and therefore predicted depths below this value are beyond the resolution of the modeling.

Texas Wild Rice

Texas wild rice habitat suitability criteria (Hardy et al. (2000) were originally generated through examination of several papers, descriptions and existing studies. Wild rice data from TPWD monitoring data shows wild rice to occupy moderately-coarse to coarse sandy soil sites (Poole and Bowles 1996). This is in contrast to study results by Power and Fonteyn (1990) that found clay to be the preferred substrate for wild rice although Power (1990) notes that in the wild: “Most *Z. texana* is presently found in sandy/gravelly soil in the mid-channel of the San Marcos River.” Vaughan (1986) found “Soil type had a minimal effect...”.

Poole and Bowles (1996) found wild rice to occur at sites with high water clarity. They also found that salt, calcium and sulfur dioxide concentrations were higher at non-wild rice transects and hypothesized that this was due to urban and agricultural run-off effects and the City of San Marcos Wastewater treatment plant affect on water quality. Dissolved oxygen concentrations were found to be significantly different between wild rice and non-wild rice areas in TPWD data (Poole and Bowles, 1996) but both values were at oxygen saturation. Average turbidity was significantly higher for non-wild rice transects in their study and may be a factor in downstream reaches of the San Marcos River, which can become highly turbid from upstream recreation use on a daily basis during high use periods.

Poole and Bowles (1996) indicated that the wild rice observed depth 95% confidence intervals were 1.97 to 3.14 ft while stream locations with no wild rice had confidence intervals between 4.19 to 7.64 feet for data taken in May and August 1994 and January 1995. These averaged confidence interval values are taken from data sets that showed significant differences in wild rice distributions. Poole and Bowles (1996) state that, “rice transects were found to be shallower ($\leq$ 3.2 feet) and with considerably faster current velocities compared to non-rice transects where the water depth was greater ($\geq$5.6 feet) and where the current velocities were slower. Vaughan (1986) found individual wild rice stands grown in depths greater than 0.66 feet were significantly larger ($P<0.05$) than those in depths less than 0.66 feet. Silveus (1933) describes wild rice as growing in water from one to seven feet deep.

Poole and Bowles (1996) report that average wild rice stand velocity 95% confidence intervals were 0.94 ft/s to 2.32 ft/s while non-wild rice transects had average 95% confidence intervals of 0.20 ft/s to 0.73 ft/s for data taken in May and August 1994 and January 1995. Non-wild rice areas clearly had lower velocities than wild rice areas. Silveus (1933) describes wild rice habitat as growing "often in swiftly running currents."

The technical team reviewed the existing wild rice habitat suitability curves for depth and velocity used in previous studies as well as the existing monitoring data collected over the past decade. This included and examination of the location of persistent wild rice stands within the San Marcos system that were overlaid on the hydraulic model solutions at different flow rates indicative of the long term flow characteristics during the last decade. Based on this review and discussions, habitat suitability curves were revised for use in modeling physical habitat in the San Marcos River. Figure 26 shows the depth suitability curve, Figure 27 shows the velocity suitability curve and Table 9 provides the corresponding HSC values used in the current analysis. Note that the curve sets labeled as 'USFWS-USU' were used in the Bartsch et al. (2000) study, while the curves labeled 'TPW' were used in the current report.

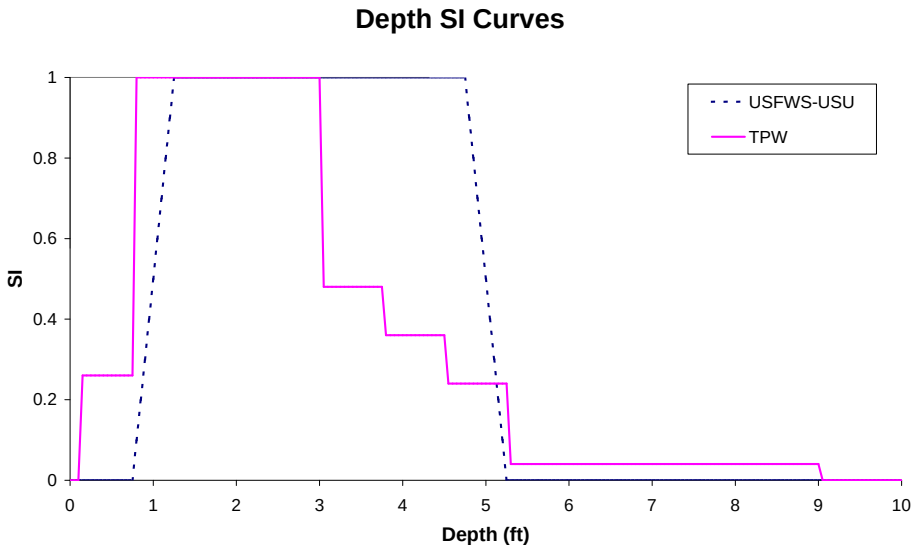


Figure 26. Texas wild rice depth habitat suitability. See text for explanation of curve legends.

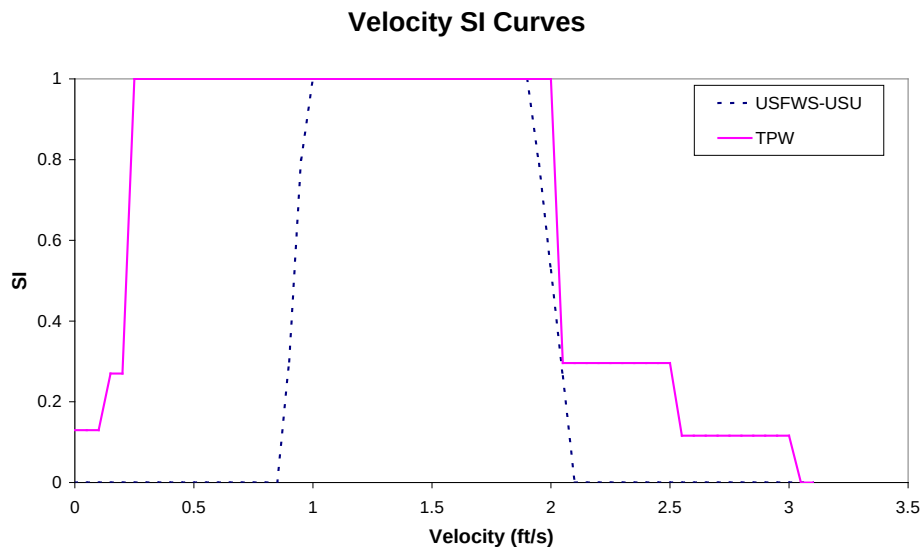


Figure 27. Texas wild rice velocity habitat suitability. See text for explanation of curve legends.

Table 9. HSC values for depth and velocity for Texas wild rice used in the current study. These values correspond to the TPW curves in Figures 26 and 27.

Depth (ft)	SI	Velocity (ft/s)	SI
0.00	0.00	0.00	0.13
0.10	0.00	0.10	0.13
0.15	0.26	0.15	0.27
0.75	0.26	0.20	0.27
0.80	1.00	0.25	1.00
3.00	1.00	2.00	1.00
3.05	0.48	2.05	0.30
3.75	0.48	2.50	0.30
3.80	0.36	2.55	0.12
4.50	0.36	3.00	0.12
4.55	0.24	3.05	0.00
5.25	0.24		
5.30	0.04		
9.00	0.04		
9.05	0.00		

The technical team also reviewed additional data on other factors related to the distribution and health of Texas wild rice. In particular, it noted that Texas wild rice appears to be excluded from stream sections with high values of canopy cover or under structures such as bridges. A relationship between Texas wild rice suitability and the percent of canopy cover was developed but the spatial distribution of these data is not available for the San Marcos River. Field work to obtain this data is underway as part of on-going studies and will be incorporated into future modeling efforts supporting the development of the HCP.

Fountain Darters

Previous modeling efforts for fountain darters reported in Hardy et al. (1998), Bartsch et al. (2000), INSE (2004), and Saunders et al. (2001) relied on habitat suitability relationships for depth, velocity, and vegetation types derived from data contained in the USFWS fountain darter biological sampling database developed as part of those initial studies. A randomized sampling protocol was utilized using a drop net structure based on a 3.2 foot sample grid derived from the hydrodynamic model computational mesh (see Hardy et al. 1998). This basic approach was subsequently adopted by monitoring activities supported by the Edward Aquifer Authority (EAA) (e.g., BioWest, 2008a).

The original studies based on drop net sampling in conjunction with scuba observations showed that fountain dater depth use increased with increasing depth and reached a maximum at approximately 2 feet. Fountain darter use of depths less than 2 feet showed a rapid decline is numbers. Scuba observations showed frequent use in Landa Lake at depths in excess of 10 feet. This work also showed that fountain darters are basically associated with boundary layer hydraulic conditions (i.e., near bottom or in velocity shelters). There is a strong negative correlation between velocity and fountain darter habitat use. Maximum densities are most often associated with near zero velocity profiles and rapidly decline as velocities increase. Very few observations are made at velocities in excess of 1.0 feet/second and are basically excluded at velocities over 2.0 feet/second.

Although fountain darters can reproduce year round (Schenck, 1975), research by Brandt et al. (1993), Bonner et al. (1998),and McDonald et al. (2007) show temperature impacts on disruption of fountain darter life stages and underscores that temperature as a macro habitat variable is an important component of darter habitat. These studies have shown that at temperatures between 77°F and 78.8°F, fountain darter egg and larval survival are reduced. It is also known that egg and larval production over 21 days are negatively impacted when daily temperatures reach these levels even if temperatures fall within their optimum spawning range during the night. Thus, 2–3°F water temperature increase above 75.2°F decreases fecundity and natality rates of the fountain darter.

A lower suitable temperature cutoff of 53EF is based on data from Bonner et al. (1998). Optimal temperature ranges occur above this value and reach optimal conditions at approximately 62.6EF. This lower temperature threshold for optimal conditions is used since 62.6EF is the lowest temperature at which larval production was unaffected. From 62.6EF to 73.4EF, no adverse effects on darters are known, based on the available literature. The percent hatch was lower at 77EF than at temperatures of 73.4EF (Bonner et al. 1998). The midpoint of these two temperatures, 75.2EF, was chosen as the maximum temperature with a habitat suitability of 1.0. A reduction in temperature suitability begins near 77EF and totally unsuitable temperatures are assumed to be reached at approximately 84.4EF. This value was derived based on the larval LC50 of 89.6EF by invoking a conservative buffer of approximate 4EF.

Previous modeling efforts for fountain darters reported in Hardy et al. (1998), Bartsch et al. (2000), INSE (2004), and Saunders et al. (2001) as well as the continued critical period monitoring supported by the EAA shows a strong correlation between fountain darter utilization of specific vegetation types. These efforts have generally supported the original work by Schenck and Whiteside (1976) which show

the fountain darters prefer *Rhyzoclonium* sp., *Hydrilla* sp., and *Ludwigia* sp. Plant species less preferred but still containing fountain darters are *Potamogeton* sp., *Vallisneria* sp., and *Zizania* sp.. Schenck and Whiteside's (1976) sampled areas with no vegetation, and these areas were described as not containing any fountain darters. However, diving observations in the Comal River by INSE research staff has documented the presence of fountain darters in non-vegetated areas, albeit at lower densities.

Given that over a decade of new sampling data was available, the technical team conducted a multivariate analysis of the available data to provide updated habitat suitability relationships for fountain darters. Their analysis found significant correlations between depth, velocity, height of vegetation, and vegetation type habitat use by fountain darters, confirming the use of these variables in the original modeling work. Although vegetation height was found to be significant, these data were not available for all vegetation polygons within the Comal and San Marcos River systems and therefore were excluded from the habitat modeling in the original work and the results reported here.

Based on this analysis, discussions, and temperature related research highlighted above, the habitat suitability curves were revised for use in modeling physical habitat in the Comal and San Marcos River systems. Figure 28 shows the depth suitability curves from the original work of Bartsch et al. (2000) and the revised curve based on the existing analyses of available data, Figure 29 shows the velocity suitability curve from the original work of Bartsch et al. (2000) and the revised curve based on the existing analyses of available data, Figure 30 shows the vegetation curve, and Figure 31 shows the temperature curve. Table 10 provides the corresponding HSC values for the revised suitability curves. It should be noted that the vegetation suitability curve utilized in all the simulations was based on the original curve developed by Bartsch et al. (2000) rather than the updated curve based on the analysis of the updated data sets. This was due to incompatibility of vegetation types delineated from the original vegetation mapping and different vegetation coding used in the EAS data sets. This will be reconciled during the revised modeling currently underway for both the Comal and San Marcos Rivers using the updated vegetation mapping for both systems.

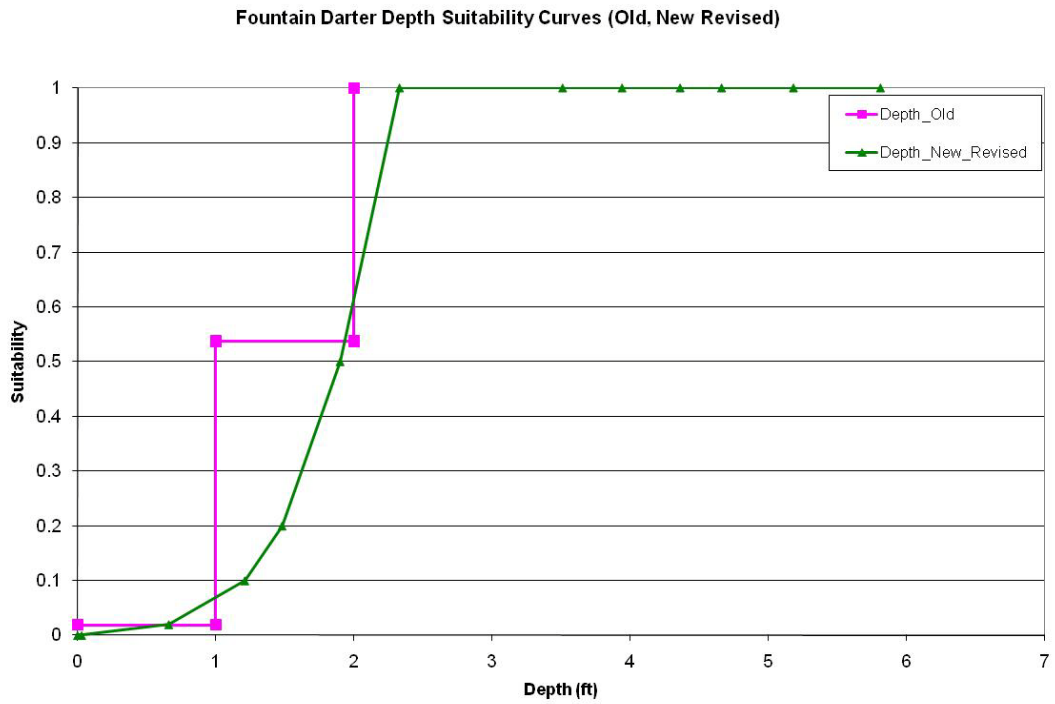


Figure 28. Fountain darter depth habitat suitability curves (Depth_Old is Bartsch el al., (2000) and Depth_New_Revised is derived from the analysis of the EAA monitoring data).

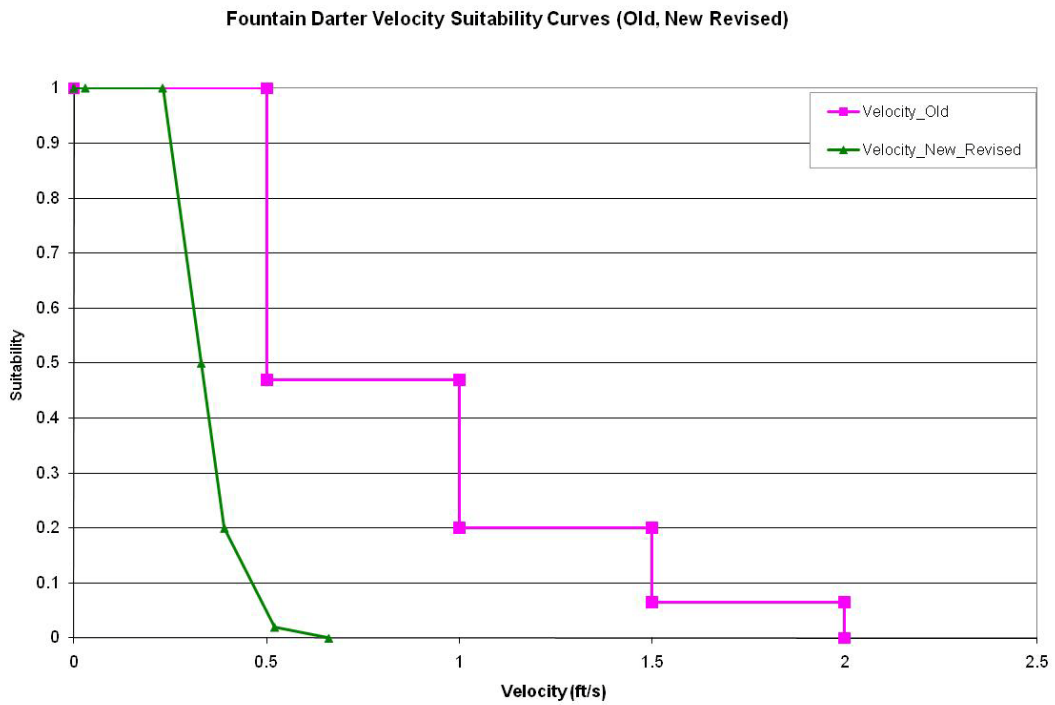


Figure 29. Fountain darter velocity habitat suitability (Velocity_Old is Bartsch el al., (2000) and Velocity_New_Revised is derived from the analysis of the EAA monitoring data).

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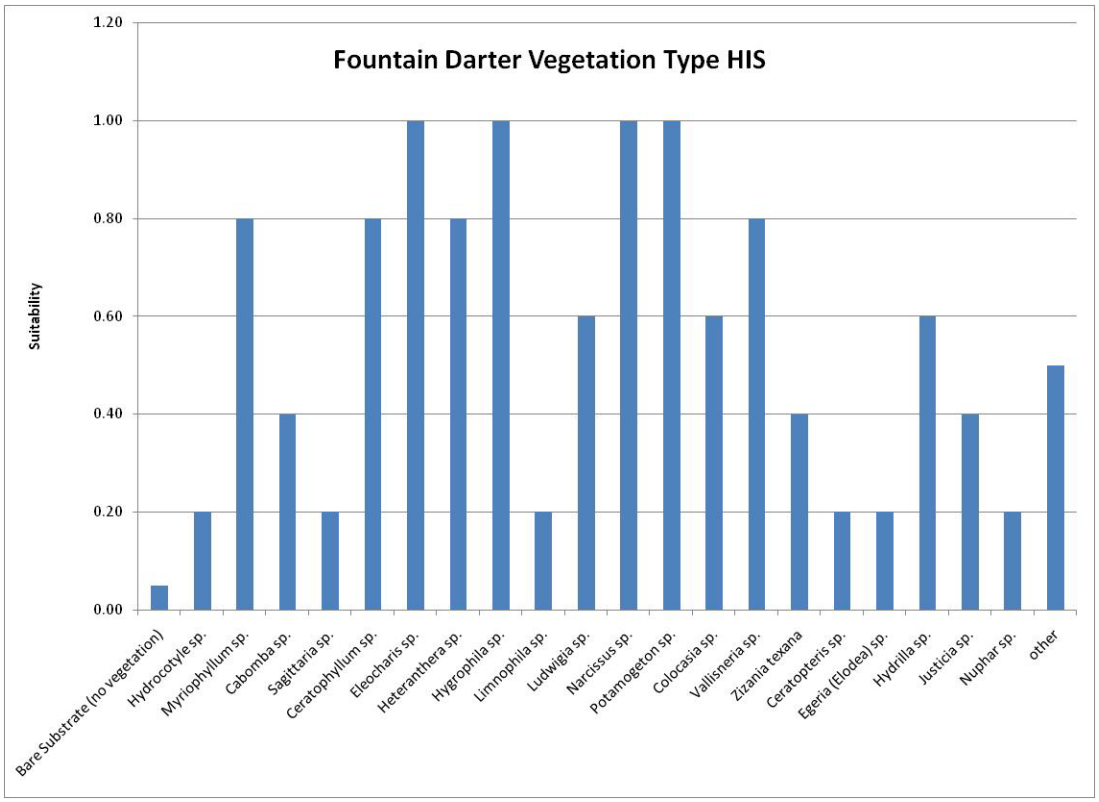


Figure 30. Fountain darter vegetation type habitat suitability.

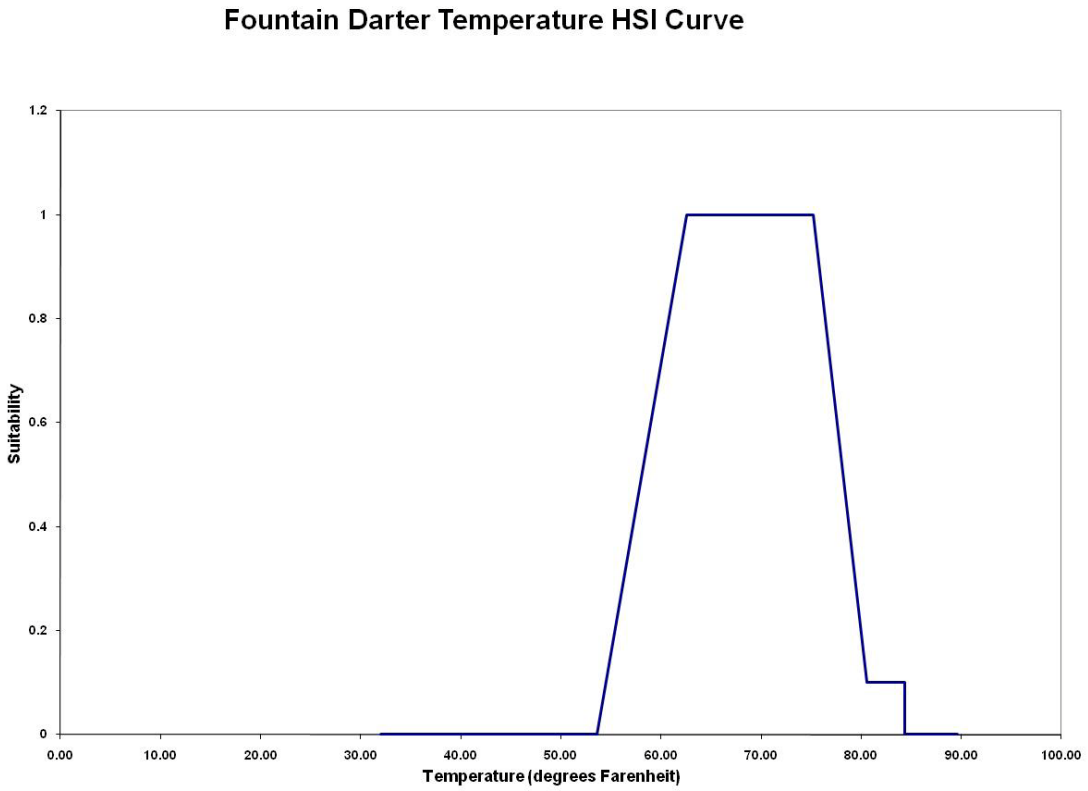


Figure 31. Fountain darter temperature habitat suitability.

Table 10. HSC values for depth, velocity, vegetation type, and temperature for Texas wild rice.

Depth ft	SI	Velocity ft/s	SI	Vegetation Type	SI
0.00	0.00	0.00	1.00	Bare Substrate (no vegetation)	0.05
0.03	0.00	0.03	1.00	Hydrocotyle sp.	0.20
0.66	0.02	0.23	1.00	Myriophyllum sp.	0.80
1.21	0.10	0.33	0.50	Cabomba sp.	0.40
1.48	0.20	0.39	0.20	Sagittaria sp.	0.20
1.90	0.50	0.52	0.02	Ceratophyllum sp.	0.80
2.33	1.00	0.66	0.00	Eleocharis sp.	1.00
3.51	1.00			Heteranthera sp.	0.80
3.94	0.50			Hygrophila sp.	1.00
4.36	0.20			Limnophila sp.	0.20
4.66	0.10			Ludwigia sp.	0.60
5.18	0.02			Narcissus sp.	1.00
5.81	0.00			Potamogeton sp.	1.00
				Colocasia sp.	0.60
	Temperature F	SI		Vallisneria sp.	0.80
	32.00	0.00		Zizania texana	0.40
	53.60	0.00		Ceratopteris sp.	0.20
	62.60	1.00		Egeria (Elodea) sp.	0.20
	75.20	1.00		Hydrilla sp.	0.60
	80.60	0.10		Justicia sp.	0.40
	84.38	0.10		Nuphar sp.	0.20
	84.39	0.00		other	0.50

Physical Habitat Modeling

The Comal and San Marcos Rivers were both modeled using two-dimensional based physical habitat modeling. This was accomplished by first assigning to each node on the computational mesh, the associated vegetation type using GIS. For the purposes of physical habitat modeling, the nodes were coded with the vegetation type, rather than an assigned roughness value used in the hydrodynamic model in order to use the fountain darter vegetation type habitat suitability curve. It was assumed that the vegetation/substrate characteristics did not change as a function of simulated flow rate. For each modeled flow, the hydrodynamic model generates the depth and velocity at each node. As noted previously, the hydrodynamic model utilized vegetation specific velocity equations that permitted the adjustment of the predicted mean column velocity by vegetation type when modeling fountain darter habitat. In the case of fountain darters, the velocity at six inches (15 cm) above the bottom was also evaluated in the simulation of available habitat. Secondly, the water temperatures for each section of stream derived from the QUAL2E modeling were overlain on the computational mesh and each node to assign its respective temperature. Inclusion of temperature was specific to fountain darter assessments.

Comal Springs Riffle Beetle Habitat Equation

As noted previously, the technical team believes that the most conservative way to represent physical habitat for the Comal Springs riffle beetle was total surface area within each of the main spring runs in Landa Lake. This was accomplished by the using a binary depth suitability curve evaluated at each node in the computational mesh within only the main spring runs of Landa Lake. This can be represented by:

$$\text{Suitability} = 1.0 \text{ for Depths} < 0.02 \text{ feet; otherwise Suitability} = 0.0.$$

This binary equation was applied for all simulated flow rates within each main spring run and the total surface area of all suitable cells were summed to derive a total habitat area as a function of flow relationship. The results were then summed across all spring runs to derive a total habitat versus flow relationship.

Texas Wild Rice Habitat Equation

Physical habitat for Texas wild rice was computed at each computational node using the depth and velocity habitat criteria in a simple multiplicative manner as follows:

$$\text{Suitability} = \text{Depth}_{SI} * \text{Velocity}_{SI}$$

where the Depth_{SI} and Velocity_{SI} are computed by taking their respective values for the hydraulic simulation results at a node and using a simple linear interpolation between the defined suitability values from the habitat suitability index curves.

The suitability value for the computational cell was then used to multiply the cell area generating a Weighted Usable Area (WUA) for that cell. At a given simulated discharge, all WUA values were summed within a specific computational reach to generate a total at the reach level. Then, for each discharge, the values were summed across all computational reaches to generate a total for the San Marcos River at that simulated discharge.

Fountain Darter Habitat Equation

Physical habitat was computed for fountain darters using four parameters, namely depth, velocity, vegetation type, and temperature. In the case of velocities, the mean column velocity and velocity at 6 inches (15 cm) above the bottom were used in the calculation of suitable habitat for separate analysis at each modeled flow rate. A simple multiplicative aggregation was used as follows:

$$\text{Suitability} = \text{Depth}_{SI} * \text{Velocity}_{SI} * \text{Vegetation\_Type}_{SI} * \text{Temperature}_{SI}$$

where the respective component suitability values are derived from a simple linear interpolation between the the component habitat suitability relationships given these attributes at a computational cell. The same procedures for calculation of WUA at the cell, computational reach and system wide values were used as described for Texas wild rice above.

Modeling Results and Discussion

Physical habitat simulation results are prepared in several different formats as requested by the technical committee. The most detail is provided by screen captures of the contoured depths and velocities for each flow rate simulated within each of the computational segments. In addition, the

combined suitability for each of the target species is also provided in these formats. Summary tables and figures are also provided for the WUA versus discharge relationships for the respective target species. In some instances as noted below additional visualization of results are provided based on a specific format when requested by the technical team. Given the extensive nature of the results, summaries and illustrative examples are provided in the body of the report, while the complete results are provided in electronic form within appendices as noted.

Comal

Temperature

Modeled temperature results for the old channel are shown in Figure 32. The old channel is a heterogeneous stretch of stream, ranging from super critical flow in narrow sections to subcritical, slow moving pools of water. In general, the flow behavior can be described as that of a small stream; however at low flow rates, the surface area to volume ratio increases sharply, causing larger temperature increases, such as those shown in Figure 32. The head of the old channel is shown on the left, at mile 2.8. Flow goes down the old channel to mile 1.2, at which point it rejoins the new channel. Consistent temperature increases are evident throughout the old channel at all five flow rates. At total spring flow rates of 150 and 300 cfs (50 and 75 cfs respectively flowing down the old channel), the old channel stream temperatures remain below 78°F. These results suggest that detrimental thermal conditions exist in the vicinity of mile 1.95 (i.e., model segment 65), for the 60 cfs flow rate and mile ~2.25 (i.e. model segment 58) at a 30 cfs flow rate. Thus, strongly suggests that lowering the flow rate to 60 or 30 cfs would reduce suitable darter habitat in the old channel due to temperature limitations. Flow rates modeled within the old channel indicate that 50 cfs maintains water temperatures below 78ºF, which is close to the upper critical thermal range.

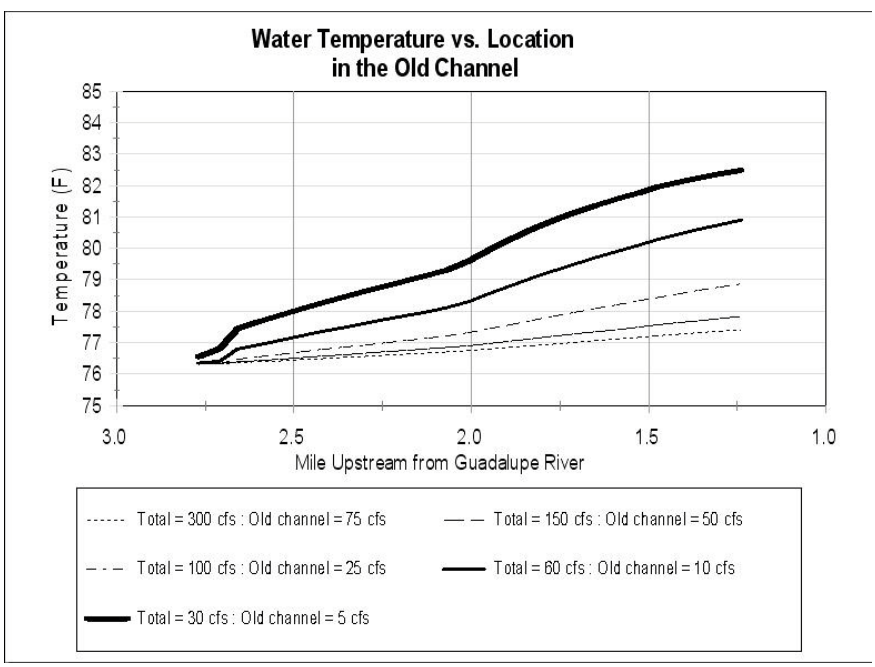


Figure 32. Simulated longitudinal temperature profile for modeled flow rate scenarios in the old channel. Flow rates shown represent overall spring flow rates for each scenario.

Temperature results are shown in Figure 33 for Landa Lake, the new channel below Landa Lake, and the Comal River proper downstream to the confluence with the Guadalupe River. Mile upstream from the confluence with the Guadalupe River is plotted on the horizontal axis with the head of Landa Lake being on the left side of the graph and the confluence with the Guadalupe on the right. The new channel runs from mile 0.0 to mile 2.3, while Landa Lake runs from mile 2.3 to mile 3.4.

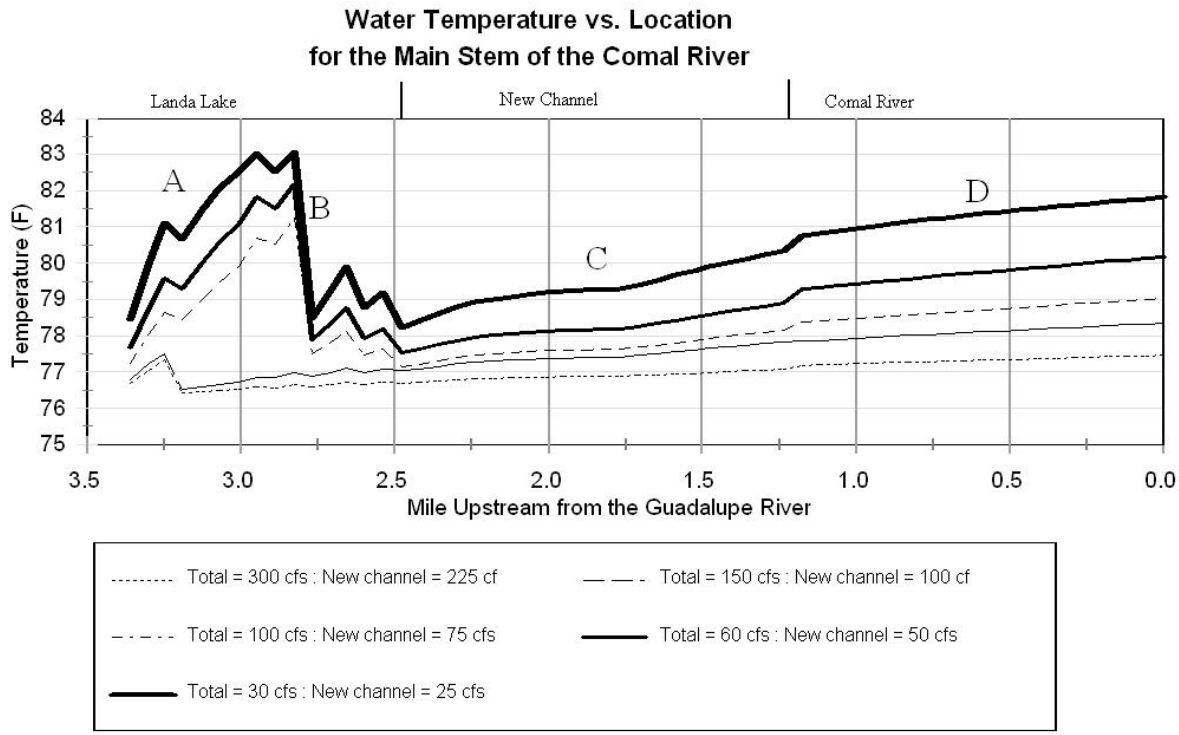


Figure 33. Simulated longitudinal temperature profile for Landa Lake and the new channel for modeled flow split scenarios. Flow rates shown are total Comal River flow rates. The letter 'A' marks significant spring locations in upper Landa Lake, the letter 'B' marks the main spring runs, the letter 'C' marks the new channel, and the letter 'D' marks the lower Comal River below Clemens Dam.

A general warming trend is noticeable for all flow rates, but its magnitude is minimized at larger total flow rates of 150 to 300 cfs. Once the main spring runs and the secondary/smaller spring flows enter the system, they cool overall river temperature. The variability in river temperature below ‘B’ in Figure 33 is the effect of numerous medium sized spring flows entering the system immediately upstream of the main spring runs (i.e., spring runs 1,2, and 3) within Landa Lake, which effectively lowers the temperature.

At the upper end of Landa Lake the effect of lowering flow rates on water temperature is quite noticeable. Increased temperatures are evident for flow rates of 30, 60 and 100 cfs. The upper temperature threshold is reached in a progressively upstream location as flow rates drop from 150, 100, 60 and 30 cfs (i.e., at model segments 10, 7 and 1 respectively). This would potentially affect darter reproduction from a temperature perspective in Landa Lake above the main spring runs as flows diminish. At present, adequate information or knowledge of the effects of lower flows in conjunction with higher summer temperatures on keystone species of the Comal River aquatic community such as vegetation or macrocrustaceans is not available for evaluation.

At the higher flow rates of 150 and 300 cfs, river velocity increases, lowering retention time, and holding down water temperatures. In reference to fountain darter reproduction, temperature is not a limiting habitat criterion at 300 cfs. At 150 cfs, the lowest 0.7 miles of the river is estimated to exceed 78ºF, which may affect darter reproduction. The break at the end of segment 'C' in Figure 33 is due to the junction of the old and new channels. Warmer water from the old channel rejoins the new channel at this point, causing the slight jump in temperature.

The 30 cfs flow rate scenario indicates that the upper temperature threshold would occur at mile 1.42 (i.e., model segment 38), while at the 60 cfs flow rate, it would occur at river mile 0.24 or model segment 87. The results indicated that for the 30 cfs scenario, virtually all habitat areas would exceed this potential limiting condition, and for the 60 cfs flow scenario, potential thermally limiting conditions to reproduction would occur by mile 2.25. These results indicate that as flows drop below 300 cfs, potential temperature limitations would begin to propagate downstream from the upper sections in Landa Lake and in an upstream direction in the lower Comal River as a function of decreasing flow rates.

It is evident from Figures 32 and 33 that reducing the flow rate causes temperatures in the system to increase during late summer simulated conditions. Water temperature also increases in a downstream direction due to decreased velocities and increased retention and travel times. Retention time is increased further due to the large number of control structures in the system and water surface elevation control practices.

Dissolved Oxygen

DO concentration modeling results are shown in Figures 34 and 35. DO values are generally higher than 6 mg/L, which are attributed to reaeration within the system primarily from turbulence associated with the hydraulic structures. It is anticipated that within Landa Lake, the upper sections of the new channel, and the old channel downstream to the water park would likely have high DO concentrations during the day due to the large amounts of aquatic vegetation. This may also result in depressed night time DO concentrations under low flow conditions, especially if a large amount of the plant community experience die offs under sustained low flow conditions.

A preliminary evaluation of the diel fluctuations at night due to the high density of aquatic vegetation to assess DO concentrations was evaluated based on unpublished data collected by USGS in Landa Lake in a large *Vallisneria sp* bed. These data showed that low DO concentrations can occur near the stream bed in these vegetation stands even during moderate flow rates. The results suggest that at very low flow rates and the associated higher retention times in Landa Lake with high vegetation densities may impose DO limitations based on this preliminary data set.

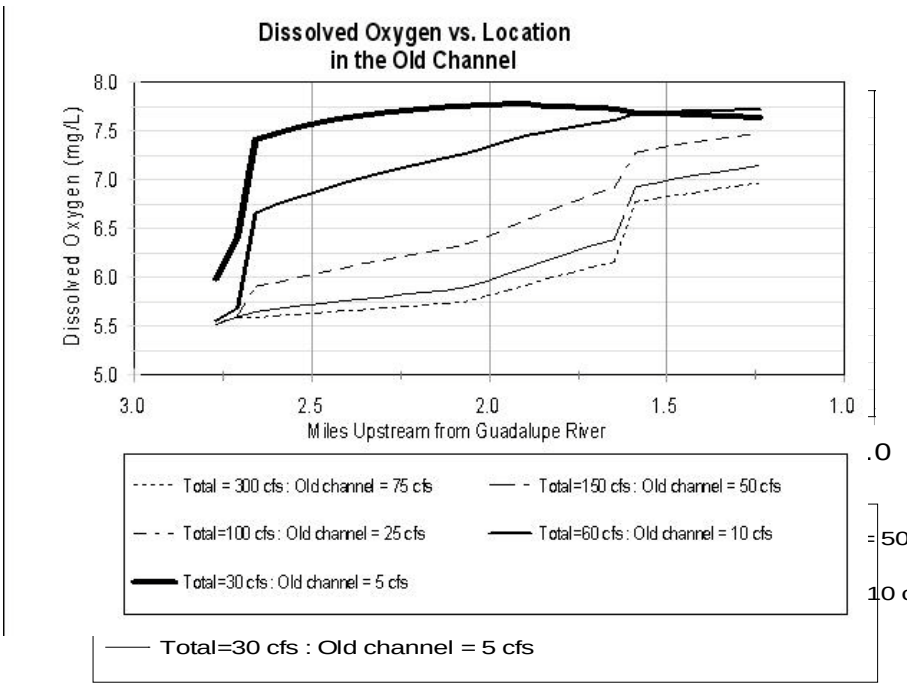


Figure 34. Dissolved oxygen concentrations plotted against mile upstream from the end of the old channel.

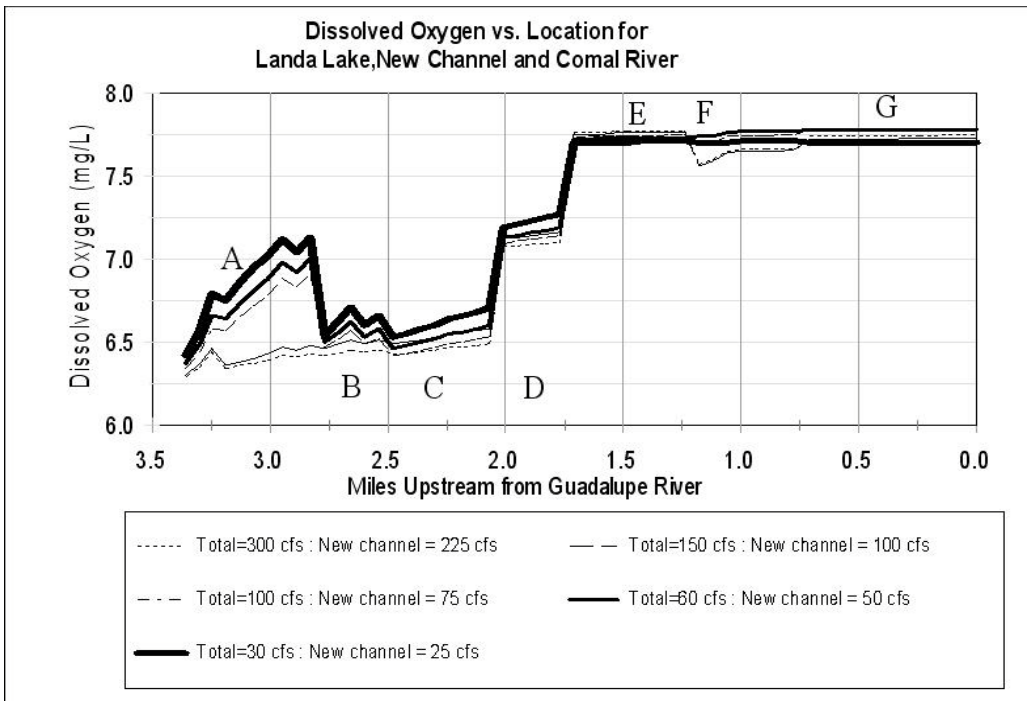


Figure 35. Dissolved oxygen concentration plotted against mile upstream from the end of the confluence with the Guadalupe River. See text for legend explanations.

Figure 34 reveals several patterns for DO concentrations in the old channel. At flow rates of 100, 150 and 300 cfs the DO shows a gradual upward trend with a jump in DO levels near mile 1.6. This jump is due to channel configuration, which we call the 'mixmaster,' a diversion that has a significant reaeration effect. At a total flow rate of 60 cfs (old channel flow of 10 cfs), DO concentration rises quite rapidly due to a higher surface area/volume ratio and is near saturation concentrations and therefore no dramatic increase is seen at the mixmaster location. At the total 30 cfs flow rate (old channel flow of 5 cfs), DO concentrations rise rapidly at the upper end of the old channel and remain high until higher water temperatures begin to lower the DO saturation level.

Figure 35 shows several discontinuities in DO concentrations in Landa Lake and the new channel. The large jumps are all due to dam reaeration. Initially, DO concentrations rise over section A for flow rates of 30, 60 and 100 cfs. This reaeration is due to the large surface area to volume ratio of upper Landa Lake at the flow rates evaluated (i.e., 30, 60 and 100 cfs). Section B in Figure 35 shows rising DO concentrations tempered by spring input DO levels. Comal Spring water is groundwater with low DO concentrations typically around 4.5 mg/L. The effects of the lower DO concentrations of the spring flows, however, is quickly attenuated within the system.

At the beginning of Section C, the main springs join Landa Lake, causing the DO concentration to drop due to the spring water's low groundwater DO concentrations. The jump at the end of Section C is due to the park office weir overfall while the jump at the end of section D is due to the power plant pool outfall. The last discontinuity in DO levels is shown at the beginning of Section F, due to the influence of the DO concentrations from the old channel, as previously discussed

Note that the above model results were run without the effects of oxygen demanding components (e.g., sediment oxygen demand or plant respiration) due to lack of such calibration data. Inclusion of these components, especially in the heavily vegetated and organic mud deposits of Landa Lake and the old channel, would likely result in much lower daily DO concentrations due to diel DO swings. However, the results do match calibration data at sample locations with the caveat that for the old channel only two such sample locations existed. For each calibration time period, only one of these locations was actively monitored. Due to the observed field values of DO, it was not felt that DO was a limiting factor and it was not used in subsequent habitat analysis.

Comal Springs Riffle Beetle

The analysis of Comal Springs riffle beetle relied on a simple calculation of wetted surface area with depths greater than 0.02 feet. The analysis showed no change in total surface area at total Comal River flows between 300 and 150 cfs and then a linear reduction in available habitat below this flow magnitude. Additional simulations were run based on criteria developed from collection data on riffle beetles in the main spring runs as follows as an alternative to the surface area analysis.

Comal Springs riffle beetle sampling was undertaken in July and October 1993 and in January 1994 within spring runs 1, 2, and 3. The data were collected using a modified random sampling technique in each of the four spring runs. The spring runs were split into upper, middle and lower sections. The number of cells randomly selected within each section corresponded to a certain percentage of the area in that section in relation to areas of other spring run sections. For example, more cells were selected in wide runs than in narrow runs, due to differences in total surface area. Selections were aided by a randomized listing of cells on spatially explicit maps for each spring run. During the selection process, any selected cell sharing a side with a previously selected cell was discarded and a replacement cell randomly selected (i.e., for a given sampling round, no sampling was done in neighboring cells). In

each cell, the following data were collected: spring run number, strata (section), cell number, date, collector, start and end times, method of collection, turbidity, percentage terrestrial vegetation cover, dominant and subdominant aquatic vegetation, organic debris type, depth and velocity, substrate codes, and miscellaneous notes and drawings.

Sampling cells were 3.2 square feet areas. The area was sampled by placing a 3.2 foot square PVC frame to delineate the sampling area. Sampling was by kick net method and consisted of stirring the gravel substrate with a garden claw and capturing the debris flowing into a 12x18 inch Wildco stream drift net with 363 micron mesh. Large rocks in the sampling area were lightly scrubbed by hand. Samples were transferred into quart jars with 80% isopropyl alcohol for sorting in the lab. Samples were sorted individually and numbers of adult beetles, larvae and other species were counted and recorded.

Based on analysis of the data, the potentially suitable habitat for the riffle beetle was restricted to the main spring runs in water depths of up to 2.0 ft and velocities of up to 2.0 ft/sec. Simulation results are shown in Figure 36. Useable beetle habitat area varies directly with discharge as the wetted areas containing suitable combinations of depth and velocity within the channels expand or contract. Under low discharge conditions (< 60-100 cfs) the main spring runs 1 and 2 may cease to flow altogether while spring run 3 decreases but flow persists, resulting in a total loss of useable beetle habitat. Spring run 1 also loses useable area at the lowest flow rates, but remains non-zero at the lowest simulated discharge. The combined useable areas for all spring runs show the greatest rate of decline around 100-150 cfs.

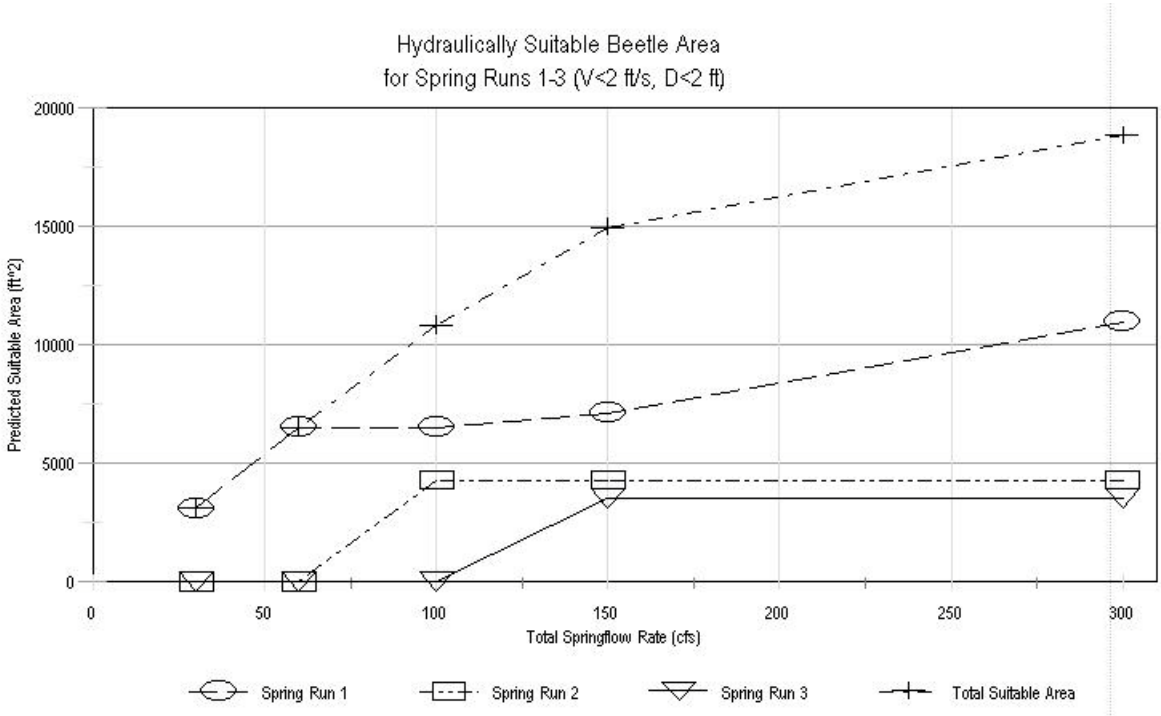


Figure 36. Simulated Comal Springs riffle beetle habitat based on depth and velocity criteria within spring runs 1, 2, and 3.

Spring run flows in the main spring runs of Landa Lake cease to flow during the drought of the early 1950s for approximately five months. In addition, although cessation of spring flows have occurred several times subsequently, Comal Springs riffle beetles have recolonized spring runs. One hypothesis is that residual populations were maintained in spring orifices in the deepest parts of Landa Lake or alternatively migrated into subsurface refugia (Bowles et al. 2002; BioWest, 2002). Laboratory studies reported in BioWest (2002) showed that Comal Springs riffle beetles responded toward spring upwelling and responded to the direction and intensity of shifts in spring flow location. This would appear to support the idea that the Comal Springs riffle beetles migrated downward in the substratum during period of loss of surface flow within springs runs. Similar findings have been reported for other related taxa in a number of systems (see BioWest, 2002). Although spring runs have been recolonized repeatedly after drying events, data on the genetic diversity between different spring runs and Landa Lake populations suggest that these events may have triggered a shift in the genetics of Comal Springs riffle beetles in spring run 1 (Gonzales 2008). The most conservative approach to long term protection of this species would be to maintain surface flows in the various spring runs of Landa Lake. This would have the added benefit or maintain flow conditions that would benefit other aquatic resources such as the fountain darter.

Fountain Darter

System-Wide Physical Habitat Using Mean Daily Temperatures

Physical habitat simulations based on system wide mean daily temperatures within the Comal River are shown in Figure 37 (See Table 1 for defined flow splits between the new and old channels) based on the Bartsch et al. (2000) suitability curves for fountain darters (see Figures 28 and 29). These results indicate that the total useable area for fountain darters shows a regular and consistent pattern for each of the five discharge scenarios. The highest discharge scenario yielded the maximum useable area for the darter and habitat area remained high at simulated discharges of 150 cfs or higher. As the total simulated discharge decreased below 150 cfs, useable habitat area declined in a non-linear manner, reaching a minimum at 30 cfs, the lowest total flow simulated. The largest proportion (50-60%) of darter habitat was found within Landa Lake under all flow scenarios. The old channel provided slightly more habitat than the new channel under most flow conditions. The main spring runs also provided a small percentage of useable habitat area, although these areas are not known to be highly utilized by darters.

The principal reason for habitat decline under lower flow rates was temperature. In general, temperature in the Comal River System increased as water traveled from the spring origins down to the confluence of the Guadalupe River. The rate of increase in temperature was driven by the difference in water and air temperature, combined with the time of travel of the water through the system. As flows declined, travel times increased resulting in higher water temperatures lower in the system. When the total discharge reached 30-60 cfs, the temperatures in the system had become potentially restrictive to darter habitat (i.e., area with less suitable conditions for larval survival) over large areas in both channels. Under low flow conditions, temperature also increased to levels that may impact available habitat in the upper section of Landa Lake as spring run 4 would cease to flow altogether. Stagnant conditions in the upper sections of the lake would potentially limit darter habitat. This is illustrated in Figure 38.

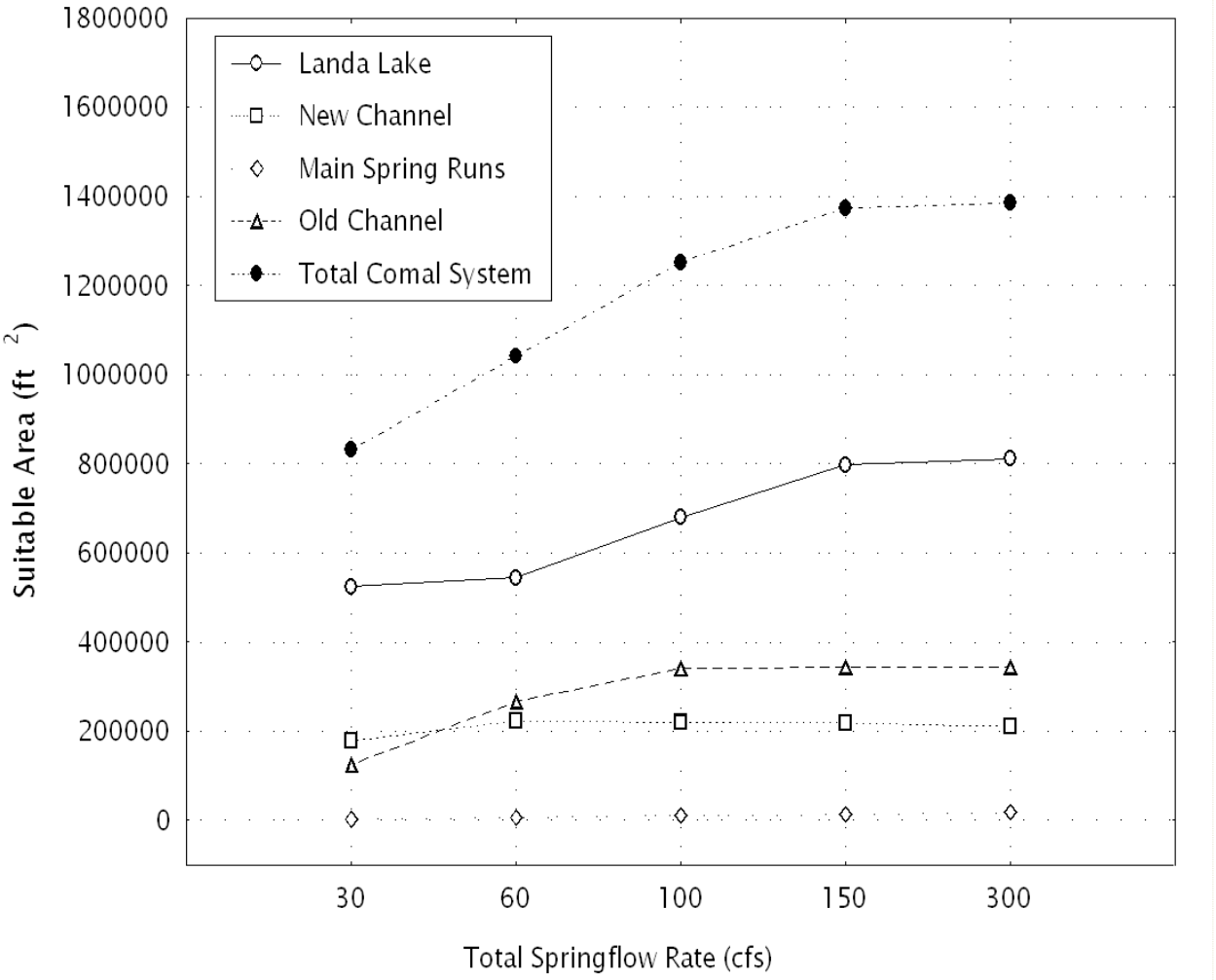


Figure 37. Total estimated fountain darter habitat in the Comal River based on physical habitat using mean daily water temperatures. Note, suitable areas in this context reflect potential areas below the thermal threshold at which temperatures are associated with reduced larval survival.

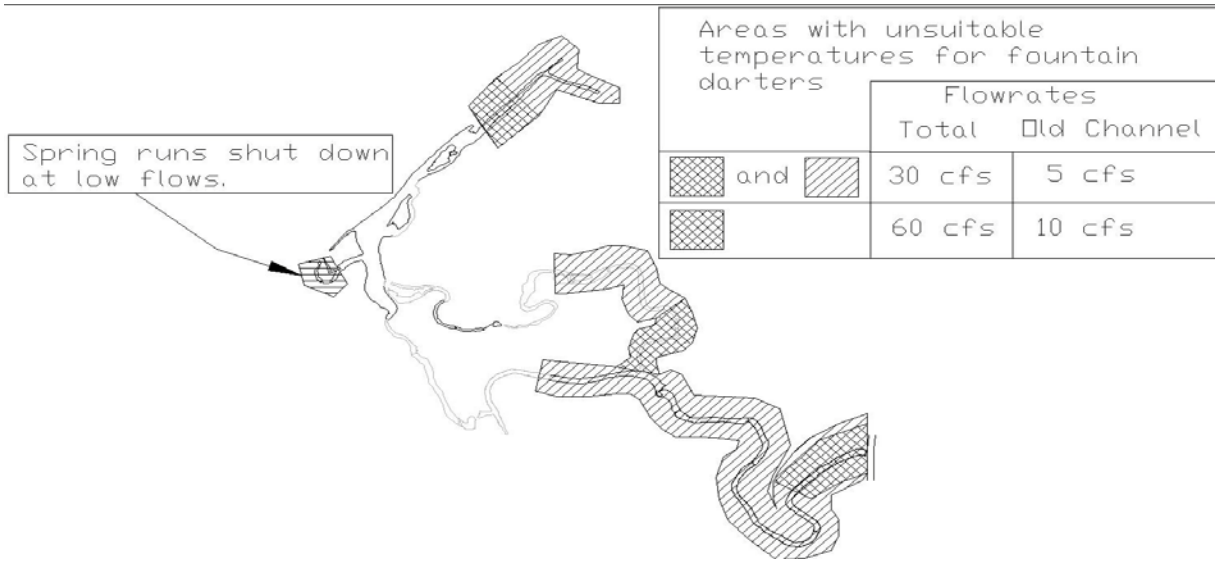


Figure 38. Available fountain darter habitat in the Comal River at a total flow rate of 30 and 60 cfs based on mean daily temperatures. See figure for flow rate splits in the old and new channel. Unsuitable habitat in this context simply refers to areas at which potentially reduced larval survival may occur.

Physical Habitat Using Maximum Daily Temperatures

Additional simulations of available fountain darter habitat in the Comal River were made based on integration of maximum daily temperatures and hydraulic habitat (i.e., depth, velocity, and vegetation type) based on flow splits in the old and new channel. In these simulations, only the lower part of Landa Lake and downstream modeling sections were included since the areas upstream are not affected by these simulations. In addition, these results include both the Bartsch et al. (2000) and revised habitat suitability curves (see Figures 28 and 29). Table 11 shows the summary of predicted fountain darter habitat versus discharge for various combinations of total Comal River discharges with flow splits between the old and new channels based on both sets of suitability curves. The summary results for the old channel are presented graphically in Figure 41 and the new channel in Figure 42 based on the new revised suitability curves. The component results for each computational segment are provided in tabular form in Appendix C for these simulation results.

At the request of the technical team, contour plots of the depth, velocity, and combined suitability for fountain dater habitat were generated for each computational segment (see Figure 16). An example of the depth and velocity contour plots (Figure 39), and the associated combined suitability for fountain darter habitat (Figure 40) within the 'Upper Old Channel Section 2'; TopOC2 (see Figure 16) are provided below. These figures compare the results at a flow rate of 10 and 40 cfs based on the revised habitat suitability criteria. The results at 10 cfs show that the overall combined habitat suitability within this section is very low (maximum of only 0.08) while at 40 cfs the maximum combined habitat suitability increases to 0.32. The technical team examined these plots during their evaluation of flow dependent characteristics of fountain darters throughout the system. Appendix B contains the complete set of screen grabs for all three variables.

Table 11. Summary WUA relationships for fountain darters in the Comal River for simulated total Comal River flows and corresponding flow splits between the old and new channels.

		Bartsch et al. (2000) HSC				Revised HSC		
New Channel Flow (cfs)	Old Channel Flow (cfs)	Comal River Flow (cfs)	New Channel WUA (ft^2)	Old Channel WUA (ft^2)	Comal River Total WUA (ft^2)	New Channel WUA (ft^2)	Old Channel WUA (ft^2)	Comal River Total WUA (ft^2)
20	10	30	9384	4123	22361	23509	6502	44161
10	20	30	7392	3983	11376	18967	7872	25230
5	25	30	7719	3558	11277	14728	8073	21173
20	20	40	9384	2541	17547	23509	6071	39431
10	30	40	7392	3990	11383	18967	8776	26141
5	35	40	7684	3560	11244	14642	19424	32485
20	30	50	8986	3990	18599	22815	8776	39840
10	40	50	7392	3204	10596	18967	19210	36615
45	30	75	7591	3990	15945	25423	8776	41140
35	40	75	7163	3204	14729	22174	19210	48365
70	30	100	8415	3990	15232	39713	8776	54418
60	40	100	8939	3204	14422	38215	19210	61429
95	30	125	7906	3990	13776	44275	8776	56945
85	40	125	9382	3204	14407	49444	19210	72588
120	30	150	7237	3990	12518	54449	8776	65836
110	40	150	8248	3204	12576	57714	19210	80030
170	30	200	4206	3990	9121	49561	8776	60190
160	40	200	4696	3204	8598	51595	19210	72299

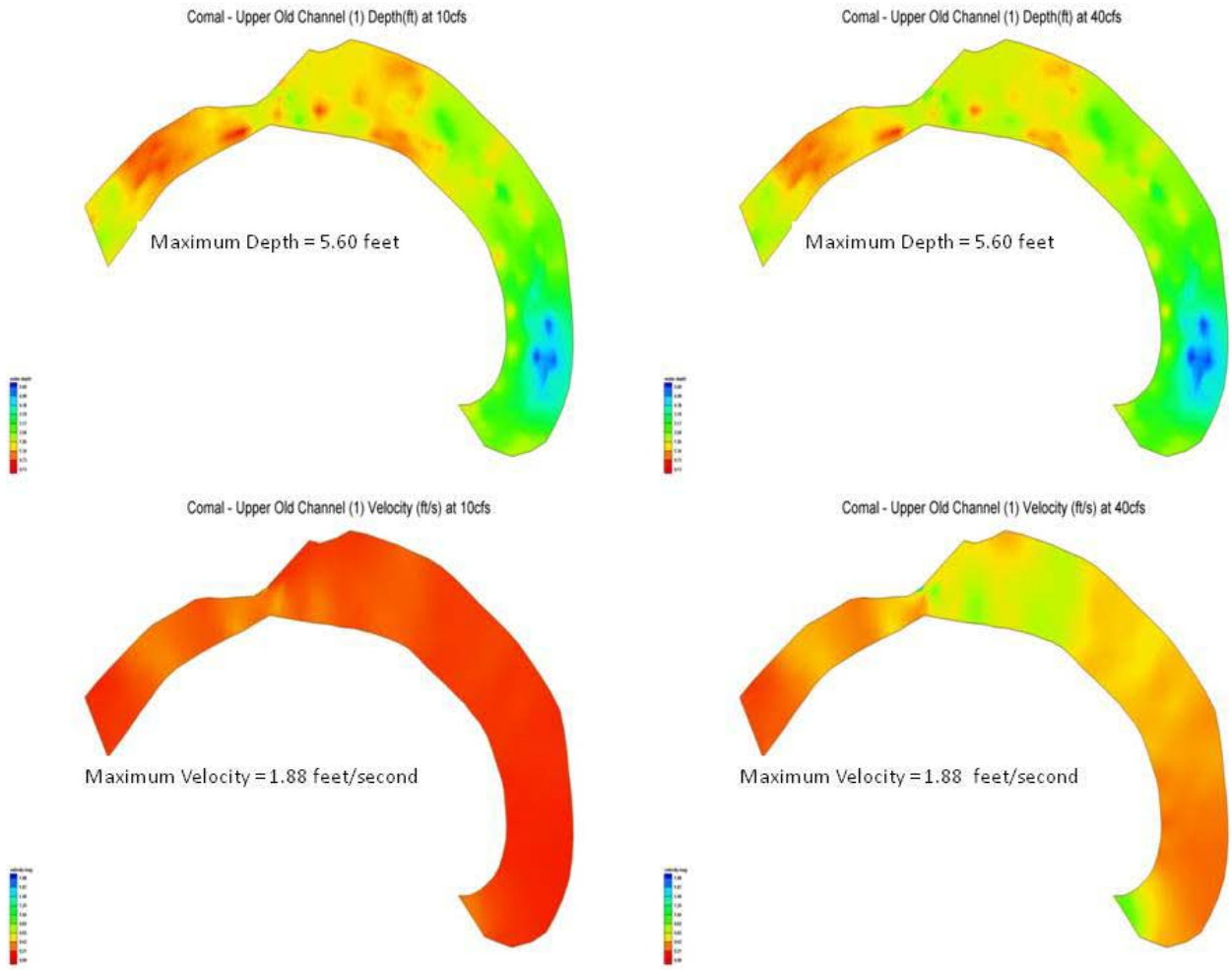


Figure 39. Depth and velocity contour plots at 10 and 40 cfs in the Upper Old Channel section of the Comal River. Color legends are scaled between 0.0 (red) and the maximum indicated (blue) in 10 increments of the maximum magnitude indicated.

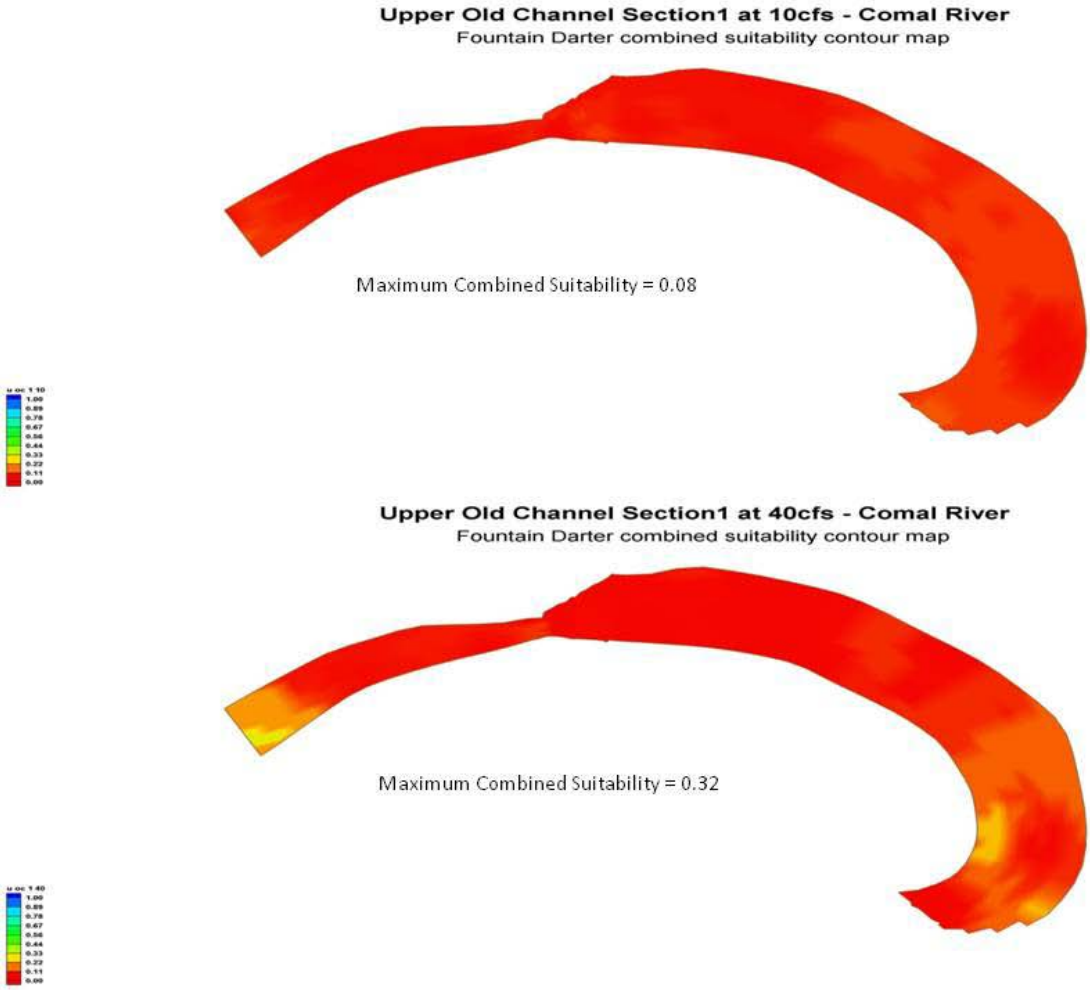


Figure 40. Combined suitability for fountain darter habitat in the Upper Old Channel section of the Comal River at 10 and 40 cfs. Legend scale is from 0.0 (red) to 1.0 (blue) in 0.1 increments.

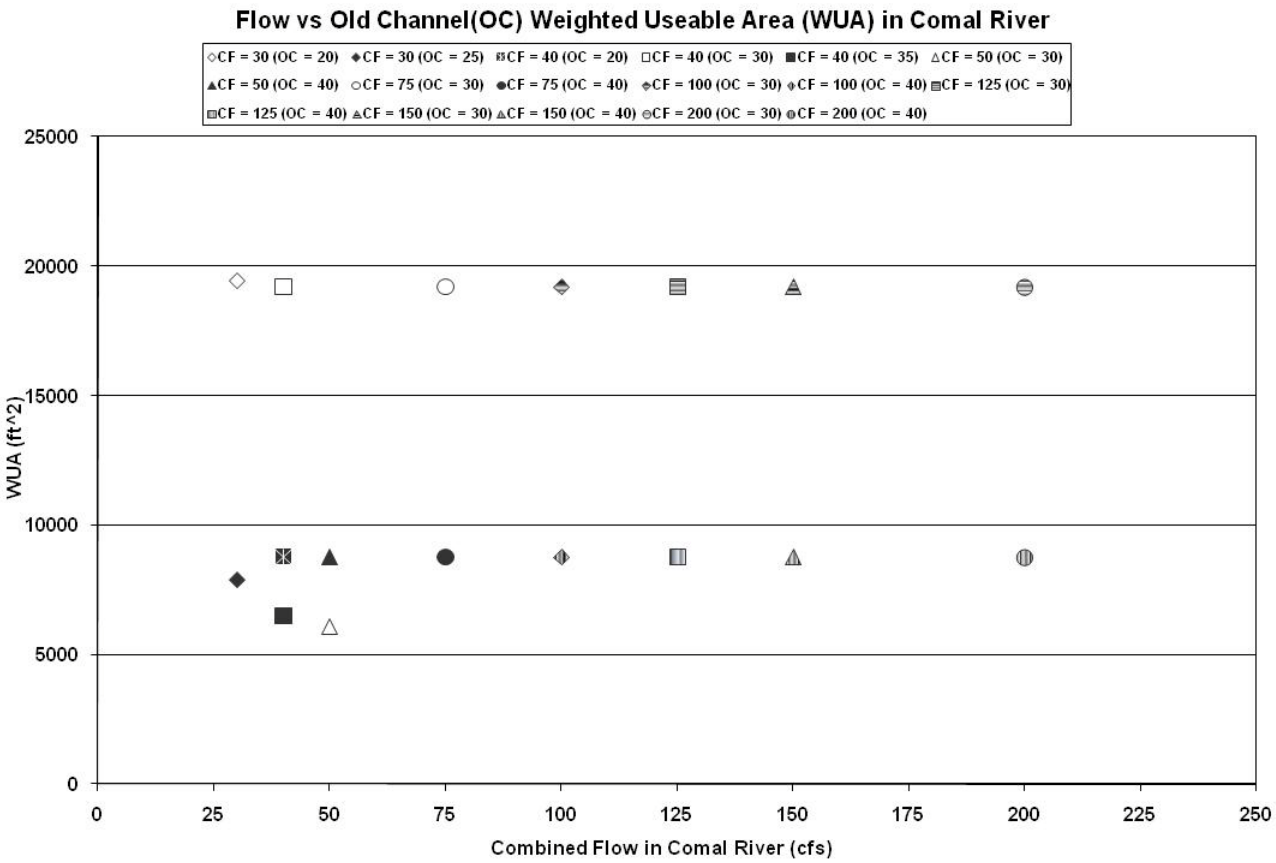


Figure 41. Relationships between total Comal River discharge and simulated available habitat for fountain darters in the old channel.

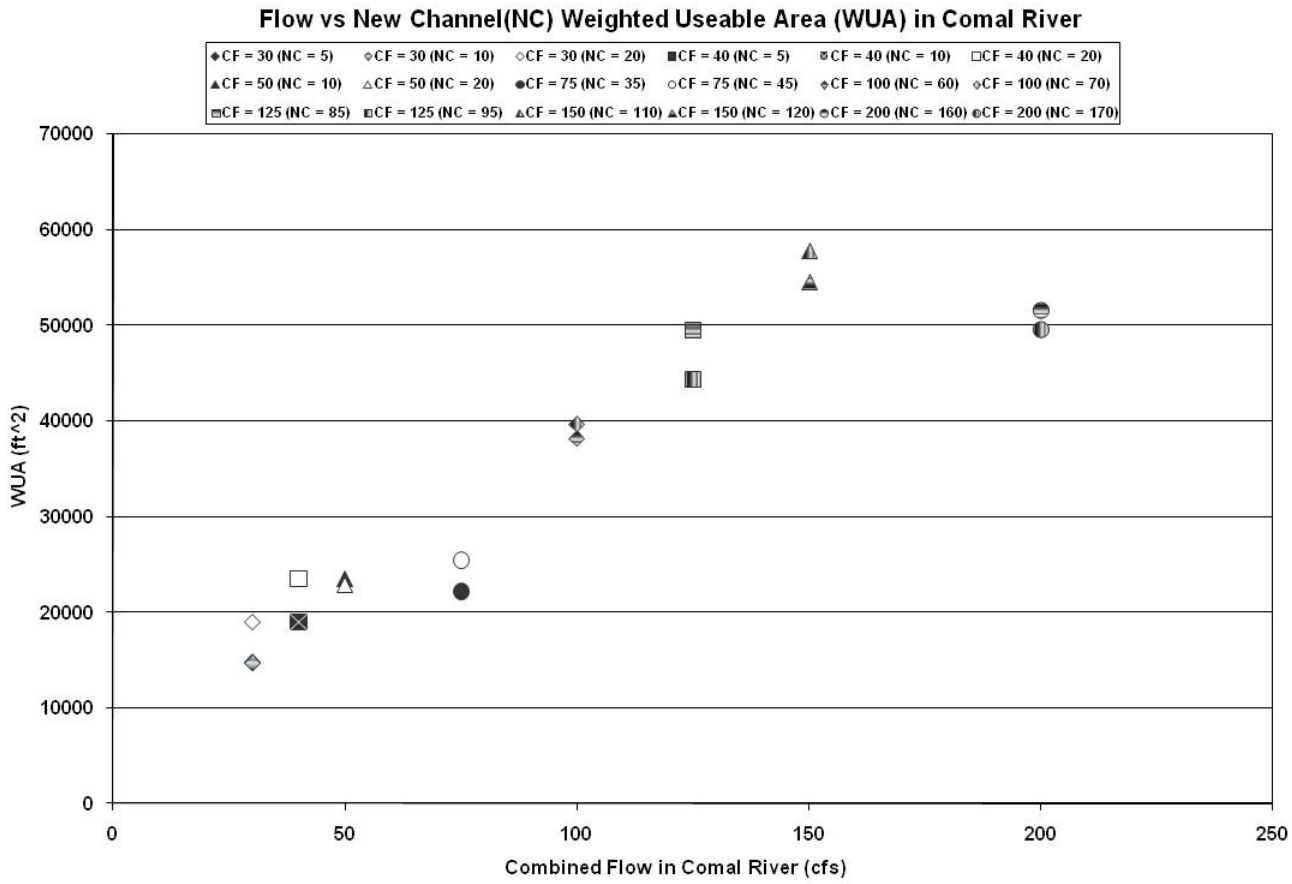


Figure 42. Relationships between total Comal River discharge and simulated available habitat for fountain darters in the new channel.

These results indicate that for a given total discharge in the Comal River, increasing flow into the old channel is somewhat insensitive to changes in available habitat, while the new channel shows a linear response to increased habitat availability as total Comal River discharges increase. These results are primarily attributed to the narrow range of velocity magnitudes that remain suitable for fountain darters as illustrated in Figure 29. These results should be viewed with some caution however, given the known channel changes within the new channel not reflected in the current analysis that includes both topography and vegetation. These results are also cautionary in that the temperature simulations used a spring orifice temperature as the boundary conditions for flows entering the old channel rather than the simulated temperature at the node in Landa Lake where the culvert orifice is located. This will be rectified in the updated modeling currently underway.

Overall, the system wide temperature simulations using both mean daily and maximum daily temperatures strongly suggest that as total Comal River flow rates decrease, thermal affects on darter life stages become limiting rather than the amount of physical habitat in terms of suitable depth and velocities. The exception to this is the habitat versus flow response within the new channel which shows somewhat rapid declines as flow rates are reduced over all ranges of simulated flows.

San Marcos

In this section of the report, results based on the original habitat modeling in Bartsch et al. (2000) are provided to contrast the revised results of the current work based on updated habitat suitability curves for fountain darters as well as changes in channel topography within the San Marcos River. These comparisons are provided as one form of sensitivity analysis based on channel changes, differences in habitat suitability curves, and evaluations based on both mean column velocities and velocities estimated at 15 cm above the channel bottom. Given similarity of these two modeling approaches, only the results for 15 cm above the bottom are presented in the report. As part of the evaluations, the technical team was also provided with the depth and velocity contour plots at each simulated flow (see Figure 39 above). These results are provided in Appendix D.

Temperature

Figure 43 provides a simplified overview map of the San Marcos River system utilized in the modeling of habitat and temperature by Bartsch et al. (2000) and is used to highlight the relationship between flow, temperature, and habitat for fountain darters within selected reaches.

Figure 44 shows the relationship between total San Marcos discharge and maximum daily temperatures within selected reaches of the San Marcos River downstream of Spring Lake. This figure clearly shows that as the total river discharge drops, major sections of the San Marcos have a higher potential to cause thermal related impacts to fountain darter life stages. This is discussed in more detail in the section on system wide fountain darter habitat below.

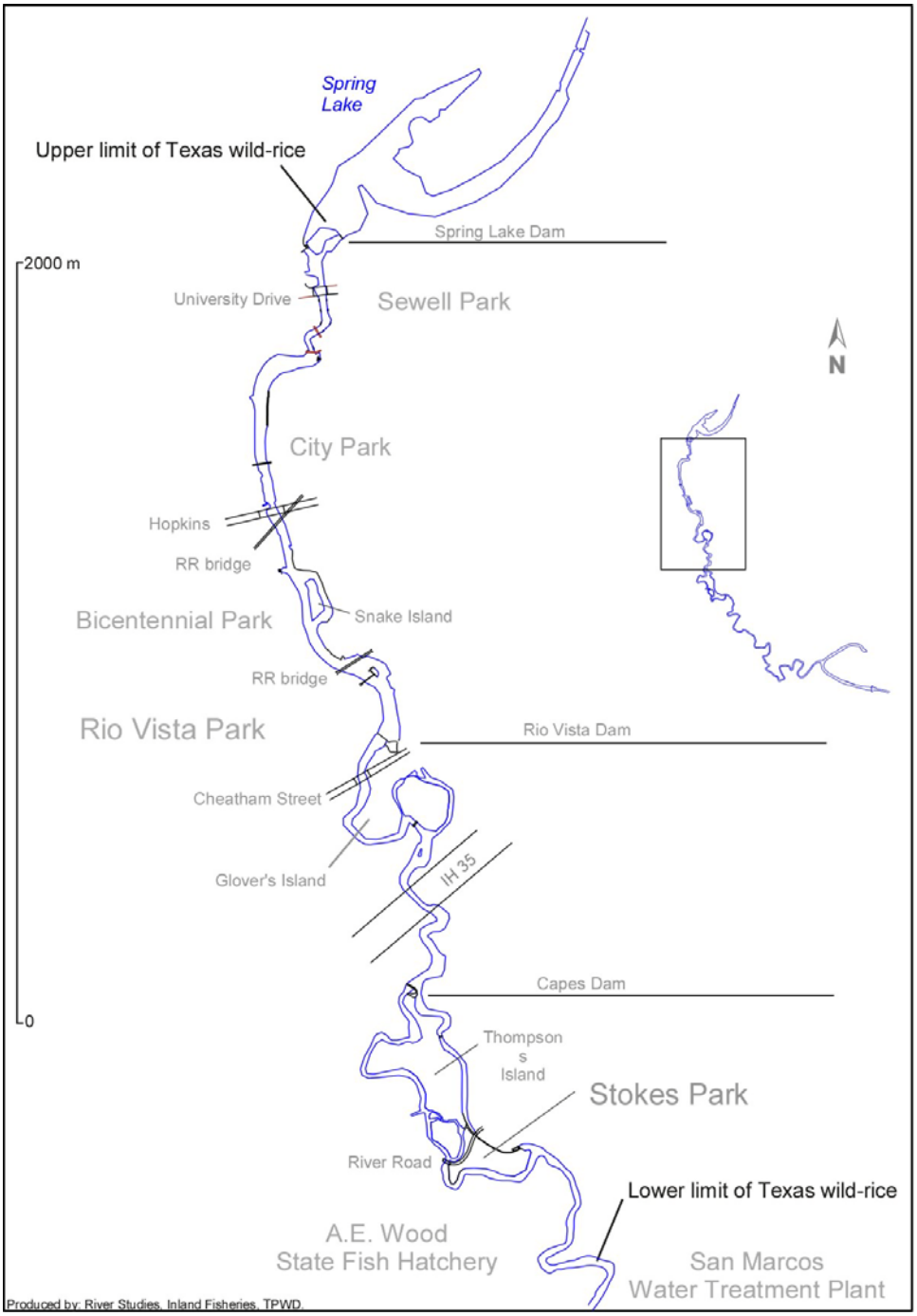


Figure 43. Major simulation reaches utilized by Bartsch et al. (2000).

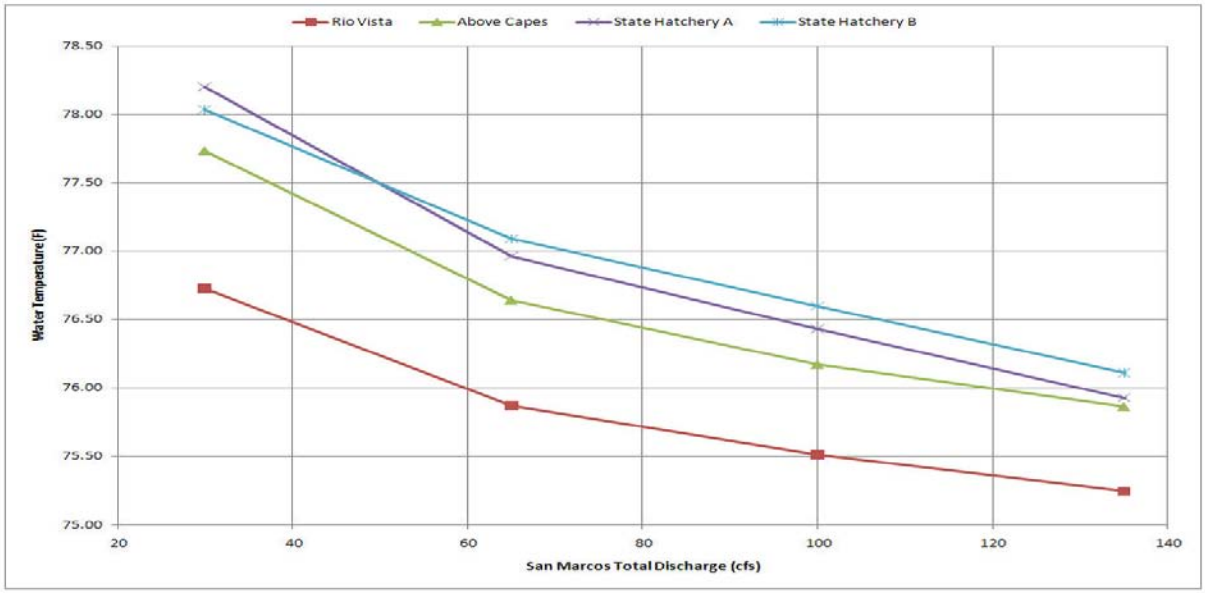


Figure 44. Relationship between total San Marcos discharge (cfs) and reach level maximum daily temperatures in selected reaches.

Dissolved Oxygen

Bartsch et al. (2000) did not include dissolved oxygen simulations in their modeling evaluations, nor were they included in subsequent modeling efforts within the San Marcos River. As noted previously for the water quality simulations for the Comal, there is concern for the potential of depressed dissolved oxygen values during night time respiration at very low flows, especially in highly vegetated areas such as Spring Lake and sections of the San Marcos River upstream of Cape's Dam. If possible, this should be addressed in the on-going modeling efforts in support of the HCP.

Texas Wild Rice

System-Wide Physical Habitat

Bartsch et al. (2000) modeled Texas wild rice throughout the Upper San Marcos River at a number of flow rates and results are provided in Table 12. Note that these results are derived from the 'USFWS-USU' habitat suitability curves shown in Figures 26 and 27. Their results are described here, while additional modeling results specific to the Rio Vista and Cape's Dam sections are provided below based on the revised habitat suitability curves. The results in Table 12 indicate that Texas wild rice habitat shows a linear increase as a function of increasing discharge for all river sections with the exception of the Lower San Marcos A section which shows a slight decline at the highest simulated flow rate (170 cfs). Results for specific sections are provided below.

Table 12. Modeled Texas wild rice habitat (WUA) by total San Marcos Spring flow rate (Bartsch et al. 2000).

Total San Marcos Springs Flow Rate					
	30 cfs	**65 cfs**	**100 cfs**	**135 cfs**	**170 cfs**
	WUA (ft2)	**WUA (ft2)**	**WUA (ft2)**	**WUA (ft2)**	**WUA (ft2)**
Spring Lake	0	0	0	0	55
Rio Vista	1624	3905	10524	17191	25992
Above Cape's Dam	1251	11068	25584	44043	56100
State Hatchery A	789	8341	17064	29683	32784
State Hatchery B	16	3952	14425	29714	33844
Mill Race	0	0	0	0	0
Lower San Marcos A	2206	4376	5617	7021	5748
Lower San Marcos B	0	0	0	0	2
Totals:	5885	31641	73213	127652	154525

Spring Lake

The analysis by Bartsch et al. (2000) indicated that suitable habitat in Spring Lake was negligible at all but the highest flow rate as shown in Table 12. Their analysis of Spring Lake habitat cells' depths and velocities revealed that an ample amount of area existed with suitable depths for wild rice. The velocity in each computational cell however was below the 0.87 ft/s threshold used in their wild rice habitat suitability curve. Based in part on these results and monitoring data, Saunders et al. (2001) did not include Spring Lake in their instream flow evaluation of the San Marcos River for Texas wild rice. It is interesting to note that Spring Lake wild rice distribution has changed from "growth .. so luxuriant that the irrigation company has trouble keeping the artificial lake .. clean" (Silveus 1933) to a few scattered stands immediately below the main lake outflows where water velocities increase in this upper section of the river system. Given these data, no further simulations of Texas wild rice were undertaken in the present study within Spring Lake.

Rio Vista

The Rio Vista habitat section showed consistent wild rice WUA increases with increasing flow rate. Depths decreased as flow rates dropped but never became habitat limiting within this modeled section. This does not imply that as flow rates drop that individual Texas wild rice stands may become stranded while suitable yet unoccupied areas are predicted to be present. Velocities were the limiting habitat factor in the Rio Vista habitat section. Mean water velocities never reached the lower wild rice HSI velocity threshold employed by Bartsch et al. (2000). Their analysis of modeled wild rice habitat results showed habitat to be concentrated in the area of the University Drive Bridge at all flow rates. Backwater effects of Rio Vista Dam tend to decrease suitable wild rice habitat due to reduced water velocities.

Above Cape's

The Above Cape's habitat modeling section began immediately below Rio Vista Dam and continued downstream to Cape's Dam. This section begins as a riffle habitat type and changes to a pool/slow moving water habitat due to Cape's Dam backwater. Simulated water depths ranged between 3.5 feet to 3.8 feet over the range of simulated flows within the section and were not habitat limiting with the notable exception of several deep pools above Cape's Dam. Simulated mean water velocities never exceeded the minimum wild rice velocity habitat threshold values utilized by Bartsch et al. (1999) at any of the simulated discharges.

Mill Race

Within the Mill Race habitat section, mean water depths increased from 3.5 feet to 4.9 feet as the range of simulated discharges increased. Over the range of simulated discharges, depth was not found to a limiting factor. Water velocities in the Mill Race were limiting to wild rice at all of the modeled flow rates. The backwater effect of the Mill Race basically slowed water velocities to the point that no wild rice habitat was simulated to exist in the Mill Race at any of the modeled flow rates.

State Hatchery A

Wild rice WUA consistently increased with increasing flow rates in the State Hatchery A habitat section with increasing discharge. Mean water depths were suitable at all modeled flow rates, while water velocities were limiting. It is interesting to note that at flow rates near the historic mean (135 cfs and 170 cfs modeled versus 148 cfs for the historic mean), mean water velocities were 0.87 and 0.95 feet per second and at the lower range of wild rice suitability utilized by Bartsch et al. (2000). Water depths were 3.5 feet and 3.7 feet at these modeled flow rates and at wild rice optimal depths.

State Hatchery B

The State Hatchery B section showed a consistent increase in wild rice WUA with increasing flow rates. Water depths ranged from 1.8 feet to 2.6 feet from the lowest to highest simulated discharges. Depths were suitable for wild rice habitat at all simulated flow rates. Suitable water velocities were found at simulated discharges above 100 cfs, while at lower simulated discharges, low water velocity was a limiting habitat factor in this section.

Lower San Marcos A

The Lower San Marcos A habitat segment begins at the Mill Race outfall, continues past the confluence with the main San Marcos River channel and the City of San Marcos wastewater treatment plant input and ends 0.8 miles downstream of the mill race/main channel confluence. This section is a transition area from the shallower upstream reaches to the deeper Cumming's Dam backwater found downstream. At the lower modeled flow rates, the mean velocity in this section was below the 0.87 ft/s threshold suitable to wild rice. Increasing the flow rate increased water velocities and consequently wild rice WUA. As modeled flows increased from 30 to 60 cfs, the mean water depths increased to over five feet and began to limit wild rice habitat in the simulations. This explains the decrease in wild rice WUA at the highest flow rate of 170 cfs. The primary limiting habitat factor for the Lower San Marcos A habitat section was water velocity.

Lower San Marcos B

The Lower San Marcos B habitat segment begins about 3.1 miles below Spring Lake Dam (0.8 miles below the Mill Race/main channel confluence) and continues downstream to the confluence with the Blanco River. This section is the deepest and slowest moving area in the San Marcos River due to Cumming's Dam backwater. Flow through this area is noticeably more turbid than areas further upstream and this could be due to urban or agricultural run-off, recreation based suspension of fine sediments, natural river processes or the combined discharges of the A.E. Woods State Hatchery and City of San Marcos wastewater treatment plant. It is important to note that this section lies downstream of historical wild rice distributions.

Wild rice habitat modeling shows no wild rice WUA existed at any of the modeled flow rates. The one suitable habitat cell out of 7551 total cells at 170 cfs is considered negligible. Mean water depth in this section ranged from 7.7 feet to 9.3 feet over the range of simulated discharges. The Lower San Marcos B section is considered too deep and slow moving to be suitable wild rice habitat due to the backwater effect from Cumming's Dam.

Revised Upper San Marcos Physical Habitat Modeling

Texas wild rice monitoring data between 1998 and 2008 show only a few Texas wild rice plants below the State Fish Hatchery (see Figure 43 for location) (unpublished TPWD/USFWS field data). Based on this, the results presented in this section of the report focus on modeled sections upstream of that location based on the revised habitat suitability curves (see Figures 26 and 27).

Table 13 and Figure 45 provide a comparison of estimated Texas wild rice habitat in the Rio Vista and Above's Cape Dam sections of the San Marcos River for three different simulation results: the original 1997 geometry based simulation results, the 2001 revised geometry simulation results, and the No Dam based geometry simulation results. The totals for these three comparisons are also provided. Figure 45 also shows the total available habitat as a percentage of maximum habitat available for illustrative purposes.

These results suggest that Texas wild rice habitat availability is maximized in both these sections of the San Marcos River as flow rates increase above approximately 100 cfs. They also suggest that rapid decreases in suitable area occur below below the 65 cfs simulated flow. At 65 cfs, approximately 75 percent of maximum habitat is maintained and drops to approximately 50 percent at 30 cfs. Loss in available habitat occurs rapidly as flows drop below 30 cfs. A comparison between the 1997 and 2001 geometry simulation results show that the implications of the measured channel changes primarily affect the magnitude of the habitat versus flow relationships rather than a substantive change in the underlying shape.

In contrast, the revised habitat suitability curves result in a the habitat versus flow relationships reaching a maximum at the 135 cfs simulated discharge and then either remaining relatively constant or show slight decreases at higher simulated flows. This is primarily attributed to the change in the depth suitability curve (Figure 26) which shows decreased suitability between 3 and 5 feet compared to the Bartsch el al. (2000) curves. Basically, as the flow rate increases above approximately 135 cfs, an increasing amount of areas fall within this 3 to 5 foot range and the resulting decrease in the computed combined suitability for Texas wild rice.

Table 13. Simulated Texas wild rice available habitat (Weighted Useable Area (WUA) in square feet) in sections of the San Marcos River based on 1997 channel geometries, 2001 channel geometries, and geometries based on assumed removal of Cape's Dam (No Dam).

San Marcos Total Discharge (cfs)	Rio Vista Section		Above Cape's Dam Section		No Dam	Total San Marcos 1997 WUA (ft^2)	Total San Marcos 2001 WUA (ft^2)
	1997 Geometry WUA (ft^2)	2001 Geometry WUA (ft^2)	1997 Geometry WUA (ft^2)	2001 Geometry WUA (ft^2)	2001 Geometry WUA (ft^2)		
15	123,570	109,550	38740	33150	55020	162,310	142,700
30	261,190	182,570	69010	46830	76110	330,200	229,400
65	351,080	307,490	110400	81720	98840	461,480	389,210
100	392,580	360,360	125480	105910	105350	518,060	466,270
135	393,250	374,390	128360	115990	105670	521,610	490,380
170	383,960	374,810	126990	118770	102050	510,950	493,580
190		350,830		118920	99980		469,750
200		339,580		115840	99090		455,420

As part of the technical team evaluations, the spatial distribution of predicted cell suitabilities were examined on a computational cell by cell basis and compared to actual wild rice distributions based on 1989 to 2008 monitoring data at each simulated discharge. Figure 46 shows the section of the San Marcos River in the Rio Vista to Cape's Dam section with the simulated suitabilities for Texas wild rice at each computational cell at a simulated discharge of 65 cfs. The known 1989 to 2008 distribution of plant locations are overlain for comparative purposes (red dots).

The results shown in Figure 47 for the 30 cfs simulation show Texas wild rice were associated with modeled cell suitabilities primarily below about 0.50 compared to results at 65 cfs, which show a proportional shift with modeled cell suitabilities above 0.50. This shift in proportionally more stands occupying modeled cells with suitabilities greater than 0.50 was observed at all higher flow rates modeled. Observed versus use frequency distributions at flow above 65 cfs are very similar to that reported for 65 cfs while the results for 30 cfs are indicative of the results at simulated flow lower than 30 cfs. This appears to be a systematic bias in the modeling results at lower flows that should be examined in more detail with the revised modeling currently underway. It should also be noted that in the simulations, the current calculations do not take into account if an existing plant species occupies the computational element. Modeling results were also examined for locations in which the simulations predicted suitabilities but were not occupied by Texas wild rice. Over 60 percent of these locations were occupied by native species.

Figures 48, 49, and 50 show the contour plots of combined suitabilities for Texas wild rice in the Above Cape's section of the San Marcos River for flow rates of 15, 30, and 65 cfs. The plots for the remaining simulated flows are contained in Appendix D. These results clearly illustrate the rapid loss of suitable Texas wild rice habitat as flow decrease over these simulated flow ranges as expected from the summary results shown in Figure 45. Future modeling efforts should increase the number of simulated flows over these ranges to provide a better resolution of the relationship between suitable habitat and discharge.

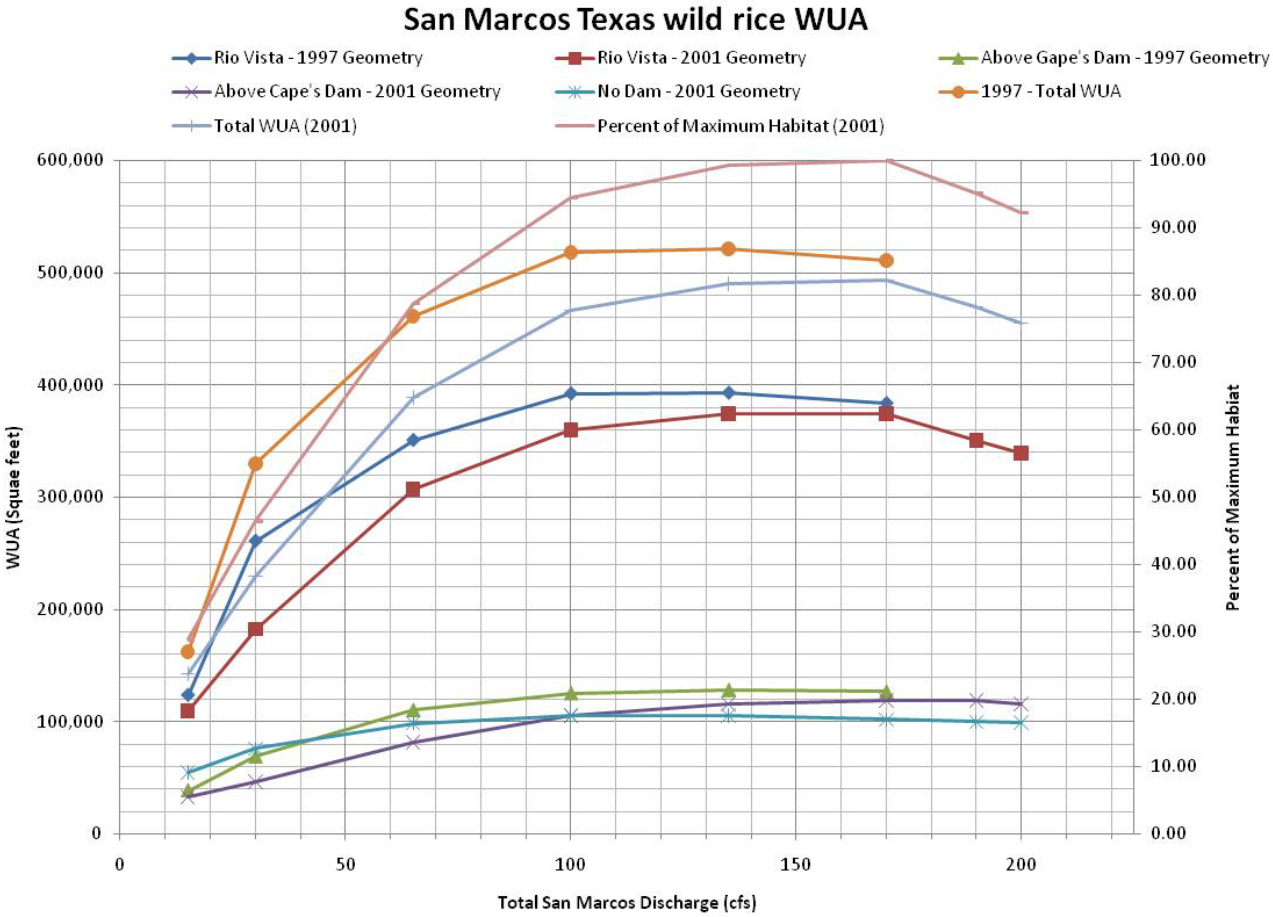


Figure 45. Simulated Texas wild rice available habitat (WUA) in sections of the San Marcos River based on 1997 channel geometries, 2001 channel geometries, and geometries based on assumed removal of Cape's Dam (No Dam). The total area based on 2001 geometry is also shown as a percent of the maximum habitat.

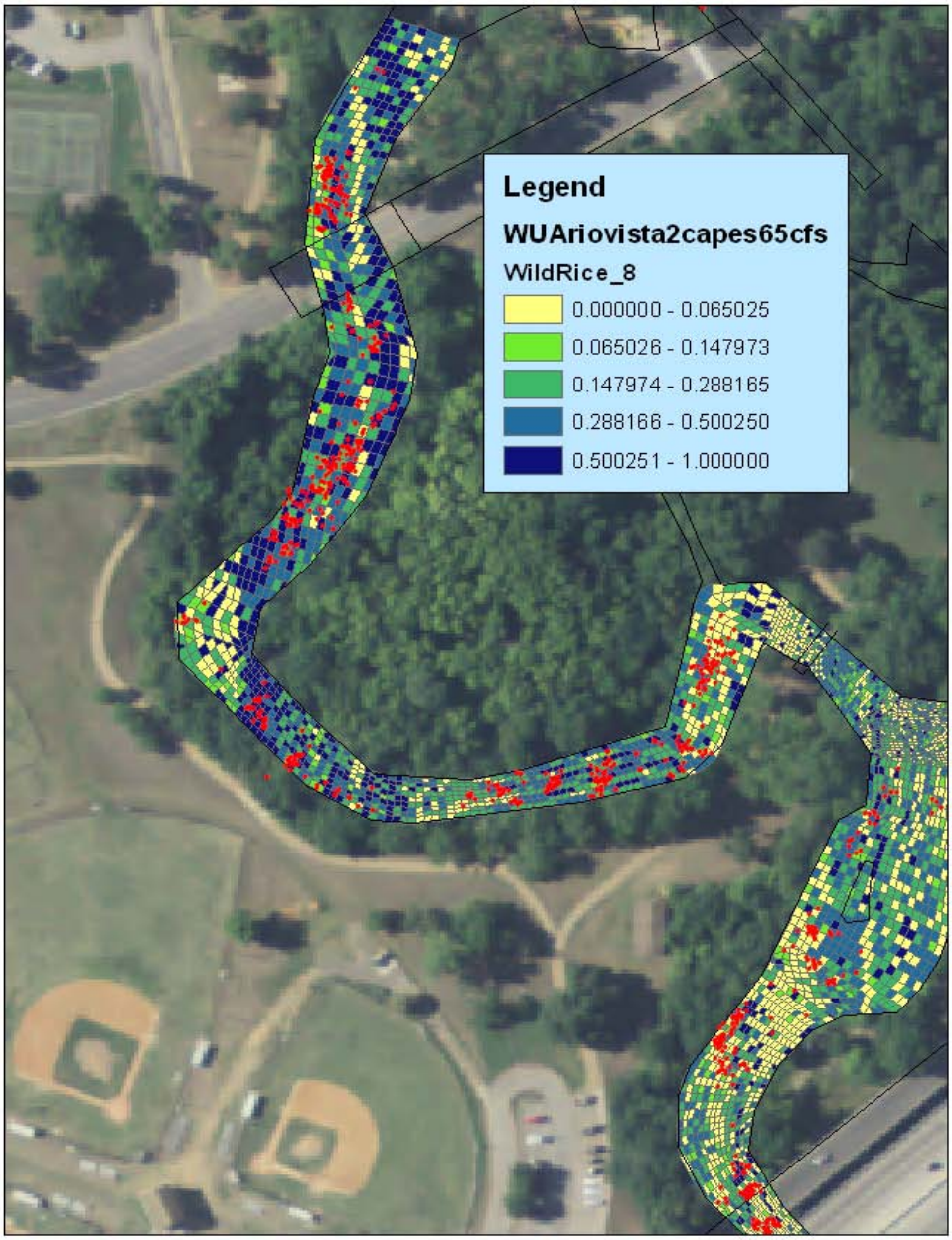
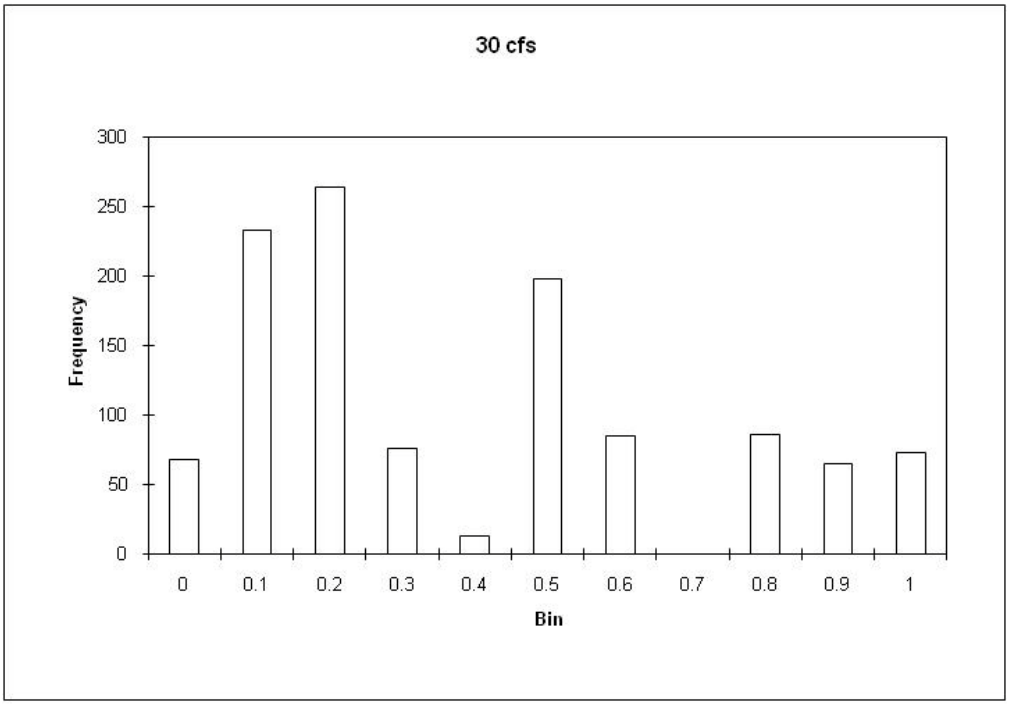


Figure 46. Spatial distribution of predicted Texas wild rice computational cell suitability ranges versus the 1989 to 2008 spatial distribution of Texas wild rice stands (red dots) in the Rio Vista to Cape's Dam section. Simulated discharge is 65 cfs.

At each plant location, the computational cell estimated suitability was extracted and the frequency distribution histogram of occupied cell suitabilities were generated. This is illustrated in Figure 47 for a flow rate of 30 and 65 cfs.



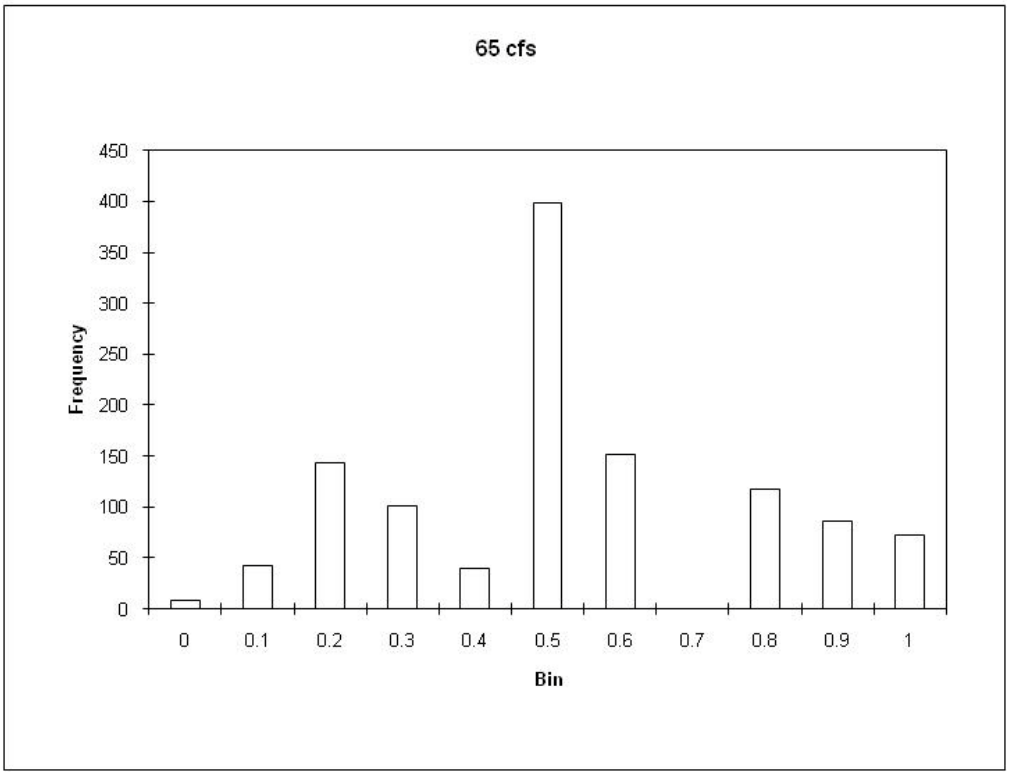


Figure 47. Frequency histograms of simulated cell suitabilities containing Texas wild rice based at 30 and 65 cfs.

The technical team utilized the combined results presented above in a qualitative evaluation of potential impacts due to recreation activities by examining the spatial locations of Texas wild rice stands in areas with depths less than 2 - 3 feet at each simulated flow rates. It was apparent that as flows drop below 65 cfs, proportionally greater areas in the San Marcos River were Texas wild rice stands currently exist become more vulnerable to physical disturbance.

Texas Wild Rice Physical Habitat Summary

The simulation results indicate that over the range of simulated discharges, Texas wild rice habitat begins to decline below approximately 100 cfs and rapidly declines below 65 cfs. Care should be taken not to treat these specific flow rates as an 'absolute' break point given the somewhat large intervals between simulated discharges. The results do clearly show however, that at a flow rate of 30 cfs, less than 50 percent of maximum wild rice habitat is predicted to be available. The steepness of the habitat versus flow relationship below the 65 cfs flow rate should however, be viewed as indicative of a rapid decline in suitable conditions with incremental reductions in flow magnitude that 'worsens' as flow overall flow magnitude drops . As noted in previously, revised modeling efforts should utilize a finer scale of flow increments below the long term average to better define these habitat versus flow responses in physical habitat.

Figure 48. Combined suitability for Texas wild rice habitat in the Spring Lake to Rio Vista section of the San Marcos River at 15 cfs.

Figure 49. Combined suitability for Texas wild rice habitat in the Spring Lake to Rio Vista section of the San Marcos River at 30 cfs.

Figure 50. Combined suitability for Texas wild rice habitat in the Spring Lake to Rio Vista section of the San Marcos River at 65 cfs.

Fountain Darter

System-Wide Physical Habitat

Summary results for fountain darter physical habitat simulations based on Bartsch et al. (2000) are provided in Table 14 (see Figure 43 for locations). Updated simulation results are presented below based on both changes in the channel topography and updated habitat suitability curves. These later simulations however, rely on the original temperature simulations results shown above.

Table 14. Simulated fountain darter habitat within sections of the San Marcos River for selected flow rates after Bartsch et al. (2000).

Total San Marcos Springs Flow Rate					
	30 cfs	**65 cfs**	**100 cfs**	**135 cfs**	**170 cfs**
	WUA (ft2)	**WUA (ft2)**	**WUA (ft2)**	**WUA (ft2)**	**WUA (ft2)**
Spring Lake	218760	239751	255885	258495	263163
Rio Vista	77633	151422	185614	220996	229134
Above Cape's Dam	46335	54197	60143	56240	51181
State Hatchery A	4524	13934	15442	16136	11782
State Hatchery B	1483	3702	3107	3052	1707
Mill Race	26572	37368	44886	47040	45698
Lower San Marcos A	19159	22343	25970	24025	21844
Lower San Marcos B	69780	78308	76482	72867	69056
Totals:	464245	601026	667530	698851	693565

Spring Lake

An analysis of the fountain darter WUA results revealed that the Spring Lake slough area had poor fountain darter WUA values at all modeled flow rates. Depths and velocities were in suitable ranges but mean water temperatures were above the 75.2 F upper threshold for suitable thermal conditions. This was attributed to lack of flow coming down the Sink Creek channel through the slough. The average water temperature was always at the upper limit of useable temperatures for the fountain darter, and at a temperature which may impact fountain darter breeding. Field observations have shown the slough to become a vegetation-choked backwater area with extremely low flow and elevated temperatures, confirming the modeling result. Note that the slough area is only wetted due to the Spring Lake Dam backwater and does not contain any major springs.

The non-slough area of Spring Lake showed slightly decreasing fountain darter WUA as flow rates decreased. Water depths remained fairly constant due to the Spring Lake Dam backwater and had little effect on fountain darter WUA. Water velocities were extremely slow at all modeled flow rates due to the backwater effect and were not a limiting factor. Water temperatures increased as flow rates decreased and became the limiting habitat factor below 65 cfs. The lowest part of Spring Lake receives the combined flows of the springs area and the slough and was more prone to high temperatures as flow rates were lowered. Overall Spring Lake fountain darter WUA showed a consistent decrease as flow rates decreased.

Rio Vista

Habitat modeling results showed consistently increasing fountain darter WUA with increasing flow rates. The WUA for 135 cfs and 170 cfs modeled total San Marcos Springs flow rates were about the same. It should be noted that the Rio Vista and Mill Race sections contained the highest aquatic vegetation aerial coverage, although Rio Vista section had much more vegetative diversity than the Mill Race section. This was of overall benefit to the fountain darter as areas with little vegetation had low HSI values for fountain darters as noted previously.

Water temperatures increased as modeled flow rates decreased and were of moderate importance as a habitat-limiting factor. Mean water depths in the Rio Vista habitat section fell below the two foot threshold between 30 cfs and 65 cfs and began to limit fountain darter WUA. Mean water velocities in this section never rose above the 0.5 ft/s threshold at which they would have become habitat-limiting. Overall fountain darter WUA was limited by depths and temperatures at low flowrates for the Rio Vista Dam habitat section.

Above Cape's

The Above Cape's habitat modeling section starts immediately below Rio Vista Dam and stretches downstream to Cape's Dam. Habitat at the upper boundary is characterized by fast, shallow water while habitat further downstream is dominated by Cape's Dam backwater and has low velocity and increased depths (up to 17 feet just above Cape's Dam). This lower section exhibited a diverse range of vegetation species beneficial to fountain darter use. Mean water depths in this section were 3.46 feet at the lowest flow rate modeled and increased as flow rates increased, never becoming habitat limiting for fountain darters. Water temperatures increased at lower flow rates and became habitat limiting at modeled flow rates of 65 cfs and below.

Mill Race

The Mill Race section had high vegetation aerial coverage and in particular was dominated by hydrilla, a non-native plant that is favorable to fountain darter utilization. The dominance of hydrilla in the Mill Race area led to high fountain darter WUA estimates when temperatures and velocities were not limiting. As flow rates decreased, fountain darter WUA decreased in the Mill Race section. Mean water velocity in this section never exceeded the 0.5 ft/s threshold at which it would have become limiting. Depths throughout this section did not vary much with discharge due to the Mill Race outfall backwater and were never limiting over the range of simulated discharges. Water temperatures increased in the Mill Race habitat section and became the limiting factor for fountain darter habitat below 65 cfs.

State Hatchery A

The State Hatchery A habitat segment starts in the main channel of the San Marcos River just below Cape's Dam and runs 0.45 miles downstream to the County Road Bridge, with the last 0.1 miles of the section characterized by fast, shallow water rapids by Bartsch et al. (2000). The section was sparsely vegetated and this lack of vegetation limited predictions of available fountain darter habitat. As with other sections, water temperatures rose as flow rates decreased, reducing the overall suitability of fountain darter habitat. Depths were not a limiting factor at any of the simulated discharges. However, in sections with higher gradients, increasing areas with simulated velocities were above the 0.5 feet/second threshold set for suitable fountain darter habitat as simulated discharges increased.

State Hatchery B

The State Hatchery B habitat section was composed of the main channel of the river from County Road Bridge downstream to the confluence of the Mill Race outfall. This section receives the A.E. Woods State Fish Hatchery discharge about 300 feet upstream from its lower boundary. This section is of moderately high gradient and characterized by shallow, fast flowing water. Vegetation coverage throughout was sparse and comprised mainly of elephant ear and hydrilla. Fountain darter WUA in this section was limited by this lack of aquatic vegetation (only 457 habitat cells of 4995 total habitat cells, or 9%, had vegetation of any sort according based on the vegetation mapping data) and the resulting WUA value magnitudes were low. Mean water depths at simulated discharges below 65 cfs were below the 2.0 foot lower threshold of suitable fountain darter habitat. As in other sections, water temperatures became limiting below 65 cfs. In summary, the State Hatchery B habitat section was limited by depth, velocity, vegetation, and temperatures. Increased water temperatures and decreased depths limited fountain darter WUA at lower modeled flow rates, while increased water velocities limited fountain darter WUA at higher modeled flow rates, and lack of vegetation limited fountain darter WUA at all flow rates.

Lower San Marcos A

The Lower San Marcos A segment showed no clear pattern in fountain darter WUA. The adverse effects of elevated water temperatures at lower flow rates were balanced by the adverse effects of increased velocities at higher flow rates with the 100 cfs modeled discharge being the break point between these competing effects. Mean water depths in this section were sufficiently deep (4.3 feet at the lowest modeled flow rate) and were not habitat limiting over any range of simulated flows. This river section had very sparse vegetation coverage based on the vegetation maps utilized, limiting fountain darter WUA. Areas with no vegetation have minimal fountain darter habitat value.

Lower San Marcos B

The Lower San Marcos B habitat section had the lowest vegetation density of any San Marcos habitat modeling section. Only 0.8% of habitat cells (51 of 7551 total) had vegetation according to the vegetation mapping. Mean water depths through this area were the deepest in the San Marcos River due to the backwater from Cumming's Dam and were not limiting any simulated discharge. This section of the San Marcos River had lower diel temperature fluctuation amplitudes than any of the upper San Marcos River reaches. Bartsch et al. (2000) attributed this result to greater thermal mass which acts as a buffer against day-and-night temperature variations. Temperatures fluctuated around 3°F at all flow rates in this section as opposed to up to 8°F in the Rio Vista habitat section at flow rates below 65 cfs. The limiting habitat factor for fountain darters in the Lower San Marcos A section was lack of vegetation. Fountain darter WUA increased slightly at higher flow rates due mainly to lowered temperature effects.

Upper San Marcos Physical Habitat

This section of the report highlights fountain darter habitat simulations in the reaches of river upstream of Cape's Dam. These results are used to explore sensitivity of simulation results to such factors as channel changes and suitability curves.

The relationship between available simulated habitat for fountain darters versus discharge for the simulated scenarios in the upper section of the San Marcos River are provided in Table 15 and Figure 51. Figures 52, 53, and 54 illustrate examples of the contour plots of combined suitabilities for fountain darters in the Spring Lake to Rio Vista section of the San Marcos River for flow rates of 15, 30, and 65 cfs. These plots for the remaining simulated flows and other key river sections are contained in Appendix D and are based on the updated habitat suitability curves for fountain darters.

Table 15. Simulated fountain darter available habitat in selected sections of the San Marcos River based on 1997 channel geometries, 2001 channel geometries, and geometries based on assumed removal of Cape's Dam (No Dam). The 2009 results are based on revised habitat suitability curves.

	Rio Vista Section		Above Cape's Dam Section		No Dam					
San Marcos Total Discharge (cfs)	**1997 Geometry WUA**	**2001 Geometry WUA**	**1997 Geometry WUA**	**2001 Geometry WUA**	**2001 Geometry WUA**	**Total San Marcos 1997**	**Total San Marcos 2001**	**Rio Vista 2009 WUA**	**Above Cape's Dam 2009 WUA**	**Total San Marcos 2009**
15	48420	50700	38720	38480	13250	87140	89180	42620	36870	79490
30	89830	89170	47640	49870	17460	137470	139040	70210	47250	117460
65	174210	156020	64930	68520	22750	239140	224540	109210	55050	164260
100	188410	179710	65870	68620	22610	254280	248330	97790	40760	138550
135	197270	183320	64280	64910	22480	261550	248230	75660	22880	98540
170	188300	174840	63220	62350	22940	251520	237190	56800	15880	72680
190		179060		52800	22180		231860	54460	11440	65900
200		179060		58760	21760		237820	51640	11950	63590

These results show that habitat availability decreases most rapidly at flow rates below 65 cfs regardless of the channel geometry utilized or the habitat suitability curves used in the modeling. The revised suitability curves used for the '2009' simulations (see Figures 28 and 29), which show a very narrow range of velocity magnitudes that are suitable as well as requiring somewhat deeper water for suitable conditions results in a habitat versus flow relationship that is more 'peaked' around the maximum values at 65 cfs. The is primarily attributed to higher velocities limiting apparent fountain darter habitat as flow rates increase above the 65 cfs simulated flow. It should be noted however, that maximum habitat may in fact occur at flow rates between 65 and 100 cfs and a more refined increment of flow simulations will be utilized in the updated modeling.

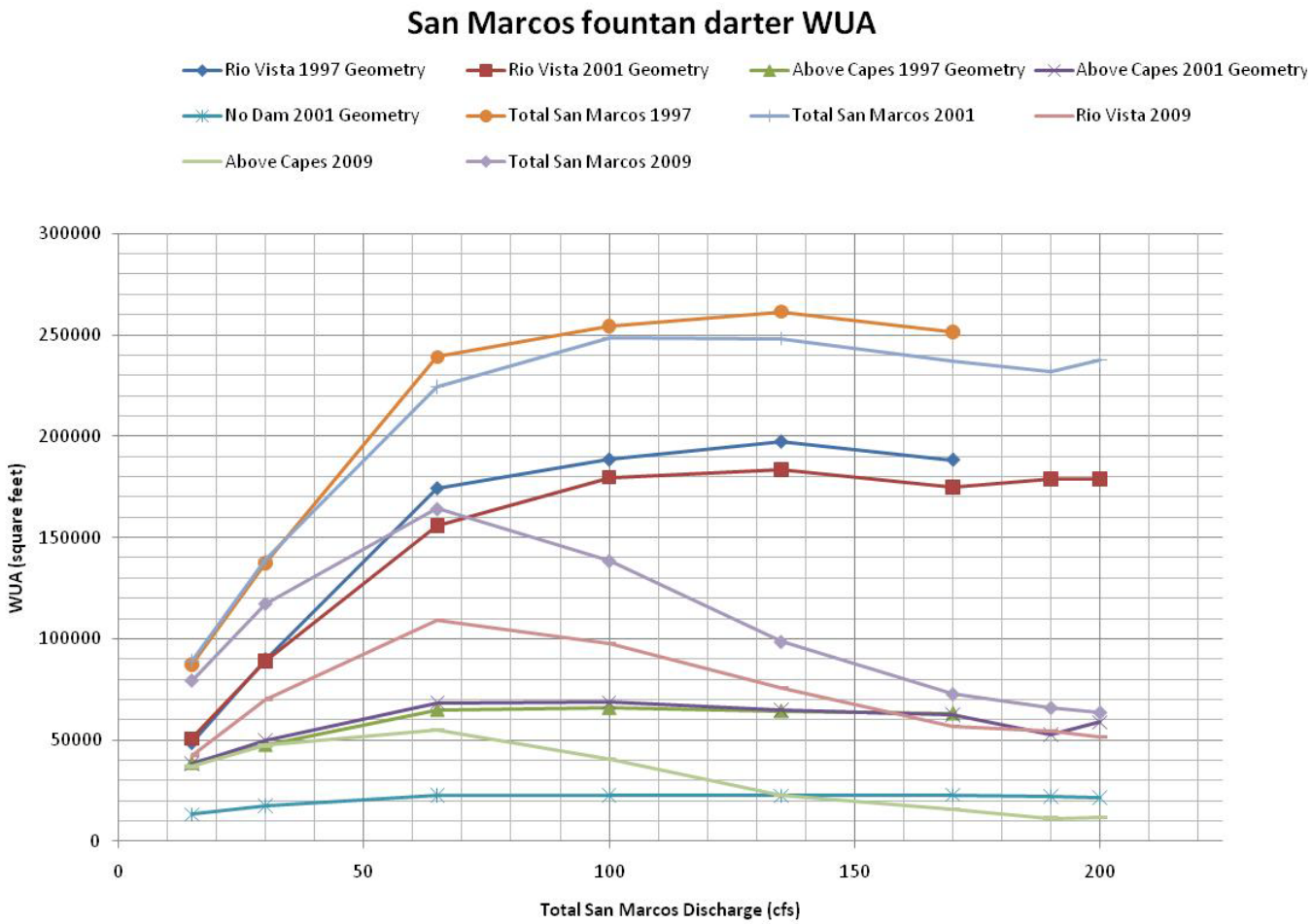


Figure 51. Simulated fountain darter available habitat (WUA) in sections of the San Marcos River based on 1997 channel geometries, 2001 channel geometries, and geometries based on assumed removal of Cape's Dam (No Dam).

Figure 52. Combined suitability for fountain darter habitat in the Spring Lake to Rio Vista section of the San Marcos River at 15 cfs.

Figure 53. Combined suitability for fountain darter habitat in the Spring Lake to Rio Vista section of the San Marcos River at 30 cfs.

Figure 54. Combined suitability for fountain darter habitat in the Spring Lake to Rio Vista section of the San Marcos River at 65 cfs.

Sensitivity to Channel Change and Habitat Suitability Criteria

These results are used to illustrate modeling sensitivity to channel changes versus habitat suitability curves as illustrated in Figure 55 which plots data from Figure 51 as the percent of maximum habitat values. These results show that the measured channel changes between 1997 and 2001 do not alter the underlying habitat versus flow relationship. It should be noted that these two comparisons only reflect changes in the topography of the computational mesh and the not revisions in the fountain darter habitat suitability functions. The results from the 2009 simulations based on the 2001 channel topographies (2001 Geometry with New HSC) reflect the updated fountain darter habitat suitability relationships. As can be seen, the changes in habitat suitability curves for fountain darter not only changed the magnitude of simulated habitat versus discharge relationship (Figure 51) but also changed the underlying habitat versus flow relationship. As noted previously, this is primarily attributed to the differences in the velocity suitability curve (see Figure 29).

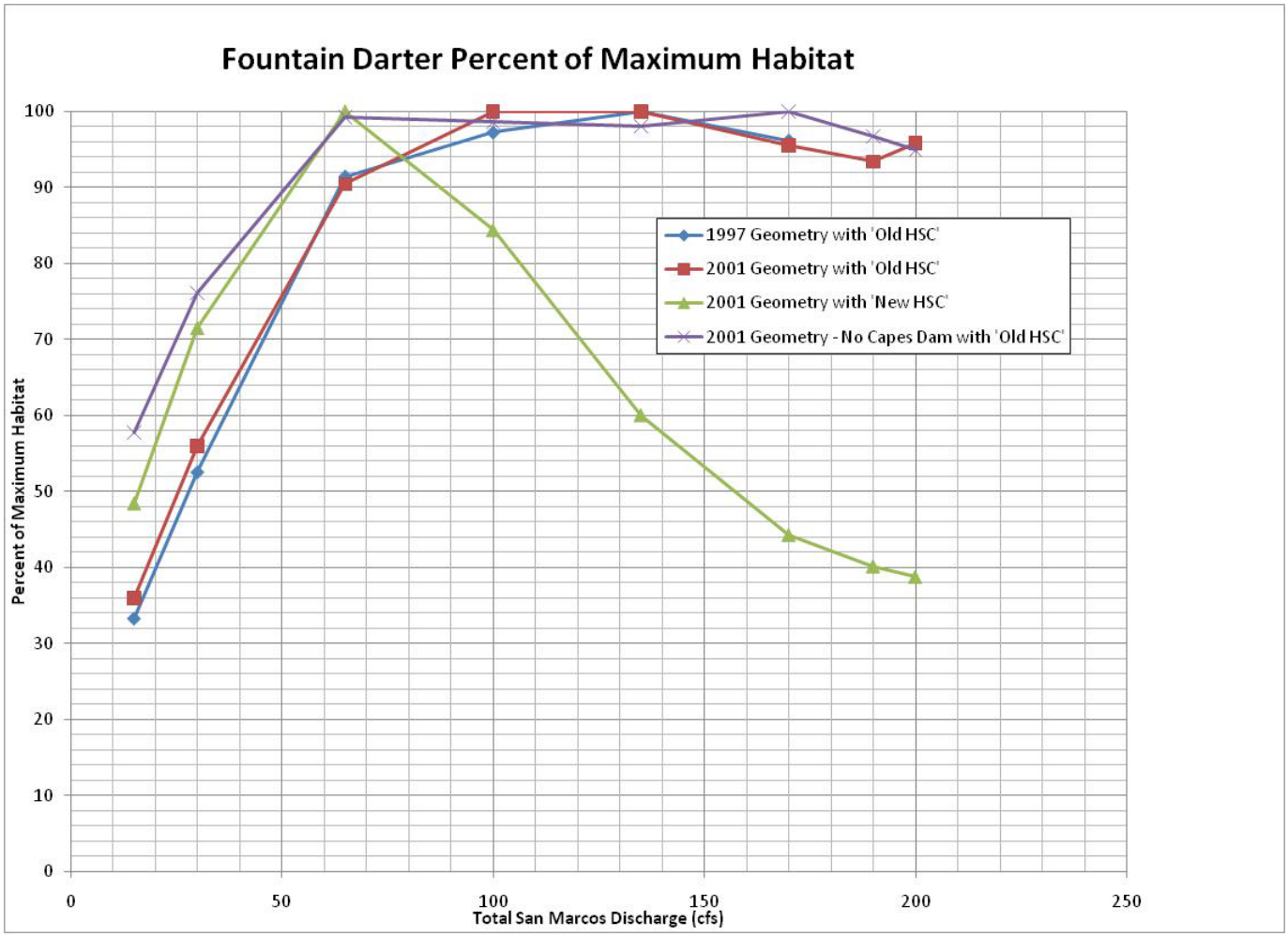


Figure 55. Relationship between total San Marcos river discharge and simulated available fountain darter habitat as a percent of maximum habitat.

Fountain Darter Physical Habitat Summary

It is apparent from a comparison of these simulation results that the combined effect of channel change and differences in habitat suitability curves for fountain darters can shift the flow rate at which habitat is maximized. The results (see Table 15) also illustrate that these factors show a differential response by specific river reach. However, it is clear that regardless of these simulation differences, fountain darter habitat quantities show declines within the San Marcos River as flow rates drop below about 65 cfs. It is cautioned however, that more simulated flows between the 65 and 30 cfs flow range are needed in the revised modeling currently underway to better define where this rapid decline in available habitat begins.

Other Native Aquatic Species

In addition to the three target species that are the focus of the quantitative assessments presented above, a number of other native species inhabit the Comal and San Marcos Rivers. In this section of the report several key species are highlighted and discussed in light of the results from the existing modeling.

Comal Springs dryopid beetle (Stygoparnus comalensis)

The Comal Springs dryopid beetle is considered to be primarily a subterranean species, although it has been collected from all six spring runs and springs located along the western margin of Landa Lake (Barr and Spangler 1992, Randy Gibson personal communication). Given its subterranean distribution and use of spring runs, it is likely not significantly impacted by changes in spring flow discharge. Assuming that flow regimes are maintained in the Comal River such that spring discharges are maintained to protect the Comal Springs riffle beetle and fountain darters, adequate protection would be maintained.

Peck's cave amphipod (Stygobromus pecki)

Peck's cave amphipods have been collected from all six spring runs and springs located along the western margin of Landa Lake (Arsuffi 1993, Barr 1993, Randy Gibson personal communication). This species appears to be primarily a subterranean species with limited distribution within spring runs. No quantitative data is available on its life history requirements. As noted for the Comal Springs dryopid beetle, maintenance of spring flow in the Comal River system would likely provide adequate protection for this species. However, it is noted that periodic drying may not result in large impacts due to its subterranean distribution.

San Marcos Gambusia (Gambusia georgei)

The San Marcos gambusia has not been collected since 1982 and is most likely extinct (USFWS 1996). The mechanisms responsible for the decline and apparent extirpation are not known but hybridization with the western mosquitofish (*G. affinis*) and loss of suitable habitat along the stream margins due to invasion of the exotic macrophyte elephant ears (*Colocasia esculenta*). It is assumed that if adequate flow regimes exist for the protection of fountain darters, suitable hydrologic and water quality conditions would be maintained for this species.

Texas blind salamanders (Eurycea rathbuni)

Texas blind salamanders are distributed throughout the aquifer in the San Marcos region of the Edwards Aquifer. Given their subterranean distribution with the aquifer, maintaining spring flows within the San Marcos River would likely ensure flow related protection for this species. However, continued protection of groundwater water quality remains a concern given the projected increases in population density within this region.

San Marcos salamanders (Eurycea nana)

San Marcos salamanders (*Eurycea nana*) have been reported throughout Spring Lake and up to ~ 500 feet below Spring Lake Dam (Nelson 1993). They appear to prefer areas with silt free rocks associated with spring openings, silt free rocky substrates within the main channel of the San Marcos River, and are associated with filamentous algae within Spring Lake. Although it appears that populations within Spring Lake would be protected as long as adequate spring flows are maintained, populations within the downstream channel of the San Marcos River are at risk from both reduced flow rates and recreation activities.

Cagle's map turtle (Graptemys caglei)

The Cagle's map turtle is distributed within areas of the Guadalupe and lower San Marcos Rivers in Kerr, Kendall, Comal, Guadalupe, Gonzales, DeWitt, Hays, and Victoria Counties (Killebrew et al. 2002) and is a candidate for listing by the USFWS. Maintaining adequate spring flow regimes for protection of Texas wild rice and fountain darters will likely contribute to suitable flow and water quality conditions in these downstream reaches.

Non-native Species

Non-native species are a concern in both the Comal and San Marcos River systems. These include mammals, aquatic plants, snails, parasites, and fish species. In most cases, the direct or indirect impacts to native flora and fauna are not known. This section of the report highlights several non-native species that are known or suspected of having potential impacts to the key target species. Tables 16 and 17 provide a list of the fish collected from the Comal and San Marcos River systems as part of on-going critical flow monitoring supported by the Edwards Aquifer Authority.

The list of species within the Comal and San Marcos Rivers include several potential native and non-native predators. However, the extent to which predation may be limiting fountain darters is unknown. Long-term monitoring of fountain darter populations over moderate to high flow rates do not indicate predation as a major factor, but may be more problematic at low discharges when spatial segregation becomes more difficult. This could be exacerbated with low flows and loss of aquatic vegetation density (and diversity) that fountain darters rely on for habitat selection. The broader impacts of introduced species in terms of alteration of trophic pathways, competition of food resources, etc. is basically unknown at this time.

Suckermouth Catfish (Hypostomus sp.)

A concern has arisen given the apparent high density of suckermouth catfish which are herbivorous. At high densities, indirect impacts to fountain darters may occur due to large scale alterations in the aquatic vegetation density and composition upon which fountain darters are dependent. Physical alteration of the stream banks due to burrowing is also a concern with large trees being felled due to bank instability. This can indirectly affect water quality by increased sediment inputs. This would also affect Texas Wild rice directly through herbivory and indirectly when downed trees scrape the river bottom during flood events.

Table 16. List of fish taxa and number collected from the Comal River between 2001 and 2007. Adapted from Bio-West (2008a).

COMMON NAME	SCIENTIFIC NAME	STATUS	NUMBER COLLECTED	
			2007	2001-2007
Rock bass	*Ambloplites rupestris*	Introduced	0	18
Black bullhead	*Ameiurus melas*	Native	0	1
Yellow bullhead	*Ameiurus natalis*	Native	4	85
Mexican tetra	*Astyanax mexicanus*	Introduced	34	285
Central stoneroller	*Campostoma anomalum*	Native	0	1
Rio Grande cichlid	*Cichlasoma cyanoguttatum*	Introduced	24	355
Guadalupe roundnose minnow	*Dionda nigrotaeniata*	Native	1	260
Fountain darter	*Etheostoma fonticola*	Native	1045	10466
Greenthroat darter	*Etheostoma lepidum*	Native	2	55
Gambusia	*Gambusia sp.*	Native	5403	72233
Suckermouth catfish	*Hypostomus plecostomus*	Exotic	1	60
Redbreast sunfish	*Lepomis auritus*	Introduced	13	132
Green sunfish	*Lepomis cyanellus*	Native	0	10
Warmouth	*Lepomis gulosus*	Native	0	24
Bluegill	*Lepomis macrochirus*	Native	0	30
Longear sunfish	*Lepomis megalotis*	Native	2	38
Redear sunfish	*Lepomis microlophus*	Native	1	1
Redspotted sunfish	*Lepomis miniatus*	Native	97	1075
Sunfish	*Lepomis sp.*	Native/Introduced	32	663
Spotted bass	*Micropterus punctulatus*	Native	0	1
Largemouth bass	*Micropterus salmoides*	Native	4	86
Texas shiner	*Notropis amabilis*	Native	1	34
Mimic shiner	*Notropis volucellus*	Native	27	28
Sailfin molly	*Poecilia latipinna*	Introduced	221	3689
Blue tilapia	*Oreochromis aurea*	Exotic	2	18

Table 17. List of fish taxa and number collected from the San Marcos River between 2001 and 2007. Adapted from BioWest (2008b).

COMMON NAME	SCIENTIFIC NAME	STATUS	NUMBER COLLECTED	
			2007	2001-2007
Rock bass	*Ambloplites rupestris*	Introduced	21	322
Black bullhead	*Ameiurus melas*	Native	0	2
Yellow bullhead	*Ameiurus natalis*	Native	7	71
Mexican tetra	*Astyanax mexicanus*	Introduced	4	18
Rio Grande cichlid	*Cichlasoma cyanoguttatum*	Introduced	5	39
Guadalupe roundnose minnow	*Dionda nigrotaeniata*	Native	13	39
Fountain darter	*Etheostoma fonticola*	Native	767	2376
Gambusia	*Gambusia sp.*	Native	1738	18413
Suckermouth catfish	*Hypostomus plecostomus*	Exotic	7	26
Redbreast sunfish	*Lepomis auritus*	Introduced	2	40
Green sunfish	*Lepomis cyanellus*	Native	0	5
Warmouth	*Lepomis gulosus*	Native	0	22
Bluegill	*Lepomis macrochirus*	Native	11	76
Longear sunfish	*Lepomis megalotis*	Native	0	3
Redspotted sunfish	*Lepomis miniatus*	Native	32	598
Sunfish	*Lepomis sp.*	Native/Introduced	16	126
Largemouth bass	*Micropterus salmoides*	Native	4	38
Gray redhorse	*Moxostoma congestum*	Native	0	3
Blacktail shiner	*Cyprinella venusta*	Native	0	6
Texas shiner	*Notropis amabilis*	Native	0	17
Ironcolor shiner	*Notropis chalybaeus*	Native	2	54
Unknown shiner	*Notropis sp.*	Native	0	4
Tadpole madtom	*Noturus gyrinus*	Native	0	4
Blue tilapia	*Oreochromis aurea*	Exotic	0	4
Texas logperch	*Percina carbonaria*	Native	0	2
Dusky darter	*Percina sciera*	Native	1	14
Sailfin molly	*Poecilia latipinna*	Introduced	0	92
Unknown molly	*Poecilia sp.*	Introduced	0	30

Tilapia (Tilapia sp.)

Landa Lake is known to support an increasing population of tilapia. This species is omnivorous with a preference for aquatic vegetation and detritus. As noted for the suckermouth catfish, indirect affects from alteration of the aquatic vegetation community are of concern.

Nutria (Myocastor coypus)

Nutria are found both in the Comal and San Marcos River systems. However, very little work has been undertaken to examine their potential impacts on native species within these river. Nutria may cause direct and indirect impacts through destruction of aquatic vegetation and eroding river banks. It is speculated that if river flows in these systems are severely reduced, potentially significant impacts may occur due to alteration of vegetation preferred by fountain darters thereby reducing overall habitat availability and quality. Nutria have been observed eating Texas Wild rice.

Elephant Ears (Colocasia esculenta)

Vegetation monitoring has shown the distribution and density of Elephant Ears is increasing in some sections of both river systems. This invasive species does not provide high quality habitat for fountain darters and can completely exclude wild rice stands. In addition, its broad aerial leaf morphology results in very high transpiration rates, which at lower discharges has the potential to impact low flow regimes.

Giant Ramshorn Snails (Marisa cornuarietis)

Giant Ramshorn snails have periodically been a concern due to their ability to significantly alter the density and composition of the aquatic vegetation community. Although the Giant Ramshorn snail has been known from the Comal Springs system since about 1983, they reached very high density in the later 1980s and significantly reduced vegetation stands in Landa Lake (Horne et al. 1992, Linam et al. 1993). However, by the early 1990s, populations underwent a significant decline. The mechanisms for their increased density may have been associated with sustained lower than normal flows, while their decline may have been related to over crowding in conjunction with higher sustained spring discharges (Horne et al. 1992). Population densities at present are low, but appear to be increasing with the sustained low flows within the Comal River (Tom Brandt, personal communication). At present, populations in the San Marcos River are at very low numbers.

Asian snail (Melanoides tuberculata)

The primary concerns with the Asian snail are its impact on native vegetation and as an intermediate host for the gill parasite (*Centrocestus formosanus*) on fountain darters. Population increases appear to be related to sustained low flows which in turn can lead to increases in the abundance of gill parasites (Tom Brandt, personal communication).

Gill Parasite (Centrocestus formosanus)

Increasing concern has arisen over the impact of the gill parasite on fountain darters. Infection of fountain darters has been traced to cercariae emerging from the exotic red-rimmed melania snail, *Melanoides tuberculata*. Impacts include direct mortality from heavy infestation and sub-lethal effects due to stress. Bolick (2007) reported that neither total stream discharge (USGS gauge) nor wading discharge (measured at each transect when collections were taken) were found to be a useful predictor of cercarial abundance. However, historical field observations in the Comal River indicate that abundance is related to sustained low flows in combination with above average water temperatures (Tom Brandt, USFWS, personal communication). Recently, increased infection rates within the San Marcos River have been reported and may be related to the lower sustained discharges during the 2008-2009 drought (Tom Brandt, personal communication and unpublished field data).

Recreation

As noted in the results section for Texas wild rice, the primary factors considered from the results of the existing modeling was a qualitative evaluation of Texas wild rice locations that would 'be at risk' from shallow depths (≤ ~ 3 feet) as flow rates drop in the San Marcos River. These risks primarily focus on physical disturbance. However, observations during the original studies cited in this report as well as on going monitoring activities for Texas wild rice clearly show that as recreation intensity increases on a given day, the downstream turbidity dramatically increases in both the Comal and San Marcos River systems. Anthropogenic suspension of fine sediments can be severe enough to preclude visual delineation of wild rice stands in the lower San Marcos River in the afternoon during high recreation use periods (Jackie Poole, personal communication). Field observations by the author while diving in both the Comal and San Marcos River systems showed that in the lower extents of both rivers, fine particulate matter completely covered the submerged aquatic vegetation. The extent to which the suspended sediment and physical sedimentation may be inhibiting Texas wild rice (or other native aquatic species) is unknown. Recreational activities also have the potential to affect fountain darter through direct and indirect impacts. Direct effects include tramping and continual displacement of individuals in high use areas. Indirect impacts include reduction of suitable habitat areas due to disturbance or complete loss of specific vegetation types preferred by fountain darters. It is anticipated that these effects are likely to be exacerbated during low flow conditions but could be mitigated through aggressive recreation control measures.

Summary

Historical and updated modeling of water quality (temperature and dissolved oxygen) and physical habitat for Texas wild rice, Comal Springs riffle beetle, and fountain darters have been summarized for use by the Expert Science Committee of the Edwards Aquifer Recovery and Implementation Program. Updated habitat suitability curves for fountain daters were developed based on a analysis of available monitoring data. Data visualization and summary results were prepared based on input from members of the Expert Science Committee as well as other knowledgeable scientists familiar with these target species and the Comal and San Marcos River systems.

Physical habitat modeling involved the application of two-dimensional hydrodynamic models to estimate the distribution of available depths and velocities as a function of simulated flow rate for specific sections of both the Comal and San Marcos Rivers. Temperatures were derived from the QUAL2E model reported in Bartsch et al. (1999) and Hardy et al. (1998) for the San Marcos River and Comal Rivers. These data were used in combination with habitat suitability curves for depth and velocity to estimate available habitat for Texas wild rice and the Comal Springs riffle beetle over a variety of flow rates. Fountain darter habitat was modeled using depth, velocity, vegetation type, and temperature. Vegetation distribution for each river was taken from historical vegetation mapping results. Fountain darter habitat suitability curves were derived from a multivariate analysis of long term monitoring data from the Comal and San Marcos Rivers.

Detailed contour plots of the combined suitability derived from the component suitabilities of depth, velocity, vegetation type and temperature (as appropriate) for Texas wild rice and fountain darters were developed for each modeled river section for the the Comal and San Marcos Rivers at each simulated discharge. In addition, summary relationships between predicted available habitat discharge were developed. Finally, modeling sensitivity to changes in channel topography and habitat suitability curves are provided.

Future Study Recommendations

- The current efforts to remodel by the Comal and San Marcos River systems should be undertaken with a single hydrodynamic model. This will allow for easier technology transfer and allow a consistent analysis framework.
- It is also recommended that a single water quality model be applied in both river systems for these same reasons. The model should simulate maximum daily temperatures and be applied system-wide for both rivers.
- Water quality modeling should consider non-point and point source pollutants to the extent these inputs can be approximated from available data.
- Analysis of alternative species beyond the three target species focused on in this report should also be undertaken. The specific species to be included should be determined after an analysis of the existing long-term monitoring data available for both river systems.
- Consideration should be given the potential vegetation changes if possible since vegetation responses to flow regime changes are critical to evaluation of available fountain dater habitat.
- A quantitative assessment of potential impacts associated with recreation should be considered that includes not only Texas wild rice but other aquatic vegetation.
- Analysis of channel topography changes due to fine sediment input should also be considered if possible.
- A finer resolution on the number of simulated flows is also important, especially for flow ranges below the average annual flow to better inform decisions on critical flow management.
- Refinement in the total Comal River discharge versus specific spring flow rates and flow rates at which specific springs cease to flow should be undertaken.
- Texas wild rice habitat simulations should be modified to account for computational cells occupied by other species.
- If feasible, system wide substrate mapping in the San Marcos “under” existing vegetation stands should be considered to allow evaluation of non-native plan removal on providing suitable Texas wild rice habitat beyond a depth and velocity evaluation.
- Evaluate the potential of including anthropogenic induced turbidity on light attenuation as a function of the longitudinal profile of the river systems and its implication on vegetation.

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Appendix A

Definition of terms used in preliminary Edwards Aquifer influence diagrams

Area/Area occupied

Physical space being taken up by any given species. Depending on context could be its actual as well as potential range. May be the area occupied, weighted by habitat quality.

Not clear yet if focus should be occupancy or more direct population measure (density) – may differ between the species' modeled (occupancy for TWR; density for FD?)

Bank erosion (disturbance)

Loss of vegetation cover and resulting soil disturbance and erosion into the river; (see 'light' for issue of lost cover and shade)

Barriers (dams, sediment, vegetation mats)

Any structure within the river channel that impedes or changes migration of biota and river flow; a barrier of any size constructed to alter or retain stream flow potentially impeding the movement of species, with potential demographic and/or genetic effects; modification of flow and habitat.

Channelization

Process where a river channel is entrenched and deepened because of stabilized banks (e.g., a byproduct of bank stabilization); resulting loss of a river's flexibility to meander and reduced variation in stream morphology.

Catastrophic spill

Spill of chemicals/contaminants into a river causing direct mortality to species in the water (e.g., of pesticide); may be spilled from trains, trucks or other vehicles on roads, or point sources near the river.

CO2

Carbon dioxide gas, used in photosynthesis; water quality indicator.

Competition

Two individuals/species using the same resource at a level which causes conflict between them. The success of one in obtaining the resource is at the detriment of the other. A concern when invasive species compete with native species.

Connectivity

The degree of continuity between suitable habitat patches, allowing for natural patterns of movement and resulting demographic and genetic interchange.

Dam Management and modification

Operation and alteration of existing dams in the river, such as to support water recreation. May alter current patterns of water flow, sediment transport and deposition both above and below the dam (with various potential effects on aquatic species, not necessarily negative).

Density (persistence measure)

Number of individual organisms per unit space, in this case either a persistent average number or annual low number of individuals.

Disease – see Parasites & Disease

DO

Dissolved oxygen in water; indicator of water quality. Essential for respiration (e.g., by fish).

Facility Development (e.g., recreation)

Creation and enhancement of buildings or other structural features supporting human use of the river or river banks, e.g., access facilities, boat or inner tube liveries, etc.

Floating mats

Plant matter uprooted or washed into the water column through artificial (human activity) or natural (flooding) means which gathers together and collects along the surface of the water in quantities large enough to disturb plant life/affect local water quality. Where floating vegetation mats aggregate they block light, and may raise water temperature, or fragment and uproot in situ plants.

Flooding

High water levels that overflow banks usually due to sudden influx of water; pulses of water in a stream caused by rain events, which vary in magnitude and frequency.

Flow

Quantity of water moving in stream/river or aquifer, measured in cubic feet per second (cfs).

Fragmentation

Separation of formerly contiguous habitat area into distinct areas, potentially limited species' movement between habitat areas. May result in patch sizes too small to support life history requirements, or reduce demographic or genetic exchange between patches that affect population persistence.

Groundwater recharge

Input of water (e.g., from rainfall) seeping into underground water storage and flow, particularly in headwater areas of the aquifer; source of continuing water flow in the aquifer.

Habitat

The physical area and structural features (aquatic or terrestrial), and associated ecological processes, that provide for reproduction, food, and shelter/cover, and thus, continued survival of species; habitat quality and quantity.

Habitat Occupied

Area of habitat in which individual of a species live at least some part of the year, for reproduction, feeding, shelter or movement; the habitat area actually occupied by individuals over some time frame, which may be less than the total habitat area suitable for the species' occupancy.

Habitat Suitability/Suitable Habitat

The relative quality of habitat, or measure of how suitable the area is to support reproduction, feeding, shelter or movement; usually on 0-1 index.

Herbivory

Consumption of plant material by animals that obtain some or all of their nutrition through ingesting plant material; may affect plant species persistence when herbivory exceeds natural patterns, such as by invasive or increasingly abundant herbivores (nutria, waterfowl, crayfish).

Invasive animals, vegetation

Any species that outcompetes native species for resources (food, refuge, space). Particularly those that are very adaptable/competitive and have been introduced by human activity from a distance not normally within the ability to naturally disperse (e,g., importing plants from other countries, ship travel, etc, e.g., Hydrilla. Unnaturally overabundant species (includes exotics).

Nuisance species.

Invasive fish

For example, Plecostomus, Tilapia, rock bass, Mexican tetra, small mouth bass, oscar, grass carp (potential).

Invasive snails

Invasive vegetation

For example, Hydrilla, Hygrohila, elephant ear, Cryptocoryne, giant cane, water hyacinth, watercress, slime algae.

Known occupancy

Habitat area actually occupied by individuals, based on empirical observation/sampling, recognizing that additional areas may also be occupied where they have not (yet) been detected.

Land cover

Vegetation or non-vegetative covering on the land, which affects movement of water across the surface and into the groundwater, streams and rivers. Also, affects the quantity and types of environmental contaminants entering waterways and their movements and concentrations.

Land (watershed) management

Any activity or structure that focuses on changing the water quality or quantity of runoff (overland or ground) into streams and rivers within the land area that drains into the San Marcos or Comal Rivers. Management can range from education to a detention pond. Implementing programs and management strategies to protect those watershed functions through sustainable use. Lack of watershed/land management affects water, sedimentation, and environmental contaminant inputs to waterways.

Light

Amount of sunlight/photosynthetic energy reaching the water surface and underwater, thus available to plants for photosynthesis. Light ranges from full to partial and no sunlight, affected by bridges, floating vegetation mats, and riparian vegetation.

Mortality

Death of individuals, and per-capita or unit mortality rates per time period.

Non-point pollution

Input of environmental contaminants into waterways from diffuse sources such as results from movement of rainwater over rooftops, roads, lawns, and industrial and agricultural lands.

Nutrient overload

Excess concentrations of organic chemicals (N, P, etc.) in water that supports concentrated growth of algae or organisms that in turn reduce oxygen concentrations in the water necessary for respiration by native aquatic species.

Overland flow

Flow of water (rainwater) over the land surface, as opposed to groundwater.

Parasite/disease

An organism utilizing a host species. Burdens can stress the host organism making it more susceptible to environmental changes. Or vice versa, populations otherwise stressed by habitat or competition factors may experience increased mortality rates due to parasites and diseases, producing chronic population impacts.

Patch size

How large the area of suitable habitat is and its contribution to overall habitat.

Persistence

Continued existence of a population for many decades to hundreds of years.

Plant restoration

Planting or otherwise replacing or increasing the number of plants growing in an area where they had been reduced or absent, e.g., in formerly occupied area.

Point pollution (discharge)

Any discernible and confined conveyance of environmental contaminants to a water body, such as from a waste discharge pipeline (for example, at the state fish hatchery).

Population growth, human

Increase in number of people who work, live and play within the watershed.

Predation

The ingestion of one species by another resulting in mortality. A normal process that can be detrimental to population persistence if it exceeds the prey species' ability to reproduce and replace the lost individuals over time. Includes predation by native and invasive fish (for fountain darter).

Prey availability/available

Quantity of and access to living food sources (e.g., invertebrates).

Pumping

Withdrawal of water from an aquifer or stream. Pumping of water from the Edward's Aquifer from Kinney County to Hays County for industrial, municipal and residential use.

Rainfall (precipitation)

The amount and frequency of precipitation and the impacts of rainfall on flow and water quality in the watershed.

Re-colonization

Re-occupancy of a habitat area by individuals following extirpation.

Recreation (trampling)

People's leisure activities in and along the river, i.e. boating, swimming, tubing, picnicking, walking, running, diving, etc. Results in direct disturbance or impacts on plants, stream banks, and river bottom substrate; plant removal; suspension of solids into the water; erosion and sedimentation.

Sediment input

Input of sediment into the river from open areas within the watershed; adverse effects on river habitat and function when it exceeds natural patterns or types of sediment, and water turbidity and sedimentation patterns.

Sedimentation

Deposition of suspended particulate matter onto a stream bottom; adverse effects on river habitat and function when the accumulations alter natural patterns of accretion, channel morphology and subsequent water flow and vegetation growth.

Sediment retention

Sediment remaining in places where it normally would not be, such as due to man-made structures or habitat change (e.g. dams); typically results from lack of flushing flows.

Spills – see Catastrophic spills

Spring flow/Spring orifice flow

The amount of water flowing from the aquifer. The cubic feet per second of water discharging from springs in the Edwards Aquifer into streams/rivers. The quantity, timing and pattern of water flowing from springs. The flow directly at the spring orifices.

Spring orifice

Place where spring flow reaches the land surface (in stream or lake).

Substrate

The “bottom type” or material covering the bottom of streams and rivers, e.g., silt, cobble, boulder, etc. The composition of the streambed.

Substrate disturbance

Direct trampling or dislodging of stream bottom substrate, such as by human walking, dogs, boats, or by events such as floods.

Subsurface flow

Quantity of water flowing in a riverbed, below the surface of the river bottom or substrate (e.g., within the soil or gravel); encompasses habitat for subterranean species such as beetles and other invertebrates.

Subsurface substrate

The “bottom type” or material underneath the bottom surface of streams and rivers, e.g., silt, cobble, boulder, etc. The composition of the layers under the streambed.

Suspended solids

Solid material (e.g., silt, organic matter) suspended within the water column.

Turbidity

A measure of water clarity; indication of quantity of solids suspended in the water column.

Total area occupied – see Area occupied

Upwelling flow

The amount of water flowing out from the aquifer at upwelling sites (which are not full sized spring orifices).

Urban runoff

Flow of rainwater across urbanized land cover. The amount of impervious ground cover in urban areas affects the quantity and rate of surface water movement; urban cover is also the source of numerous environmental contaminants.

Urbanization

Conversion of natural, agricultural and other land uses to cities. Establishment or expansion of urban land cover and uses, and human populations; increase in human activities and impacts in the watershed.

Vegetation

Plants. Aquatic plants needed for cover, forage, and reproduction; also includes undesirable/invasive species.

Water depth

Measure of vertical water column; depending on stream morphology, water flow, and time of measurement.

Water quality

The physical, chemical and biological characteristics of water. Degradation indicators/measures include concentrations of DO, surfactants; and turbidity (suspended sediments).

Water quantity – see Flow

Water temperature

The temperature of the water within the stream column; patterns of temperature variation from headwaters to confluence and over time; affects species occupancy, growth and mortality.

Water Velocity

Speed of water flow.

Definition of terms not used in preliminary Edwards Aquifer influence diagrams

Associated native species as factor: lack of?

Bridges

Structures which span the river channel from one bank to another. Could be natural such as fallen tree or more likely to be man-made.

Source of shade; locations for potential contaminant spills (& recreational access?)

Climate change

long-term alteration in global weather patterns, typically seen as increases in temperature extremes and storm activity (due to both natural and human causes)

as factor: higher temperature, decreased precipitation

Exotics

any species that is not native to the drainage

Dispersion

the ability to migrate upstream and downstream between different groups in a population

Hydrologic regime change

as factor: Loss of seasonal and/or quantitative natural flow variation

Impervious area

the amount of area within the SMR/CR watershed that is covered by an impervious material (no infiltration/total runoff). Need to list which materials are to be considered impervious and which are somewhat pervious and which, if any, are mostly pervious.

created ground cover that no longer permits natural penetration of water and increases surface runoff

as factor: groundwater recharge, runoff (change in)

Land Development

the change from natural to developed land and the associated impacts of varying amounts of impervious cover and types of land use (direct and indirect) on the SMR/CR

the construction of commercial and/or residential buildings and associated infrastructure

Preferred vegetation

the types of aquatic plants preferred by the listed species in the SMR/CR for refuge and food sources (direct or indirect). All other things being equal, the vegetation chosen for use by the species.

Only native vegetation?

Reproduction

the reproductive characteristics of the species (timing, fecundity, mate selection, etc..)

Riparian changes

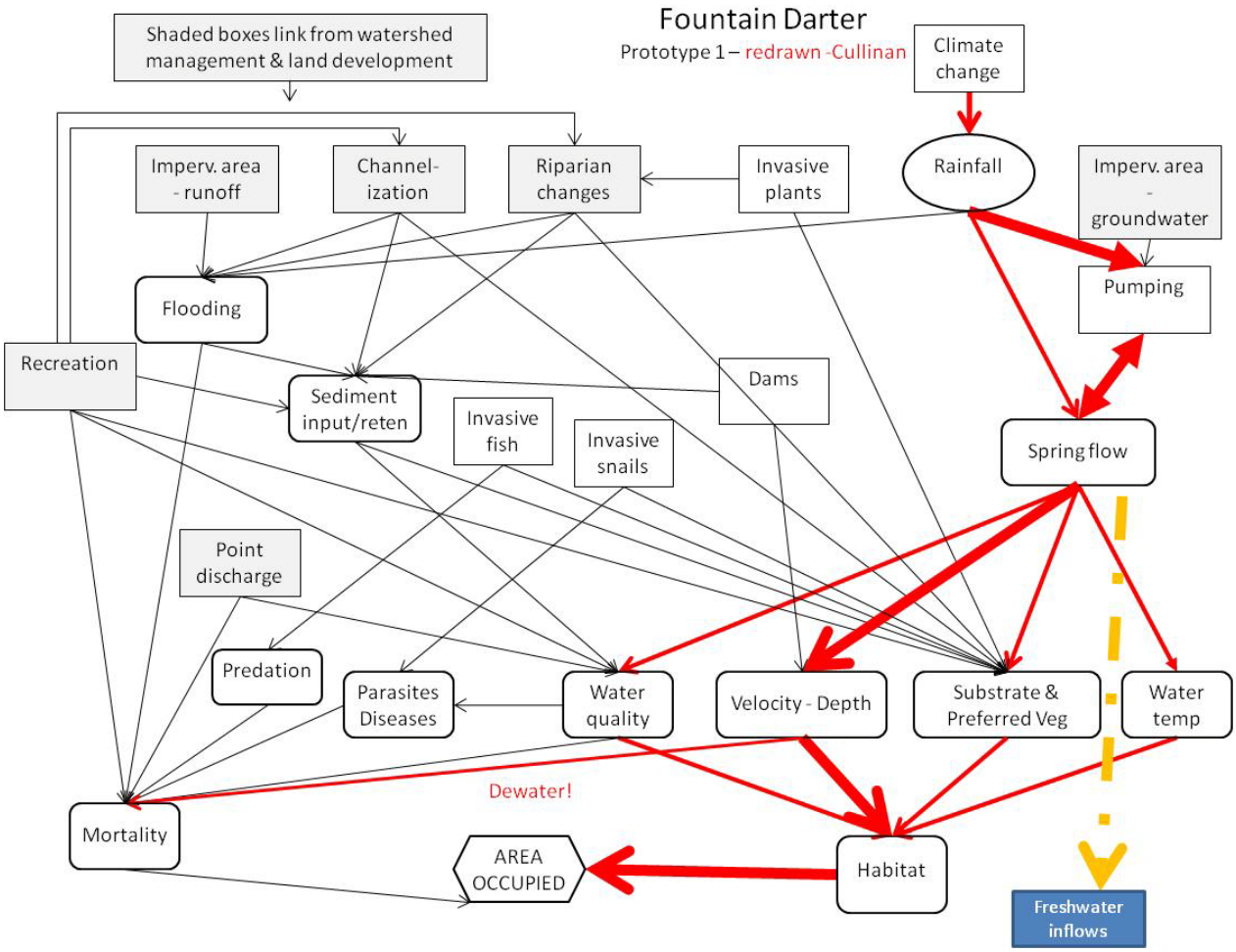
change in the native/historical plant species along the SMR/CR. Focus is on the introduction of invasive species and loss of riparian area.

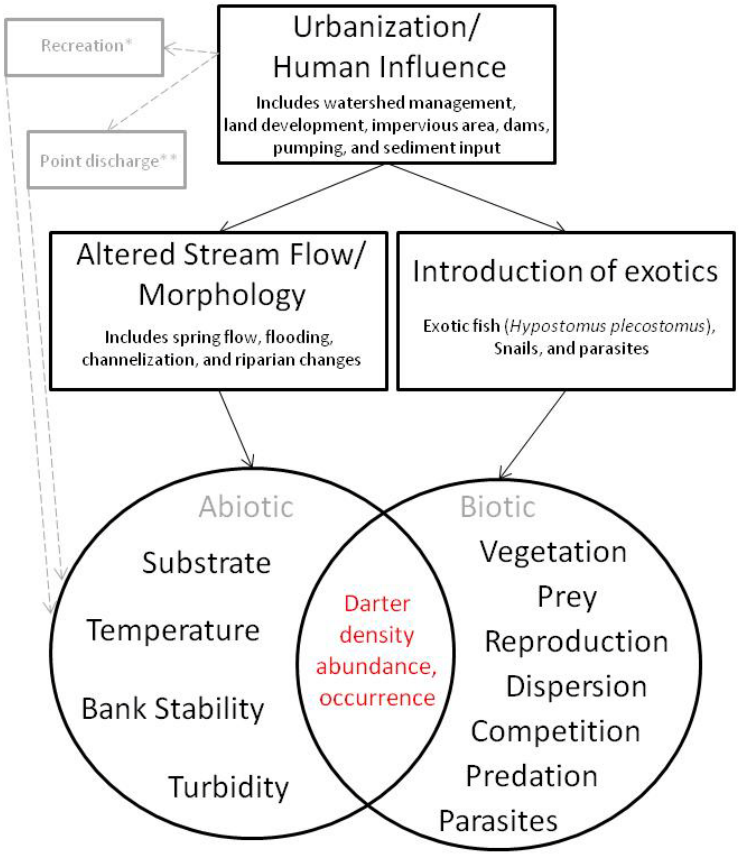
changes in natural plant species and abundances along the riparian corridor

as factor: Tree fall, increasing canopy coverage blocking light; loss of natural shoreline, detritus

Submitted revisions and comments to the preliminary Edwards Aquifer influence diagrams

Steve Cullinan

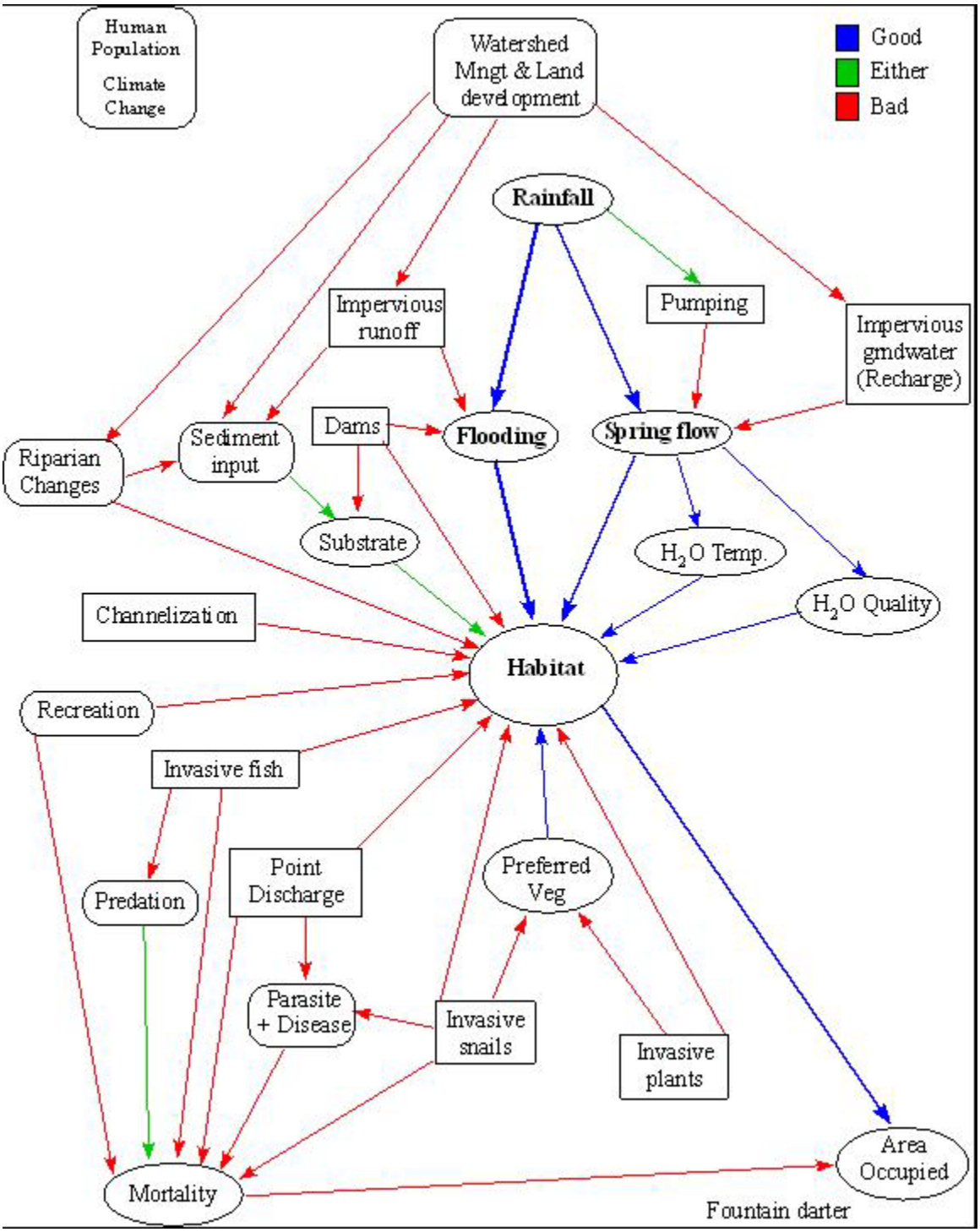


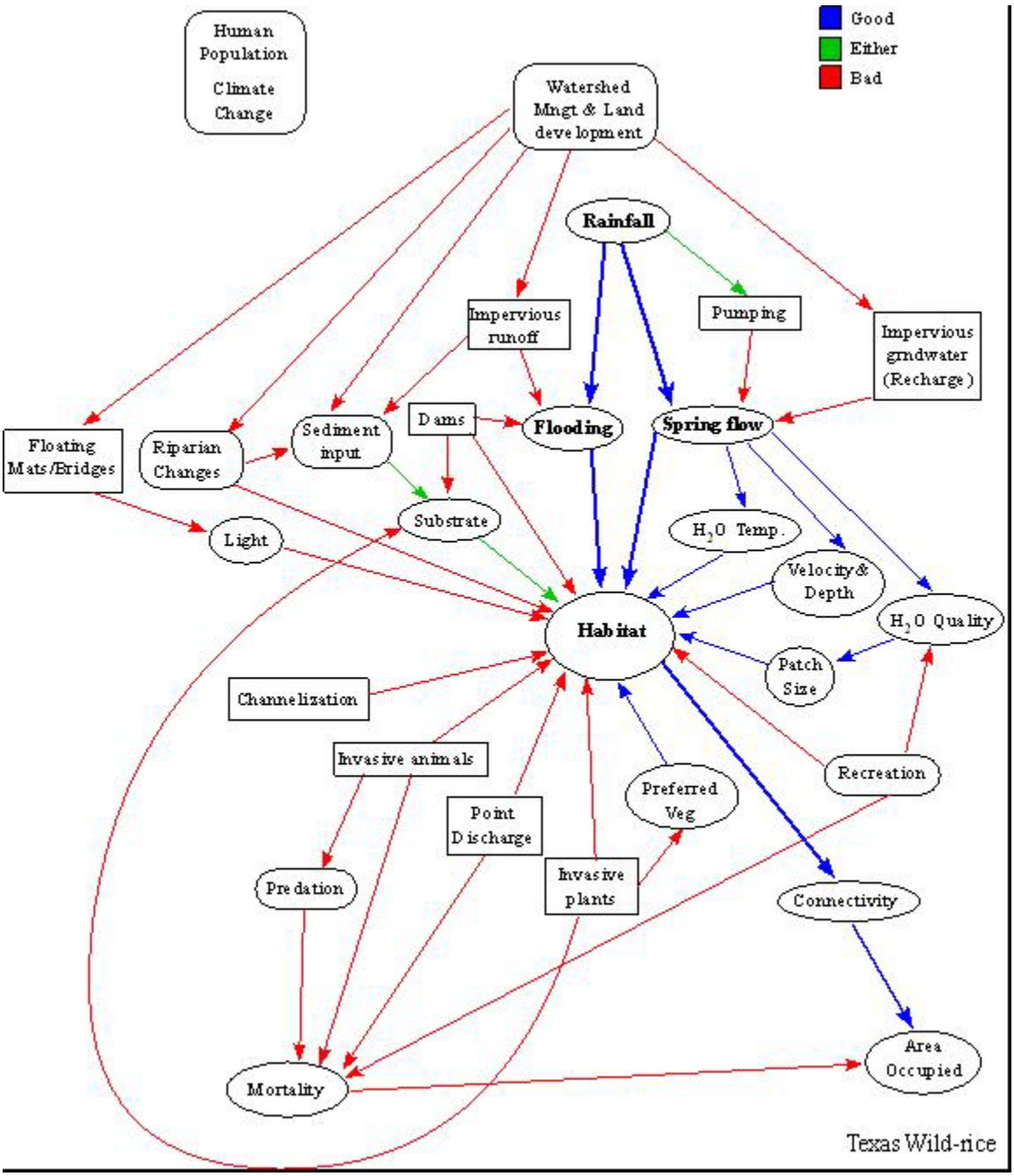


(Grey boxes indicate concerns that are less of a priority than those in black boxes)
* The impacts of recreational activities are suspected but have not been demonstrated
** Point source pollution is not likely an issue for darters in the San Marcos River

Definitions:

Urbanization- the establishment or expansion of cities
Watershed management- the process of gathering information about all aspects of watershed processes and usages and then implementing programs and management strategies to protect those watershed functions through sustainable use
Land development- the construction of commercial and/or residential buildings and associated infrastructure
Impervious area – created ground cover that no longer permits natural penetration of water and increases surface runoff
Dams- a barrier of any size constructed to alter or retain stream flow potentially impeding the movement of fish
Pumping – withdrawal of water from aquifer or stream
Sediment input – deposition of particulate matter into a stream
Spring flow – the amount of water flowing from the aquifer
Flooding – pulses of water in a stream that vary in magnitude and frequency caused by rain events
Channelization- process where a river channel is entrenched and deepened because of stabilized banks
Riparian changes- changes in natural plant species and abundances along the riparian corridor
Exotics – any species that is not native to the drainage
Substrate- the composition of the streambed
Turbidity- a measure of water clarity
Vegetation – aquatic plants needed for cover, forage, and reproduction; also includes undesirable species/exotics
Prey – invertebrate food sources
Reproduction – the reproductive characteristics of the species (timing, fecundity, mate selection, etc..)
Dispersion – the ability to migrate upstream and downstream between different groups in a population
Competition - utilization of the same resource (a concern with the exotic species)
Predation – ingestion resulting in mortality
Parasites- an organism utilizing a host species; burdens can stress the host organism making it more susceptible to environmental changes


Human Population
Climate Change
Watershed Mngt & Land development
Good
Either
Bad
Rainfall
Impervious runoff
Pumping
Impervious gmdwater (Recharge)
Riparian Changes
Sediment input
Dams
Flooding
Spring flow
Substrate
H2O Temp.
H2O Quality
Channelization
Habitat
Recreation
Invasive fish
Predation
Point Discharge
Preferred Veg
Parasite + Disease
Invasive snails
Invasive plants
Mortality
Area Occupied
Fountain darter


Good
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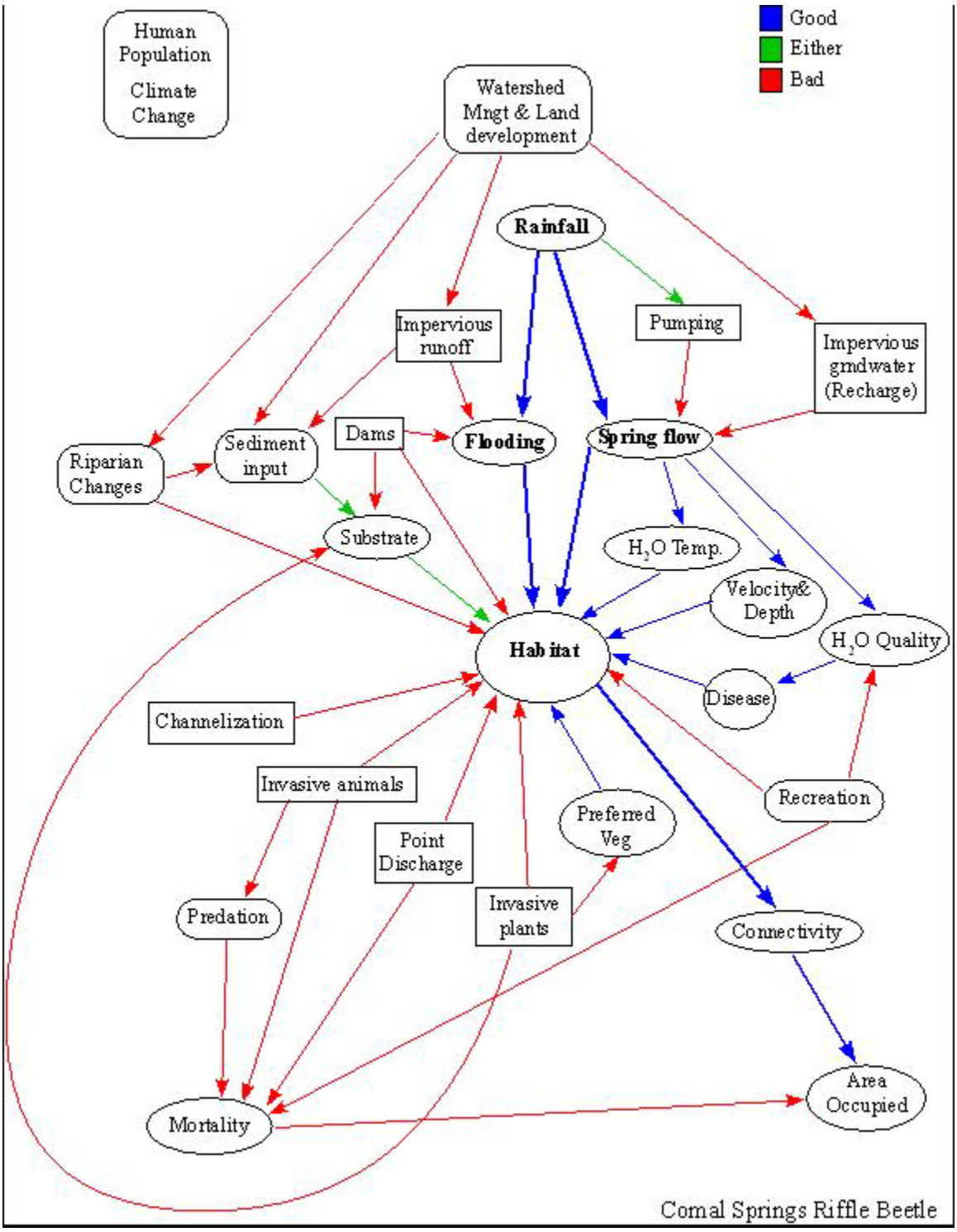
Human Population
Climate Change
Watershed Mngt & Land development
Rainfall
Impervious runoff
Pumping
Impervious grndwater (Recharge)
Floating Mats/Bridges
Riparian Changes
Sediment input
Dams
Flooding
Spring flow
Substrate
Light
H2O Temp.
Velocity& Depth
Habitat
H2O Quality
Patch Size
Channelization
Invasive animals
Recreation
Preferred Veg
Point Discharge
Invasive plants
Predation
Connectivity
Area Occupied
Mortality
Texas Wild-rice


Good
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Human Population
Climate Change
Watershed Mngt & Land development
Rainfall
Impervious runoff
Pumping
Impervious grndwater (Recharge)
Riparian Changes
Sediment input
Dams
Flooding
Spring flow
Substrate
H2O Temp.
Velocity& Depth
H2O Quality
Habitat
Disease
Channelization
Invasive animals
Recreation
Preferred Veg
Point Discharge
Invasive plants
Predation
Connectivity
Area Occupied
Mortality
Comal Springs Riffle Beetle

Alisa Shull

Comments on fountain darter prototype 1 (redrawn) influence diagram

1. how is “water quality” defined?
2. how confident are we that the influence on parasites is water quality and not, for example, velocity or temperature?
3. invasive snails - are they influenced and spread by birds (e.g. herons?) and are they influenced by water quality, velocity? Does invasive snails specifically mean melanoides? Looks like it based on influence arrow to parasites. What about ramshorn snails – are they included for their potential influence on veg? and what are ramshorn influenced by? Why have they declined in numbers – high flows? crayfish?
4. does water temp. also influence mortality directly? And/or through effects on reproduction?
5. is preferred veg influenced by velocity and depth?
6. is recreation directly influencing sediment input, as shown, or is the influence via riparian changes?
7. how are “riparian changes” defined?
8. is recreation causing direct mortality (as indicated) or is it through effects on veg., etc.?
9. specify that dams referred to means dams in the river system – correct? As opposed to flood control dams in the watershed.
10. isn’t flooding also influenced by flood control dams in the watershed? Also, does flooding have an influence on parasites? Or invasive snails? Or substrate and preferred veg? or velocity and depth?
11. what does “point discharge” include here? Does it include wastewater trt plants, catastrophic spills, storm drains? Is point discharge also influencing veg through water quality?
12. how are you capturing the influence of velocity and depth on substrate and preferred veg – and vice-versa?
13. it’s not clear why the “dewater” is off by itself?
14. impervious cover – groundwater: not all pumping is for impervious areas (e.g. ag use); and influence of pumping comes from more than the local watershed – this isn’t clear from the diagram.
15. what do the different shaped boxes on the diagram mean?

<u>Comments on Comal Springs riffle beetle prototype 1 (redrawn) influence diagram</u>

Note many of the same comments made on fountain darter diagram apply here. Plus:

1. invasive fish are competing with riffle beetles? Which fish? What are they competing for – food?
2. what parasites and disease? Are they ones known to occur in the riffle beetle?
3. are there no water temp effects on direct mortality?
4. how does the spring orifice influence mortality?

Comments on Texas wild-rice prototype 1 (redrawn) influence diagram

Note many of the same comments made on fountain darter diagram apply here. Plus:

5. Isn't light also influenced by turbity (water quality effects from point discharge and sediment input)?
6. does recreation influence connectivity of habitat?
7. are floating mats influenced by invasive plants? by recreation?
8. do invasive plants affect direct mortality? Or some influence besides those shown? What is cryptocoryne influencing that would influence wild-rice – light?

Jenna_Melani

Area occupied – physical space being taken up by any given species, depending on context could be its actual as well as potential range.

Bridges- Structures which span the river channel from one bank to another. Could be natural such as fallen tree or more likely to be man-made.

Channelization - loss of a river's flexibility to meander

Climate change - long-term alteration in global weather patterns, typically seen as increases in temperature extremes and storm activity (due to both natural and human causes)

Competition- Two individuals/species using the same resource at a level which causes conflict between them. The success of one in obtaining the resource is at the detriment of the other.

Connectivity- the degree of continuity between suitable habitat patches

Dams (barriers) – any structure within the river channel that impedes or changes migration of biota and river flow

Floating mats- plant matter released into the water column through artificial (human activity) or natural (flooding) means which gathers together and deposits along the surface of the water in quantities large enough to disturb plant life/affect local water quality.

Flooding - overflow of banks usually due to ppt/sudden influx of water

Habitat – the area that has the necessary factors for continued survival of listed species in the SMR/CR

Hebivory- animals which obtain some or all of their nutrition through ingesting plant material.

Human population – the people that work, live and play within the SMR/Comal watersheds

Impervious area – the amount of area within the SMR/CR watershed that is covered by an impervious

material (no infiltration/total runoff). Need to list which materials are to be considered impervious and which are somewhat pervious and which, if any, are mostly pervious.

Invasive fish/snails/plants - any species that outcompetes native species for resources (food, refuge, space). Particularly those which are very adaptable/competitive and coming from a distance not normally within the ability to naturally disperse (other continent) due to human activity (importing plants from other countries, ship travel, etc…)

Land Development – the change from natural to developed land and the associated impacts of varying amounts of impervious cover and types of land use (direct and indirect) on the SMR/CR

Light- amount of sunlight/photosynthetic energy available to plants.

Mortality – death (individual or population/community….).

Parasite/disease – parasites and diseases harmful to the listed species in the SMR/CR and that are present in the SMR/CR

Patch size- how large the area of suitable habitat is/the contribution of the area to overall habitat

Point discharge – any discernible and confined conveyance of pollutants to a water body (for the SMR – the WWTP and state fish hatchery)

Predation – the ingestion of one species by another, while a normal process can be detrimental if it exceeds a species ability to grow or reproduce.

Preferred vegetation – the types of aquatic plants preferred by the listed species in the SMR/CR for refuge and food sources (direct or indirect). All other things being equal, the vegetation chosen for use by the species.

Pumping – pumping of the Edward's Aquifer from Kinney County to Hays County for industrial, municipal and residential use

Rainfall – the amount and frequency of precipitation and the impacts of rainfall on flow and water quality in the SMR/CR

Recreation – people's leisure activities in and along the SRM/CR, i.e. boating, swimming, tubing, picnicking, walking, running, diving, etc.

Riparian changes – change in the native/historical plant species along the SMR/CR. Focus is on the introduction of invasive species and loss of riparian area.

Sediment input – input of sediment into the river from open areas within the SMR/CR watershed

Sediment retention- sediment remaining in places where it normally would not be were there not man-made structures or habitat change (e.g. dams)

Spring flow – the cubic feet per second of water discharging from the Edwards Aquifer into the SMR/CR.

Spring orifice- place where spring flow reaches surface

Substrate – the “bottom type” – silt, cobble, boulder, etc.

Velocity/Depth- how fast and how deep

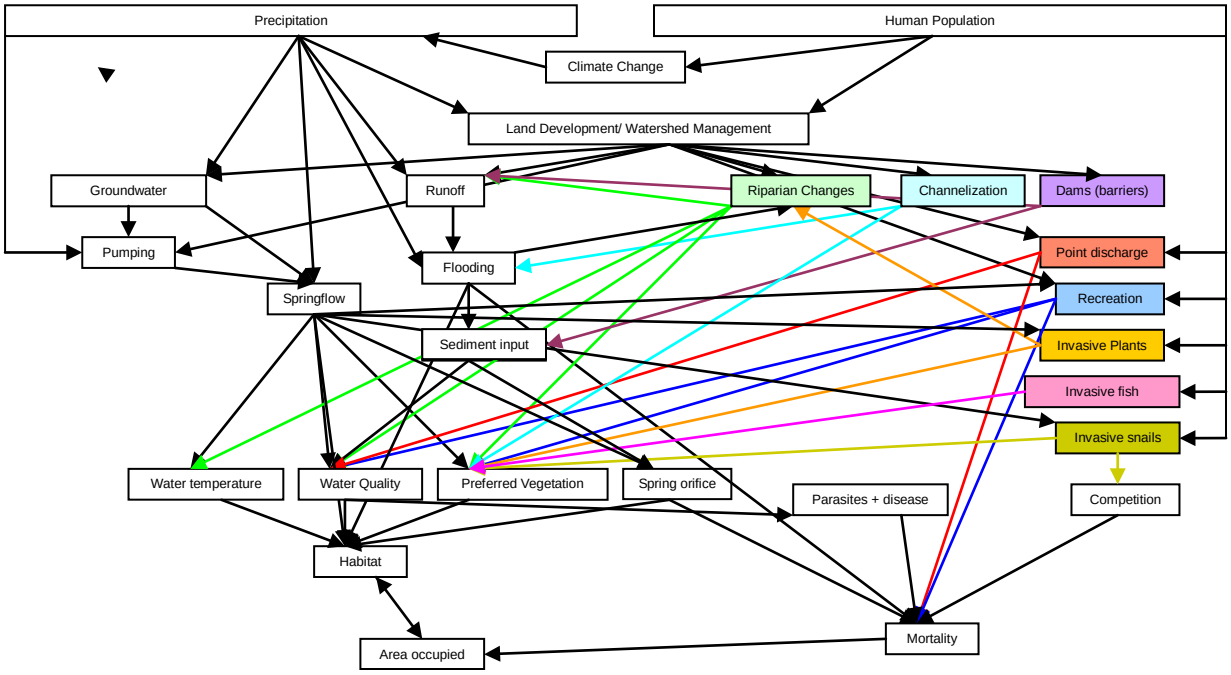
Water quality – the physical, chemical and biological characteristics of water

Water temperature – the temperature of the water from headwaters to WWTP (in the SMR); in the CR – from the headwaters to confluence with Guadalupe

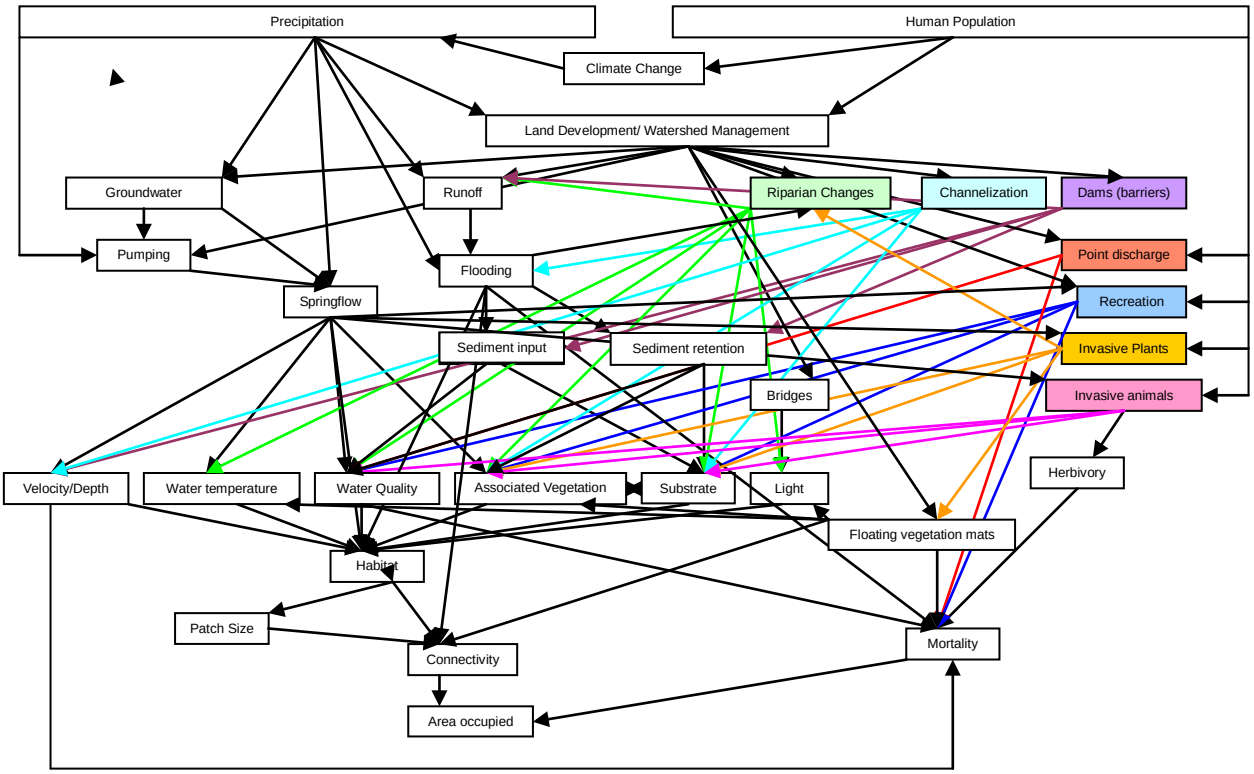
Watershed management – any activity or structure that focuses on changing the water quality or quantity of runoff (overland or ground) into the SMR/CR within the land area that drains into the SMR or CR. Management can range from education to a detention pond.

Jackie Poole

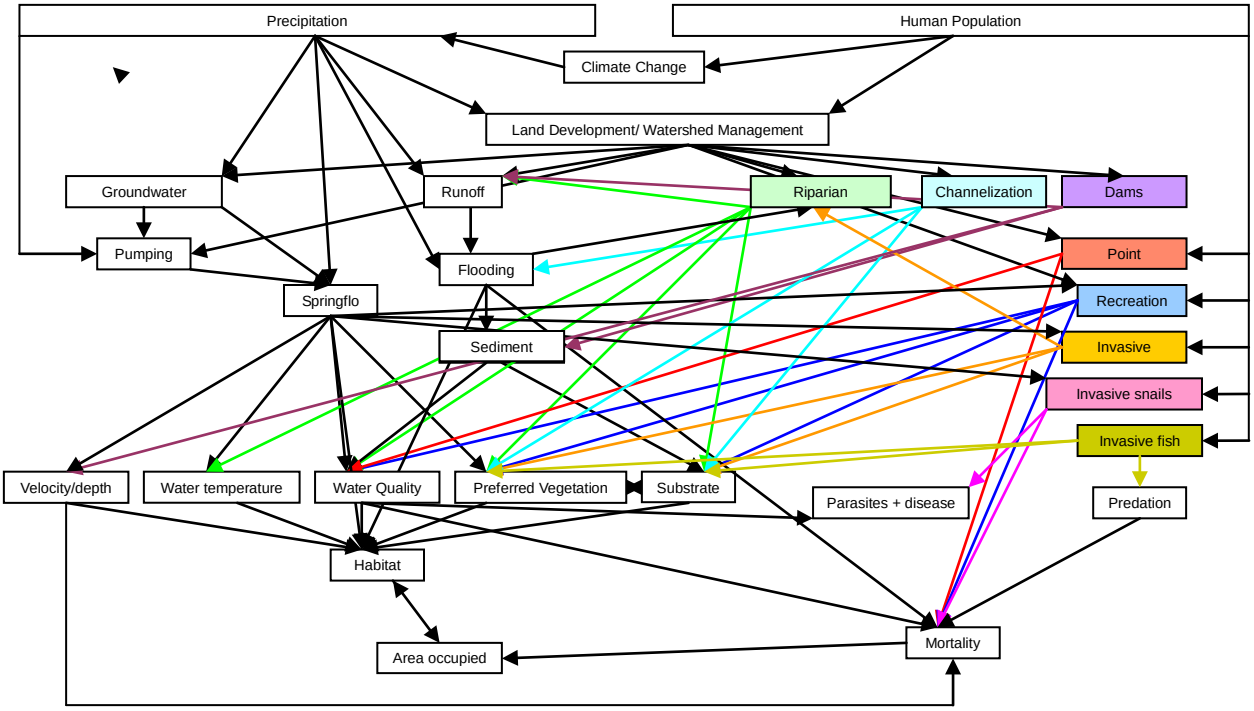
Hey everyone - I spent a day going over the diagrams and the species factor list. I redid the diagrams, primarily to help me reconnect to the project and keep my thinking straight. I hope that no one is color blind as I added color because there were too many lines! I added definitions or clarifications to the intrinsic and extrinsic factors and used Track Changes for that and to add comments (mouse over the cells with colored corners to see the changes/comments). I had a somewhat cryptic note about "identifying areas where we have information". I wasn't sure exactly sure if that was to be applied to the factor lists and/or influence diagrams so I've left it off for now. I was sure what constituted "information" (i.e., published? anecdotal?). It seemed to me that we had some sort of information about everything so I must be misinterpreting something.



Texas wild rice



Fountain darter



Species List

Intrinsic Factors	vulnerability and resiliency										
	FOUNTAIN DARTER	v/r		TEXAS WILD-RICE		v/r		COMAL SPRING RIFFLE BEETLE		v/r
1	Restricted distribution	v	1	Restricted distribution	Upper two miles of the San Marcos River	v	1	restricted distribution		v
2	Specificity of water quality	v	2	Restricted habitat	Depth, flow, water quality, CO2, temp, substrate, associated species, light	v	2	genetically isolated populations		v
3	tolerance to water temperature range	r	3	Short-lived perennial	Individual plants (genets) probably less than 10 years	v	3	short lifespan (1 yr in refugium)		v
4	genetically diverse - San Marcos	r	4	Out-crossing	Requires pollen transfer between individuals; requires larger populations but produces genetic heterogeneity	r	4	plastron respiration (O2 sensitivity)		v
5	sight feeder - sensitive to turbidity	v	5	Low fecundity	Few reproductive individuals result from amount of seed produced	v	5	not subterranean		?
6	tolerant to low oxygen	r	6	Vegetative reproduction	Production of more individuals under certain conditions (R) but individuals lack genetic diversity (V)	r/v	6	genetically diverse in spots		r
7	strong correlation to vegetation (structure)	v	7	Low survivorship	Few individuals make it to reproductivity	v	7	eat fungus		?
8	strong correlation to low velocity	v	8	Vegetative dispersal	Tillers may root in place or float downriver (potentially beyond habitat - V)	r/v	8	reproduce year round		r
9	Diet flexibility	r	9	Resilient	Able to recover to pre-disturbance state	r	9	environmentally sensitive	only high water quality, near springs	v
10	Movement ability (within reach)	r	10	Short-term seed viability	Not viable after 1 year; recalcitrant	v	10	detritus-fungus associated	roots, rocks, wood, plants--riparian shoreline	v
11	Dispersal ability (meta-poplulation; between reaches	r	11	High environmental variation	climatic variability (droughts, floods) which also causes changes in sediment, associated vegetation, etc.	v	11	interstitial species (gravel, cobble)		v
12	high population turnover rate	r	12	Climax species	persistent in native version of river	v	12	larvae tolerate lower DO than adults		r
13	high variance in abundance	v	13	only one population	prone to damage by stochastic events	v	13	low dispersal ability (flightless)		v
14	lack response to parasites	v	14	high heterozygosity	most heterozygoisty concentrated in large stands	r	14	larvae have gills	may be resilient to low spring flow for ? time	r
			15	large, medium & small stands	can fragment & coalesce	r	15	pollution sensitivity (plastron)	surfactant pollution	v
			16	Seed dispersal	Limited by floating only short distances	v				
			17	dispersal limited	for sexual reproduction; depensatory threshold	v				

Extrinsic Factors

1/21/2009			number of 'votes' most influence		least influence
FOUNTAIN DARTER			3	2	1
1	Dewatering		15	0	0
2	Flooding		3	7	5
3	Imprevious area increase	Groundwater recharge	6	9	0
4		Runoff	3	12	0
5	Sediment input	fine & coarse	9	6	0
6	Hydrologic regime change		6	6	3
7	Invasive fish	Tilapia	1	8	6
8		Plecos	6	9	0
9		Rock bass	0	10	5
10		Mexican tetra	0	4	11
11		Small mouth bass	0	5	10
12		Oscar	0	4	11
13	Invasive plants	Cane giant	2	0	13
14		Elephant ear	2	5	8
15		Hydrilla	3	10	2
16		Hygrophila	3	4	7
17		Water hyacinth	2	5	7
18		Watercress	1	2	11
19		Slime algae	1	7	6
20	Recreation	Substrate disturbing/removal	5	10	0
21		Bank disturbing	1	13	1
22		Plant disturbing/removal	5	10	0
23	Parasites & disease		8	6	0
24	Dams - barriers & habitat alteration		1	12	2
25	Channelization		2	10	3
26	Water quality - degradation		7	7	0
27	Watershed management		6	9	0
28	Riparian changes		1	8	6
29	Invasive snails		3	8	3
30	Point discharge		0	9	5
31	Catastrophic spill	Vehicular - road	5	2	7
32		Rail	4	2	9
33		Pipeline	1	5	7
34	Climate change		4	8	2

1/22/2009			
TEXAS WILD-RICE			Influence
1	spring flow	Quantity, quality, changes	1/2
2	flooding		1/2
3	impervious cover		1/2
4	sediment input	Too much, incorrect type	1/2
5	sediment retention	Lack of flushing flows	1/2
6	invasive fish	Grass carp potential	1/2
7		plecos	1/2
8	invasive plants	hydrilla	1/2
9		hygrophila	1/2
10		elephant ear	1/2
11		Cryptocoryne	1/2
12	Floating vegetation mats	Block light, raise water temperature, fragment & uproot plants	1/2
13	recreation	substrate disturbance	1/2
14		plant disturbance	1/2
15		plant removal	1/2
16		bank disturbance	1/2
17	Dams	Modification of flow & habitat	1/2
18	channelization		1/2
19	water quality	Degradation	1/2
20	watershed management	Lack of, or degradating	1/2
21	riparian changes	Tree fall, increasing canopy coverage blocking light	1/2
22	bank disturbance	Erosion	2/3
23	point discharge		2/3
24	catastrophic spills	(e.g., pesticide)	2/3
25	climate change	Higher temperatures, decreased percipitation	2/3
26	associated native species	Lack of ?	2/3
27	Herbivores	(waterfowl, nutria, crayfish)	2/3
28	light	Bridges, riparian vegetation, floating vegetation mats	2/3
28	fragmentation	(inadequate patch sizes)	2/3
29	temperature	Limited temperature growth range	
30	Hydrologic regime change	Loss of seasonal and/or quantitative natural flow variation	

COMAL SPRING RIFFLE BEETLE		
1	spring habitat (oriface area) limited	only found w/in feet of spring
2	spring flow	
3	water quality	DO, surfactants, etc
4	riparian changes	loss natural shoreline; detritus
5	channelization	
6	substrate change (loss interstitial habitat)	
7	sediment input/retention	
8	dams	
9	watershed management	
10	impervious areas	
11	bank disturbance	
12	recreation	bank & substrate disturb
13	point discharge	incl spills
14	water temperature	
15	climage change	
16	invasive snails (compete in refugia at low flow)	
17	invasive fish (plecos)	bank disturbance

Ed Oborny

A few weeks ago when I was in meetings out west developing conceptual models for endemic species in springs, I spent some hotel time playing around with a conceptual model/flow chart for fountain darters to stimulate thoughts regarding potential predictive ecological modeling activities. This is what I was talking to Tom Brandt about at the last SSC meeting.

It is attached. It is a first cut based on my experience on the system over the past 8 years but was also put together on the road in my free time, so it is what it is, just an initial flow chart. I have not done the same for riffle beetles or Texas wild-rice even though the rumor mill apparently begs to differ.

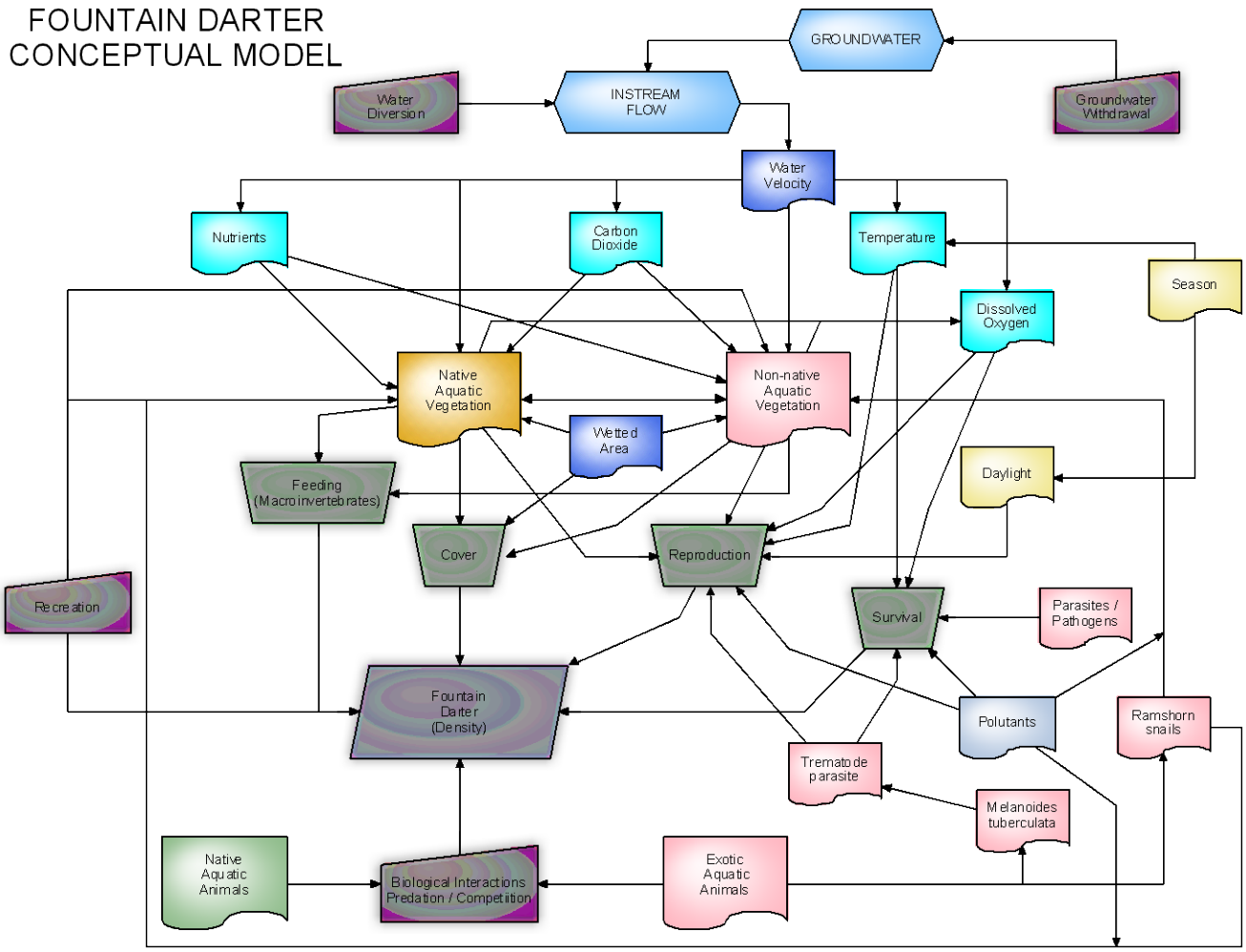
I have not even generated any text for the flowchart, but it is pretty self-explanatory. The endpoint is fountain darter density (although "health" may be more appropriate - I am still pondering this). Focal inputs (green) are food, cover, reproduction, and survival. Obviously overlap exists with these, so one needs to be careful relative to double dipping here. However, this was a way to best get my mind around it. Clearly, aquatic vegetation (either native or exotic) is a key driver for 3 of these. Water quality (CO_2 is a key driver for the veg) and temperature is a key driver for veg and darter reproduction, and at some extreme temp., survival. Light pink reflects the exotic species (plants, animals, parasites) most likely to influence other key factors. Recreation and Biological interactions (predation and competition) also act directly on the darter. One can likely quantify recreational impacts (with some assumptions) but the biol. interactions is difficult. A lot of arrows going all directions and likely several are missing, but hopefully this helps.

My goal for years has been to develop a predictive ecological model for darters in these systems, but a key factor missing has always been low-flow data. That has been why I have pushed for years to get

some low-flow experimentation done to evaluate these parameters to better fill in the assumptions that will needed to be develop a predictive model that one can have some confidence in. Had we started when this concept was first discussed, we would have that data now along with detailed predictive models, but that's life.

As I see it, we currently have enough data to make best guesses at several of the parameters which in my mind is what I see the RIP process currently requesting of your project. However, until we can quantify via observation some of these responses during low-flow conditions and/or experimentation, it leaves a lot of holes for criticism. But that's what professional judgment and best available science is, right?

Maybe this will be the year for some good low-flow data on both systems. As an FYI, we have contracts in place to do low-flow monitoring at both systems should certain triggers or durations be met. This is a solid program funded by EAA. We don't have any contracts in place to do low-flow experimentation or develop detailed predictive models. Regardless, we will continue to play (on our own time) with the development of bits and pieces of a predictive model(s) that we think would be beneficial in the long-run. I will keep you posted on what we get accomplished as it relates to your efforts.


FOUNTAIN DARTER
CONCEPTUAL MODEL
GROUNDWATER
Water Diversion
INSTREAM FLOW
Groundwater Withdrawal
Water Velocity
Nutrients
Carbon Dioxide
Temperature
Season
Dissolved Oxygen
Native Aquatic Vegetation
Non-native Aquatic Vegetation
Wetted Area
Feeding (Macroinvertebrates)
Daylight
Cover
Reproduction
Recreation
Survival
Parasites / Pathogens
Fountain Darter (Density)
Polutants
Ramshorn snails
Trematode parasite
Melanoides tuberculata
Native Aquatic Animals
Biological Interactions Predation / Competition
Exotic Aquatic Animals

Appendix B

Depth, Velocity, and Combined Suitability Contours for the Fountain Darter in the Comal River for Simulated Discharges

(by electronic download)

Appendix C

Weighted Useable Area relationships for fountain daters within the Comal River for different total Comal River flow rates and various flow split combinations between the old and new channels.

Table C.1. WUA relationships for fountain darters in the Comal River for computational segments as a function of total Comal River flows and corresponding flow splits between the old and new channels.

NC Flows (cfs)	OC Flow (cfs)	Combined Flow(cfs)	NC WUA	OC WUA	Combined (WUA)
5	25	30	14728	8073	21173
5	35	40	14642	19424	32485
10	20	30	18967	7872	25230
10	30	40	18967	8776	26141
10	40	50	18967	19210	36615
20	10	30	23509	6502	44161
20	20	40	23509	6071	39431
20	30	50	22815	8776	39840
35	40	75	22174	19210	48365
45	30	75	25423	8776	41140
60	40	100	38215	19210	61429
70	30	100	39713	8776	54418
85	40	125	49444	19210	72588
95	30	125	44275	8776	56945
110	40	150	57714	19210	80030
120	30	150	54449	8776	65836
160	40	200	51595	19210	72299
170	30	200	49561	8776	60190
Notes: NC = New Channel; OC=Old Channel; WUA = Weighted Useable Area (ft^2)					

Table C.2. WUA relationships for fountain darters in the Comal River for computational segments as a function of total Comal River flows and corresponding flow splits between the old and new channels.

NC Flow(cfs)	OC Flow (cfs)	Combined Flow(cfs)	LowerLanda WUA(ft^2)	BelowWeir WUA(ft^2)	LowerNC WUA(ft^2)
5	25	30	6948	4899	11662
5	35	40	6946	4314	7707
10	20	30	6948	4899	11662
10	30	40	0	8851	5877
10	40	50	6946	4314	7707
20	10	30	6948	4899	10968
20	20	40	8988	5938	10496
20	30	50	18548	9475	11689
35	40	75	23501	9528	11246
45	30	75	33443	10244	10762
60	40	100	33740	7789	8032
70	30	100	0	8765	5877
85	40	125	6946	4314	7707
95	30	125	6944	5136	10094
110	40	150	17155	9434	11626
120	30	150	23418	10917	15109
160	40	200	33879	12687	11147
170	30	200	34063	8736	8796
Notes: NC = New Channel; OC=Old Channel; WUA = Weighted Useable Area (ft^2)					

Table C.3. WUA relationships for fountain darters in the Comal River for computational segments as a function of total Comal River flows and corresponding flow splits between the old and new channels.

NC Flow(cfs)	OC Flow (cfs)	Combined Flow(cfs)	UpperOC1 WUA(ft^2)	UpperOC2 WUA(ft^2)	UpperOC3 WUA(ft^2)	UpperOC4 WUA(ft^2)
5	25	30	690	0	0	0
5	35	40	1057	368	0	0
10	20	30	575	0	0	0
10	30	40	989	523	0	0
10	40	50	992	316	0	0
20	10	30	655	0	0	0
20	20	40	409	0	0	0
20	30	50	989	523	0	0
35	40	75	992	316	0	0
45	30	75	989	523	0	0
60	40	100	992	316	0	0
70	30	100	989	523	0	0
85	40	125	992	316	0	0
95	30	125	989	523	0	0
110	40	150	992	316	0	0
120	30	150	989	523	0	0
160	40	200	992	316	0	0
170	30	200	989	523	0	0
Notes: NC = New Channel; OC=Old Channel; WUA = Weighted Useable Area (ft^2)						

Table C.4. WUA relationships for fountain darters in the Comal River for computational segments as a function of total Comal River flows and corresponding flow splits between the old and new channels.

NC Flow(cfs)	OC Flow (cfs)	Combined Flow(cfs)	BottomOC1 WUA(ft^2)	BottomOC2 WUA(ft^2)
5	25	30	0	5755
5	35	40	10830	5588
10	20	30	0	5688
10	30	40	0	5662
10	40	50	10820	5520
20	10	30	0	5847
20	20	40	0	5662
20	30	50	0	5662
35	40	75	10820	5520
45	30	75	0	5662
60	40	100	10820	5520
70	30	100	0	5662
85	40	125	10820	5520
95	30	125	0	5662
110	40	150	10820	5520
120	30	150	0	5662
160	40	200	10820	5520
170	30	200	0	5662
Notes: NC = New Channel; OC=Old Channel; WUA = Weighted Useable Area (ft^2)				

Table C.5. WUA relationships for fountain darters in the Comal River for computational segments as a function of total Comal River flows and corresponding flow splits between the old and new channels.

NC Flow(cfs)	OC Flow (cfs)	Combined Flow(cfs)	Above Clemens WUA(ft^2)	Above VNotch WUA(ft^2)	Above Guad WUA(ft^2)
5	25	30	0	0	0
5	35	40	0	0	0
10	20	30	0	0	0
10	30	40	0	0	0
10	40	50	0	0	0
20	10	30	0	0	14150
20	20	40	0	0	9851
20	30	50	0	0	9851
35	40	75	0	0	8543
45	30	75	0	0	8543
60	40	100	0	2126	3440
70	30	100	1965	2126	3440
85	40	125	1995	1473	2028
95	30	125	1995	1473	2028
110	40	150	2499	896	1273
120	30	150	2044	896	1273
160	40	200	2000	383	673
170	30	200	2000	572	882
Notes: NC = New Channel; OC=Old Channel; WUA = Weighted Useable Area (ft^2)					

Appendix D

Depth, Velocity, and Combined Suitability Contours for Texas Wild Rice and Fountain Darter in the San Marcos River for Simulated Discharges

(by electronic download)

Appendix E

Comment response matrix for Draft Report

Commenter	Comment	Response
Myron Hess	Page 43: I found the last paragraph regarding the Comal Springs Riffle Beetle to be a bit difficult to follow. Would it be possible to expand a bit on the rationale for using surface area of flow in modeling and, specifically, how that relates to the recolonization aspect?	Text was updated and clarified on the rationale used for surface area modeling and includes more discussion on recolonization.
	Page 43: In the last sentence of this paragraph, should "but" be "by"?	Fixed.
	Page 43: Also, the basis for the use of the 0.02 foot depth is unclear. The previous discussion seems to suggest that 1 inch is the usual minimum depth. Further explanation would be appreciated.	Text was clarified to address the 0.02 foot criteria as this is the threshold depth for wetting and drying in the solution of the hydrodynamic model and therefore the accuracy limit on depths for this application.
	Page 45: Figure 26, although labeled as depth habitat suitability, appears to be a duplicate of Figure 27 and a depiction of the velocity habitat suitability curve.	Updated the correct Figure.
	Page 57: I found the last paragraph in the Dissolved Oxygen section to be a bit difficult to follow. Would it be possible to expand a bit on the discussion of the diel DO swings? In particular, it is unclear if the observed field values of DO include 24-hour monitoring. At any rate, some expanded discussion, if possible, of the diel swings would be helpful	Expanded the discussion on implications of diel oxygen swings. See page 41 where it states that the diel model calibration and validation runs were based on measured hourly data sets.

	Page 57: Also, the discussion here seems to suggest that night-time DO levels likely would not be limiting at low flows. However, discussion elsewhere in the document, e.g. p. 67, seems to suggest that night-time DO levels could be problematic for some species. Some further clarification would be helpful.	This section was clarified to explain that the diel swings in DO under existing vegetation and flow conditions are not anticipated to be limiting. Also added discussion that with low flows and potential vegetation die-off's that night time DO levels may become problematic.
	Page 81: The references, on this page, to Figures 52-54 are, apparently, all off by one Figure. That is, it appears that the reference to Figure 52 should be a reference to Figure 53, etc.	Fixed figure reference sequence.
Jackie Poole	Hard copy edits to the report were provided.	All editorial comments were made as suggested. Clarifications were also made were suggested edits were related to unclear material presentation.
	p. 22, paragraph 2 - Hydrodynamic Modeling - Physical Characterization - While the 1998 flood did deposit some material above University Drive bridge, most of the material came from construction sediment from Sessoms Creek.	Revised to text to note the contribution of sediment was primarily from Sessoms Creek construction sources.
	p. 32, Table 4 - Why wasn't wild-rice included in the vegetation class and roughness assignments?	All of the data were collected from the Comal River and therefore no wild rice stands were measured. At the time that the work on the San Marcos was undertaken, the USFWS asked that we not disturb wild rice stands so no data was collected. Roughness was assigned however based on other codes. Text clarified in this regard.
	p. 45, Fig. 26 - Graph should be the depth HSI curve.	Fixed.

	p. 61, Fig. 39 - The plots for depth for 10 & 40 cfs look identical. Are they or does one need to be replaced?	Revised the scaling for these figures, changed to larger plots for readability.
	p. 66, Fig. 43 - This figure is very difficult to read; plus are the simulation reaches in black or brown?	Revised this figure to make it readable .
	p.67, Table 12 - This table shows that WUA increases steadily with increasing flows in Rio Vista and Above Cape's Dam. When is this data from? Why does it differ significantly from Table 13?	Text was clarified in terms of source of data and modeling. Table 12 was based on suitability curves used in Bartsch et al. 2000 and are different than the TPWD curves used in the current analysis.
	p. 68, Rio Vista, 2nd sentence - I'm sure that it should "mean depths". Somewhere there should be an explanation that "mean" depths and/or velocities are averages, with much higher and lower depths/velocities. For example, in 1996 and 2009 there were dozens of stands that were stranded at 100 cfs.	Text was clarified to highlight that the modeling outputs mean column velocities or velocities at 15 cm above the bottom. Depths are not averages but the depth at each computational cell based on topography and water surface elevations. Text was modified to be clear on this.
	p. 69, Upper San Marcos Physical Habitat, 2nd paragraph, 3rd sentence - I don't see the "same values" among any of the simulations.	Text clarified.

	p. 70, Table 13 - What units are the WUA in? What is the 2009 analysis based on? There's not an explanation that I can see. The 2009 numbers are problematic. All show a break point at 65 cfs. WUA show shouldn't peak at 65 cfs if observations show that depths are unsuitable (i.e., plants stranded) at 100 cfs. There are similar issues with the fountain darter Table 15.	Units were added and text clarified as to the source data used in the modeling. Do not confuse the estimated total habitat for wild rice or fountain darters versus specific locations where stands may have been dewatered while other areas are predicted to be suitable although not occupied. Text was added to address this issue and clarify interpretation of modeling results.
	p. 88, Suckermouth catfish - Suckermouth catfish would also affect Texas wild-rice directly through herbivory and indirectly through downed trees that could scrape wild-rice off the river bottom during floods.	Text was added to note this potential impact from catfish and the potential for impacts associated with physical disturbance of tree movement during flooding.
Calvin Finch/San Antonio Water System	On May 15, 2009, SAWS submitted comments on the Influence Diagrams that are an important component of this study. Other EARIP stakeholders also submitted comments. In keeping with the procedures utilized to date with other Science Subcommittee reports, an appendix should be developed that catalogs this feedback. This appendix should also be referenced in the report on page 11 (Executive Summary) and page 15 (Influence Diagrams for Target Species). The final report would be further strengthened by an explanation as to whether and how the comments received were incorporated into the analysis.	These diagrams were primarily developed to support the USFWS HCP analysis and ancillary to the work reported in this document. However, an appendix was added to highlight comments received. Reference to the added appendix was inserted as requested. Text was added to the report to clarify this issue.

	Additionally, describe how the influence diagrams touch upon the various aspects of the model results. For example, what aspects of the model could management strategy proposals, such as ecological restoration activities being considered by other EARIP subcommittees, improve upon? Also, how would those improvements be reflected in the outputs of the model?	Text was added to highlight where the modeling in this report 'fit into' the influence diagrams although the figures do in fact explicitly show where these data/results fit! A small section was added to the report that highlights how the revised data and modeling could be used to support these analyses under the HCP but are beyond the scope of this report.
	In general, a section of the report should be developed that states the appropriate uses of the biological flow model. What can the stakeholders ask the model to simulate, and what kinds of scenarios can the model not accommodate? A local example can be found in the Edwards Aquifer MOD-FLOW model, where the appropriate usage of the model (i.e. regional management strategies) is contrasted with unsuitable uses of the model (i.e. molecules of contaminant movement or transport). A similar format in the report will be undoubtedly helpful as the stakeholders and Steering Committee work towards identification of actions, alternatives, management, etc.	This is really a HCP level question and not a J charge report question. As noted in the previous response, text was added to highlight how the revised data/modeling can be used to answer specific types of scenarios.
	In the Introduction paragraph on page 12, an extraneous word ("and") is inserted into the name of the process (Edwards Aquifer Recovery and Implementation Program). SAWS would recommend deletion of the extraneous word.	Fixed throughout the document.

	Figure 1 on page 13 is mislabeled as a map of the San Marcos system, but the map is of the Comal system. A notation in the text indicates that Figure 1 will be updated to reflect the style in Figure 2. During this update process, the caption label should be corrected.	Fixed.
	On pages 16 and 19, the report states that additional components to the influence diagram will need to developed to evaluate the effects of possible HCP actions on Comal Springs riffle-beetle, Texas Wild-rice, and Fountain Darers. Would the authors undertake this process of expanding upon the initial Influence Diagrams, or would the process of expanding upon the Influence Diagrams include all interested EARIP stakeholders?	This would be undertaken as part of the HCP process as the USFWS works on issues related to the BiOp. I will be part of this process as can the stakeholders.
	The portion of the report that focuses on "Development of Computational Meshes" on page 23 discusses examples of varied interpolation algorithms or gridding procedures to create the Most Representative Surface (MRS). Was the same interpolation method used in both river systems? Did each of the river segments evaluated in both systems use the same interpolation algorithms, or were there differences between systems and within each system between reaches? A notation is given in the last sentence for finding the details of the methods used; however, an expanded, yet still generalized, discussion of the type(s) of gridding procedures by system and by reach might be helpful.	The same gridding algorithm (natural neighbor) was used for both systems and all sections. This has been added to the text for clarification.

	Page 24 discusses the use of two-dimensional hydraulic models, such as Surface-Water Modeling System (SWMS or SMS), RM2, and HEC-RAS, to derive water surface elevation and flow velocity. The draft report could be enhanced if a general introductory paragraph was developed where an examination of the available scientific literature were to be undertaken to determine the strengths and limitations of these various models and the suitable versus unsuitable application environments the models may or may not be applied within.	Text was added the highlights the appropriateness of the hydrodynamic models used. These models are in common use for this class of modeling in applied river studies and references to document this have been added. Since this is relying on a 'legacy model development and application' it will be more appropriate to include this material when the updated models are used in the new work currently underway.

	The last paragraph on page 24 describes cross-section calibration to match observed water-surface elevation-discharge data through the manipulation of the cross-section's Maning's n-value within HEC-RAS. In simplified verbiage, the cross-section was made more or less "rough" until the water level in the model matched water level observations. Is the manipulation of Maning's n-value an accepted technique in river modeling? Might other characteristics of the model profile be manipulated to match observed water levels, such as cross-sectional profile, depth, or shape? The concern here is that roughness coefficient manipulation has an impact on modeled velocities. Velocity of flow is an important component of the habitat references of the sentinel species, such as fountain darer (slow but not stagnant), wild-rice (quicker up to a point), and riffle-beetle (fast enough to facilitate gaseous diffusion across the air 'bubble' the beetle breathes from). The final report would be strengthened if a section was developed that addresses whether or not, and how much, the manipulation of Maning's n-value impact the suitability of habitat in that cross-section.	This is the standard accepted approach to calibrate one-dimensional hydraulic models used to predict water surface elevations. Modification of measured topography is not an acceptable practice! The HEC-RAS model was only used to estimate the water surface elevation versus flow relationships used in the 2-dimensional model where the velocities are predicted. HEC-RAS was never used to simulate velocities. Text was modified to make this clear. This is not necessary as Manning's n only applies to estimate the stage-discharge boundary conditions for the 2-dimensioanl model and therefore has absolutely no impact on suitability of fountain darter or wild rice habitat!

	On page 27, an assumed ratio of partition of flow rates (3:2:1) between large, moderately-large, and medium springs (respectively) was used. A similar procedure is described on page 28, where more than 200 springs at San Marcos were simplified into eighteen or twenty-one spring inputs. Providing a discussion of any other ratios examined would be helpful, and what were the possible effects of varying this assumption? This kind of an examination would be analogous to a simplified sensitivity analysis to determine the influence of where and at what proportion (ratio) the influence of smaller springs and seeps have on the system relative to large and medium springs. This is thought to be especially important in riffle-beetle habitat.	No other ratios were examined. I provided a spreadsheet to the RIP early on and requested review and comment. None were ever provided. This is however, something that will need to be addressed/reviewed for use in the revised modeling currently underway.
	Landa Lake is misspelled on page 27 in the ninth line on the page.	Fixed.
	The last sentence of the first paragraph on page 27 discusses interpolation of data for 'other discharges' simulated in the report. Please elaborate on the flow data that forms the basis of this section, and on the methods or techniques used to interpolate. This sort of a discourse is important as the Science Subcommittee, Steering Committee, and stakeholders will be using this tool developed by Dr. Hardy et al. for support of decision-making concerning flow levels that have not been formally studied.	Text was clarified to indicate a simple linear interpolation of values was used for specific spring flow discharges from the data in Table 1. The flow data is presented in Table 1 and as the text indicates, the origins of these data are Brune 1981 for spring flow rates. Flow splits are simply what were modeled to examine potential implications of different flow volumes split between the old and new channels.

	In the third paragraph on Page 28, an addition of 5 cfs to the slough area of Spring Lake was simulated in the 2-D hydraulic model to account for 'golf-course runoff through the area. What is the source of the golf-course runoff (i.e. municipal water, well water, surface water, etc.) and what is the literature or regulatory source for the 5 cfs number?	The 5 cfs was taken from our synoptic flow measurements during the original fieldwork. Text was clarified to indicate this and was intended to account for all unmeasured sources contributing to this section of the lake.
	The first paragraph on Page 29 discusses interpolation of flow values at other discharges for the San Marcos system. Please apply Comment #12 above to this section also. It will be helpful to the decision-making process for stakeholders and decision-makers to have an understanding of the assumptions, which form the basis of the interpolations, which in the end result in the outputs of the flow model.	See response to previous comment.
	The scaling of wastewater treatment plant discharge cures discussed on page 29 would seem appropriate for standard municipal wastewater discharges, such as from the City of San Marcos wastewater treatment plant. Does discharge from the A.E. Woods state fish hatchery mimic the same pattern as the City wastewater plant? It would seem that these two facilities might have differing operational patterns - does the Tchobanoglous (1991) citation include different curves for different types of facilities, or was the same curve used, and what is the effect of this assumption and scaling on habitat in affected downstream reaches?	At the time of the original study there was not available data for the A.E. Woods hatchery. This is something that needs to be addressed in the revised modeling currently being undertaken in support of the HCP. The citation was used based on our evaluation as the most reprehensive for this type of facility. There is no implication of this assumption on scaling of habitat in downstream reaches. It only affected the simulation of temperature and dissolved oxygen or the addition of incremental flow accretions.

	On page 31, why was Texas Wild-rice excluded from other vegetation species that were assigned roughness values based on vegetation/vertical velocity profile data? Is this omission due to the data being collected from the Comal River, where Texas Wild-rice is not found? It would seem that omitting roughness values for Texas Wild-rice would impact the results of suitable habitat to some degree. Wild-rice is known to prefer a certain range of velocities, as do fountain darers. Is there a potential to exclude segments of suitable habitat for these species based on the omission of Texas Wild-rice roughness values?	All of the data were collected from the Comal River and therefore no wild rice stands were measured. At the time that the work on the San Marcos was undertaken, the UWFWS asked that we not disturb wild rice stands so no data was collected. Roughness for wild rice was not omitted but assigned roughness from similar plant forms where data was available. There is no potential to exclude segments of suitable habitat due to omission of roughness values since roughness was in fact assigned for wild rice!

	Table 4 on page 32 indicates two vegetation classes where the lack of vertical velocity distribution caused the assignment of generic roughness values. Aquatic plant pictures found in various locales online show two vegetation classes with very different morphologies and different growth environments. Riccia thatans seems to be a submerged low-profile aquatic plant, while Justicia Americana appears to be grown more emergent and with a larger vertical profile. Insertion of a sentence or two that describes the percentage of the study area affected by these generic roughness values would be helpful, including a discussion of possible suitable habitat within that percentage of the study area that is impacted by this generic roughness value. It is reasonable to assume this impact would be relatively small, though examination of this aspect would be beneficial.	Text added as requested. This will be addressed in the revised modeling using the updated vegetation polygon mapping.
	On page 32 in the first paragraph of the "Vegetation Mapping" section, Texas State University's former moniker (Southwest) is used.	Fixed.

	The top of page 34 discusses the simulation of water temperature over a 48-hour period associated with the hottest meteorological conditions as a worst-case scenario. SAWS understands the value of having these snapshots" of habitat temperature at different flow levels, though is concerned about the usage of the snapshot over long-term conditions in the habitat. The report examines available scientific studies on the reproduction and various life-stages of fountain darers on page 47. Later, on pages 52, 54, 55, 59, 65, 79, 80, and others, temperature is singled out as the limiting factor or part of a suite of limiting factors for various reaches of the habitat in both the Comal and San Marcos systems. It is difficult to understand how a 48-hour temperature can be 'stretched' out over longer durations of time such that it impacts fountain darter reproduction. How could a duration of 48-hours of high temperatures be sustained over days, months, or a year such that it results in the loss of multiple cohorts of breeding fountain darters, thus threatening the species' survival and recovery in the wild?	The modeling in this manner was undertaken in the original study explicitly at the request of the USFWS and no new water quality simulations were undertaken for this report (out of scope). This will be addressed with the revised water quality modeling currently underway to support the HCP. This is simply a very conservative approach that offers the maximum protection for the species. I agree to some extent. More refined simulations need to be undertaken as part of the revised water quality modeling efforts.

	This kind of an assumption in the study is an important issue that scientists and stakeholders will have to examine. While short-term temperatures may exceed a threshold of fountain darer preference for a given time-frame, it is unlikely that those temperatures will be sustained for periods or lengths of time that affect the survival of the darer. Impacts from temperature on eggs laid or larvae developing in those time periods have been demonstrated, but it is a tenuous stretch to state that temperature becomes a limiting factor in habitat over the long term and it is not entirely valid to limit a habitat solely on temperature modeling outputs generalized from a short-term duration to a long-term duration.	This should be addressed during the revised modeling where time series of flow regimes should be used to reflect the duration of conditions rather than the snap-shot index day used previously. This will allow a much better assessment of potential temperature induced bottlenecks if they in fact exist under different low flow sequences during any period of the year.
	Short-term deleterious temperatures should not mean an entire portion of habitat is unusable or that species reproduction is irreparably harmed. It is unclear how the model can take an instantaneous temperature that persists long enough to adversely impact darter habitat over an extended time scale based on a short time scale sample of temperature data.	See previous comment.

	On page 37, water quality model calibration is discussed, including the adjustments necessary to wind speed and cloud cover. Was there a scientifically based rationale for adjusting solely those factors, or are there other factors such as local runoff, mixing within the water column, canopy cover, etc. that might have been adjusted? Why were these factors selected over others, and what was the discrepancy between the model and the observational data? Was the model systematically too war or too cool, and how was the adjustment handled (i.e. more or less wind, more or less clouds)?	This is the accepted method for calibration of water temperature models. We had no data of these types and not sure they exist even now. This is clearly illustrated in the predicted versus observed simulation results provided in the report. The model over and under estimated the temperature depending on location and time and but was within accepted calibration limits. This is obviously something that will be documented and discussed in the revised modeling.
	On page 37, dissolved oxygen (DO) was modeled without considering a number of other chemical and biological processes. Do the authors have an estimate, based on their experience or knowledge of other systems and other work, of the DO demand from these processes that were not considered?	This is because the requisite data for this was not available. We considered the fact that the observed versus predicted DO from the data collected during or studies to have been sufficiently close and therefore these were not a primary concern.
	It is stated that calibration of DO on page 37 relies heavily on the use of dam reaeration. This would seem to indicate that the modeled DO was lower than the actual DO measurements. Is this the case, and if so, are there any explanations as to why this might be occurring? Does the model under-contribute DO from phytoplantonic algae and other macrophytes, or is there another possible source?	No. It is simply that this parameter in conjunction with the physical setting of the various dam structures was practical and defensible for model calibration. The simulation results compared to observed data clearly shows acceptable calibration and validation of model results.

	Page 38 discusses division of the San Marcos River into twenty-one sections based on in-reach similarities. In what aspect were these similarities based that resulted in the division into like segments (i.e. vegetation, substrate, depth, etc.)?	The primary factor was computational efficiency and physical characteristics (i.e., backwater reaches immediately above dams, reaches below dams, and the factors listed in the comment.
	A citation is needed on page 42 at the end of first paragraph of the "Habitat Suitability Cures" for the annual wild-rice monitoring data.	Added.
	A citation is needed on page 43 in the third and fifth paragraphs describing the genetic analysis that suggests a riffle-beetle “population genetic bottleneck" and "recolonization" of previously dry spring runs. A similar citation is needed on page 59 discussing a shift in the genetics of the riffle-beetles in spring run 1.	Added.
	In Table 9 on page 46, are the Suitability Indexes for Texas Wild-rice the same (0.04) between 5.30 feet of depth and 9.0 feet of depth?	Yes.
	In the last paragraph of page 47 there is a discussion that the expert technical team "felt that use of vegetation type was sufficient.." and so excluded vegetation height from the habitat modeling. Explanation or elaboration as to why this approach was chosen would be appreciated in the final report.	As noted in the text, vegetation height is not available for either the Comal or San Marcos River systems so could not be included in the analysis.

	On page 50 in the section on "Physical Habitat Modeling" an assumption was used that vegetation and substrate characteristics would be unchanged due to fluctuations in simulated flow rate. Over what time scales would this assumption be valid, and on what time frame do vegetation changes begin to occur based on available observational and monitoring data to date?	This is simply the assumption necessary at the time of the original studies were collected (basically one set of vegetation maps existed!). Updated modeling to support the HCP can utilize changes in vegetation coverage and composition and should be discussed during the revised modeling and potentially in light of either restoration actions or changes in vegetation due to sustained low flows.
	On page 51, the Comal Springs riffle-beetle habitat equation does not include substrate. However, on page 43, riffle-beetles are stated as preferring gravel substrates. This binary habitat equation is characterized as "the most germane way" of representing habitat. It seems that a binary approach is overly simplistic and may under-estimate or over-estimate habitat given the previous section's statement on beetle substrate preference.	We felt that since the beetle has been empirically demonstrated ‘to recover’ from complete spring run dewatering, the role of substrate was not as important relative to maintaining surface flows. This is a bit simplistic but is conservative in terms of preserving potential habitat areas as long as one maintains surface flows. This can be revisited under the revised modeling current underway.
	On page 51, interpolation from the habitat suitability relationship to each node is discussed. What was the interpolation method or technique used?	The associated depth or velocity value at the node is used to interpolate the associated suitability value for the habitat suitability graphs using linear interpolation. Text added to clarify this.

	The section entitled "Fountain Darter: System-Wide Physical Habitat Using Mean Daily Temperatures" on page 59 states that the primary reason for habitat decline under lower flow rates was temperature. It is unclear why temperature is a limiting factor for fountain darers, especially since the timeframe of the temperature occurrence is artificially stretched in duration in the model.	This statement is consistent based on the modeling assumptions used where maximum daily temperatures limit habitat from a decreased reproductive perspective. As noted in previous responses to comments on the temperature issues, more refined analyses are anticipated using the revised models currently being developed.
	In figure 39 on page 61, the color-ramp "keys" are difficult to read. Are the colors in each contour plot of the Upper Old Chanel (Comal) similar between plots, or do the values for each color change between plots?	Graphs have been clarified.
	On page 74, there is a statement that flows below 65 cfs cause stands of Texas wild-rice to be proportionally more vulnerable to physical disturbance from recreation. In the qualitative evaluation, were the Weighted Usable Areas (WUAs) adjusted based on this evaluation? If so, by what amount?	No adjustments in WUA were ever made based on this or other qualitative evaluations.

	In general, it seems that the model focuses on riverine habitats. Monitoring by BIO-WEST on behalf of the Edwards Aquifer Authority (EAA) indicates that a relatively small portion of the fountain-darter population is found in the rivers. The lakes provide space the most abundant populations and highest quality habitats in the system. How does this report incorporate the lakes as important habitat with quality WUAs? Also, the stakeholders may benefit if context is provided between the WUAs identified in this draft report compared to previous work in these systems.	Both Landa Lake and Spring Lake were modeled for fountain darter habitat. No specific focus was given to only riverine habitats. As noted, both lakes systems were modeled and included in the habitat summary analysis. The report does in fact report on habitat modeling from the previous studies for each system!
	On page 91, provide a citation for the increased infection rates by gill parasites on San Marcos darters.	Added.
Glen Longley	Editorial comments provided in report electronically.	All suggested editorial comments were made in the report.
Ed Oborny	Acknowledgements - Oborny not Orborny	Sorry Ed!
	Page 11 - Executive Summary - Paragraph 1: scientific names switched for fountain darter and riffle beetle.	Fixed.
	Page 11 - Paragraph 3: As written this paragraph is very misleading. It claims data collected through 2009 was used and models were updated, when in fact a lot of the information used for the modeling was the same as the original and in many cases the old modeling was not updated at all, and results were the same as originally reported. This needs to be clear throughout the report.	This has been clarified to indicate what was updated and what was used from previous work throughout the report as requested.

	Page 12 - last paragraph - Why not use BW spring flow data from 2003 through 2008. 13 times measurements were made over this period. Min. 22.9% Median 23.8% and Max. 30%. The use of old data happens repeatedly in this report when much newer information is available.	We updated to use your numbers, although there is in fact very little difference between the two sets of numbers and likely the differences are well within measurement error.
	Page 12 - last paragraph - "Old channel only holds 40cfs". This was before the installation of the new culvert system. Can easily handle 100 cfs now.	Modified the text to clarify this change in capacity.
	Page 12 - last paragraph - "…3.2 miles long…, …another 2km…" - consistent units.	Revised to report to use all English units.
	Page 14 - Figure 2 - Scale way off.	Fixed.
	Figures 4, 5, 6, & 7 - Riffle beetle section - All your pictures are of the Comal Springs Dryoptid beetle.	Fixed and thanks for the photos!
	Figure 6 - No Comal Springs riffle beetles have ever been found at your picture of Spring run 5 at Comal.	Updated with the picture you sent.
	No real discussion of the influence diagrams or summary paragraph to say what they were or will be used for. See next point.	Text was added to clarify the purpose of the diagrams, what their intent is, and how the modeling 'connects' to them.

	No transition from Influence diagrams to Hydrodynamic modeling. Need some text to make this smoother. If there is no transition, you need to set up this section better with the why this is being done. What it is going to be used for. What are the advantages and limitations. The entire section needs to cover either in summary format upfront, or in each individual component moving through the report. Start with what was originally done, what was discussed among the group as needing revision, what was actually revised, and what is still to be done.	A transition was added as suggested. See previous comment.
	Page 22 - Physical Characterization section: You talk about 1998 flood, failure of Capes dam in 1999, and conclude with you are using the channel topographies collected during 1991? Assuming you mean 2001?	Fixed dates and clarified text throughout the report.
	The physical characterization section would also be a good section to talk about all the sedimentation that has occurred in Sewell Park and City Park since the 1998 flood, cite the work done by Texas State (Curran, Engel and others), and discuss how this might affect modeling results.	Added text to highlight the sedimentation accumulations, and potential effects.
	SWMS and SMS the same - consistency needed	Model nomenclature has been made consistent throughout the report.

	Page 25 - Comal river - spring nodes? Was any of this updated based on work conducted the past 10 years (springflow augmentation, dye tracer studies, etc.) by the Edwards Aquifer Authority? Might be good just to mention some of this work and the possibility of it's inclusion in the next round.	Text was added to indicate that this data was derived from the reference sources, new work is now available, and will be incorporated into the updated modeling currently underway. A spreadsheet of these assumed flow contributions was in fact provided to the RIP for comment but none were ever provided.
	Page 28 - San Marcos river - FESWMS Paragraph 1, RMA-2 Paragraph 2	Clarified.
	Page 29 - Unclear as to whether current day City of San Marcos WWTP information was used or the original information.	No new water quality modeling was undertaken. Text clarified throughout to highlight this fact.
	Page 31 - VEG Dependent Hydraulic Roughness section - veg maps available for both systems? Were the original vegetation maps used in the updated models? What were the dates of the maps used?	Vegetation maps were available for both systems but only hydraulic roughness data was collected from the Comal. Dates and sources of maps were added to the report and clarified that these maps were used in all simulations.
	Page 32 - Veg mapping section - I recommend moving this section ahead of the VEG Dependant section to avoid the questions I just asked above. Who mapped the Comal? You say Roland Roberts and David Lemke in sentence 1, then Jonathan Beale on the next page.	Moved as suggested. Added clarification of sources as noted in responses above.

	Page 37 - Comal River WQ modeling. Was any new water quality modeling done at Comal? Or does this report just discuss what was presented in the original report? Was any of the intensive temperature information being collected throughout the Comal River via the EAA Variable Flow Study over the past 9 years used to validate these model results? If not why? Seems like this data should at least be mentioned?	No new water quality modeling was undertaken and text added where appropriate to clarify this. No. Text was added to indicate the availability of these data and that it is being used in the revised modeling for both river systems.
	Same question as above for the San Marcos WQ modeling?	Same response as above!
	Page 42 - Habitat Suitability Curves - First sentence - What data and how was it used to update? This needs to be explained to the reader. This is especially critical considering the major change in results for Fountain darter habitat at SM shown later in the document.	Clarified.
	Page 43 - ComalSprings Riffle beetle. 4th sentence is not accurate, although this is what was thought in 1998. They also occur in upwelling areas in Landa lake. Paragraph 3 needs a major update. Need a description of the range expansion study done back in 2002. Also need to discuss that they have recently been found at several locations with a number of individuals in Spring Lake. Paragraph 3 - need to reference your genetic statement.	Obtained an updated map from USFWS that show known locations and updated the text based on this map. Updated the text to reflect this updated material as requested. Added.

	Maybe a description is upcoming, but Randy Gibson has delineated a map of CSRB area in all three spring runs and that should be used in the assessment. Also, although a consensus was reached for surface modeling, it was only because it was the easiest thing to do with the time available. In my mind, there was always the assumption that this would be explained in this report. This being the fact that the CSRB is found throughout the lake, and that the spring runs only make up a portion of the habitat, etc. etc. However, modeling this area will provide some indication of potential impacts. Also the discussion on subsurface habitat needs to happen here. Just because an effect is shown at the surface for this species does not necessarily mean that the population is at risk because they simply may go subsurface.	Has been included. Updated the text to reflect this modeling approach and that refined modeling with the updated modeling efforts will revisit the approach taken. Agree. And added text to point this out.
	Figure 26 and 27 are the same - just the velocity plot.	Fixed.
	Page 47 - 4 or 5 degree F buffer. Struggling with the math here.	Clarified text.
	Figure 28 - being that fountain darters are found throughout Landa Lake at depths to 10 feet and in Spring Lake at depths exceeding 20 ft, this curve needs to be explained. Either some discussion that only riverine habitat is being modeled (true at San Marcos but not at Comal) so I am not sure how best to explain this. Thoughts?	HSI was modified to show no reduction in suitability for depths and the models rerun with this updated HSI.

	Figure 30 - What information was used to generate this figure. It does not match at all with the last 9 years of EAA data. Was the EAA data actually used at all? Or was it just reviewed to see if stuff was in the ball park. An explanation of how that data was used or not used needs to be presented.	The original vegetation HSI was used for all the simulations runs due to incapability of the vegetation coding used in the original vegetation mapping for both systems and text was added to document this issue, which will be addressed in the revised modeling based on the updated vegetation mapping for both systems.
	Page 52 - Comal Temperature. Figure numbering wrong. Need to define "upper critical thermal range" As presented here one would think the old channel would be a barren wasteland at 78 F, rather than just a channel with summertime temperatures that it sees pretty much every year in which some larval success would be reduced. Wording is way too suggestive here. Just needs to be defined and described for what it is. Also need to discuss in the text that this means only 10cfs and 5cfs would be flowing through the old channel at 60 cfs and 30 cfs respectively. This is an extremely important point.	Fixed. Text was added to clarify how this 'concept' was applied and a better explanation of the practical implications. Text was added to clarify this.
	Need to pick 80 F or 78 F, jump back and forth through section.	Standardized the temperature used.
	Page 55 - please provide a reference for the USGS diel DO study in Landa Lake.	Personal observation of them doing it! I found the spreadsheet of their data but have no idea now who did it!
	Page 57 - CSRB section - What is this sampling discussion. There is so much more recent and better data here. I am not sure what sampling you are even talking about.	This is data we collected during our original study on Comal. I do not agree that the newer data is necessarily better!

	Figure 36 - Is this all Spring run area, or the area the Randy Gibson provided as known CSRB habitat in these springs?	All spring run area only. Text added to clarify this.
	Page 59 - I'm Confused. The comal section shows WUA with temperature included for a number of flow scenarios. Then moves to the San Marcos section that just talks about mean daily temperature and shows one figure of temp but no WUAs presented in this section. Then moves directly to Texas wild rice. Then to SM WUA.	Reorganized the text to keep systems together. Cut and paste error on moving things around!
	Somewhere need to state that although new HSI criteria were generated, no new modeling was done at Comal for the fountain darter. This might be important because of the major change the new criteria caused in overall WUA results in the SM.	New modeling was in fact done in Comal for fountain darters based on the updated habitat suitability curves.
	Page 59 - last paragraph - 2nd to last sentence. Please describe what you mean by "unacceptable levels". Isn't this simply "area with less suitable conditions for larval survival"? Need to formally define "unacceptable" and then state over what time period this might be unacceptable, etc. Using that term requires more explanation. Might consider simply calling it what it is and avoiding that term.	Text was clarified to use your suggested language as it better reflects what is actually being presented.

	Page 60 - figure 37. The legend states “unsuitable temperatures for fountain darters”. Again, these temperatures are fine for darters to survive, and even reproduce at some level. It does cause lower success rates of larval survival based on laboratory studies, but does not mean that darters could not reproduce successfully in Landa lake and move back into these areas for feeding, living, etc. Again a better description of what is meant here needs to take place in the text.	Clarified the associated text to reflect what it is intended to illustrate.
	Page 61 - can’t read legends at all in Figure 39	Added text to clarify the legends.
	Page 62 - Figure 40. Again can’t read legends, but assuming blue is 1.0, the figures appear to be flipped, unless I am missing something. I would anticipate better habitat conditions at 40 cfs than at 10 cfs, which is not what the figure is saying. Looking at the supporting text, it appears my assumption is wrong. Regardless, the maximum combined suitability values on the figure don’t match with their respective examples. (Probably flipped).	Fixed and added text to better describe to the reader what the results mean. Figures were not reversed.
	Page 63 - Table 11 formatting needed	Fixed.
	Page 70 - 2nd full paragraph. Can you include a table of the comparison that you describe here. I am unclear what was actually done. Does not seem to jive with what Jackie has been telling me about how far off the model is relative to occupied areas. What am I missing?	Figures were in fact mislabeled and were simply the frequency of predicted suitability values for all modeled cells. The correct histograms showing the frequency of suitability of occupied rice cells have been updated.

	Page 73 - 1st paragraph - the word “occupied” simply means model predicted, correct? It is not what Jackie would call occupied? - which means really there, correct?	Occupied means a wild rice plant was at that location compared to the model predicted suitability at that location.
	Page 78 on - Fountain Darter SM - The bulk of the discussion (text) is on the old results. However, the new HSI criteria causes such a drastic change in the overall results that it would be good to have a discussion on why this is and which you feel is more appropriate, etc. This will influence whether or not to even use Figure 52, which is completely misleading if you feel the update HSI information is valid.	Text added to discuss changes in the relationships (and why) as well as having added text on use of the various simulation results.
	Page 83 - last paragraph - Sentence 3, “However, it is clear regardless…….rapid declines…….below about 65 cfs”. I contend this is no more true than rapid declines occur from 65 cfs to 100 cfs - see Figure 51 Total 2009 if one considers the updated HSI info. Again highlighting how Figure 52 can be misleading. More discussion is needed in this section to clarify between old and new results.	Text was modified to better describe the functional relationships between the various simulation results and implications on interpretation. I maintain habitat availability does in fact drop more rapidly below 65 cfs than between other increments of flow.
	Page 84 - 86. Assuming Figures 53 - 55 are for the old data. Why not include some comparative figures with the updated HSI info. Seems appropriate to at least compare them. Can again be unintentionally misleading.	Added material to better compare the results and associated discussion.

	Page 87 - would be good to at least mention the CS dryopid beetle data that Randy Gibson's has collected on the variable flow study over the last 9 years. Same comment on Peck's Cave Amphipod.	Added text from Randy's work as suggested.
	Page 91 - Giant ramshorm snail at Comal. Need a reference for your statement, "Population densities at present are low, but appear to be increasing with the sustained low flows within the Comal River." Our data supports the first part of the sentence but not the second part.	Added reference. Others believe that ramshorn snails are in fact increasing. Modified text to indicate that changes may be occurring.
	Page 91 - Asian snails - again I would reference the statement on snails and low flow (probably Brandt pers. Comm.).	Added.

APPENDIX I:

ANNEAR ASSOCIATES, LLC, PROFESSIONAL PEER REVIEW OF EVALUATION OF THE PROPOSED EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM DROUGHT OF RECORD MINIMUM FLOW REGIMES IN THE COMAL AND SAN MARCOS RIVER SYSTEMS," JUNE 13, 2011

Final Report
June 13, 2011

Professional Peer Review of

Evaluation of the Proposed Edwards Aquifer Recovery Implementation Program Drought of Record Minimum Flow Regimes in the Comal and San Marcos River Systems

Final Hardy Report to the Edwards Aquifer Recover Implementation Program

Prepared for:

Edwards Aquifer Recovery Implementation Program

Attention: Dr. Robert Gulley

Review Prepared by:

Annear Associates, LLC

Cheyenne, Wyoming

Introduction

This review was conducted under contract with Texas A&M University and per the authority and direction of its Program Manager, Mr. Robert Gulley. As provided by contract, a review team of highly qualified environmental flow professionals was assembled (Appendix A) and assigned the charge of providing an objective scientific analysis of the contents of the *Final Hardy Report to the Edwards Aquifer Recover Implementation Program* (Final Hardy Report). In keeping with the guidelines we were provided, the review team's comments were strictly limited to facts, assumptions, and conclusions contained in the Final Hardy Report. At the time when the review was conducted, review team members were unaware of specific program details or recovery time lines. As a consequence, comments in this report are provided in a context that the flow levels studied in the Final Hardy Report might apply to both short (one or two years) and long-term (permanent) conditions.

Understanding how ecosystems function, let alone modeling how various components will respond to natural or anthropogenic inputs and then managing them for intended outcomes necessarily incurs relatively high degrees of uncertainty. The longer the chronological horizon of interest, the greater the degree of uncertainty. Modeling such as was conducted by the Final Hardy Report is essential to manage uncertainty, and the degree of effort invested by the authors of that report is impressive.

However, the review team members agreed that there are several other factors, not included in the study, that could affect the report's outcomes and conclusions, especially over a longer term. Many of those factors can take several years or decades to become evident, thus the basis for the cautionary, adaptive perspective we provide. Ecosystem function (and true species recovery) is a reflection of pattern and process over long periods and static, threshold flow standards typically cannot sustain these processes and the organisms that have evolved in association with them.

Within these sideboards, the conclusions presented in the Final Hardy Report are valid on a short-term basis (one or more consecutive years). However with each successive year, the potential for efficacy decreases largely due to generally unpredictable, and sometimes unidentified, environmental factors. For the target organisms and the habitats in which they live to achieve recovery and persist over the long-term, additional information is needed to understand, anticipate, and manage these factors as much as possible. We trust that the interpretations, opinions, and suggestions we have provided in this peer review are a constructive and helpful tool to help shape that future work and advance recovery efforts.

Overarching Comments

The San Marcos and Comal river systems and associated human and natural communities represent a complex, linked ecosystem. Over time both river systems have adjusted to a number of new controlling variables (e.g., increased water use, impervious cover, introduction of non-natives, increased recreation, and other factors).

Overall, there are no serious flaws or errors in the Final Hardy Report as related to short-term management considerations for recovery of the target species. However, there are significant omissions, as discussed below that may compromise the validity of the findings on a long-term basis. Assumptions of the approach are well documented and are reasonable given present understanding of aquatic ecosystems. The tools and methods of analysis employed, with respect

to habitat modeling, are appropriately used and based on best available information. The acknowledgement of data gaps and uncertainties is commendable. Aquatic ecosystems are very complex and even though considerable effort has been expended to understand the Comal and San Marcos River systems, much is still unknown and developing a functionally complete comprehension of the system is a high standard to achieve. Studies such as this are intended to minimize or manage uncertainty – not eliminate it. Within this constraint, appropriate knowledge gaps were identified and addressed by suggested monitoring and adaptive management recommendations.

The Final Hardy Report focuses on the potential effects of degraded habitat in a relatively short period of time (a single drought year). Though long-term drought may not have been experienced in recent history, prospects for an extended drought (possibly associated with the effects of global climate change) are real and possibly increasing. If the flow criteria analyzed in the report are intended to be institutionalized for a long period of time or in perpetuity, analysis of the cumulative effects of longer term drought periods on ecosystem processes would be appropriate.

The application of the models to produce flow-habitat relationships and temperature time-series outputs are accepted practice. The models used were all appropriate and appear to have been properly calibrated or adapted for use in this study. The report identifies many of the readily apparent potential threats to these populations and habitats. Accepted methodological approaches were used to analyze the relationships between critical environmental attributes (habitat suitability and temperature) and flow levels. Most of the important limitations to the scientific analyses and assumptions upon which data interpretations were based were clearly articulated, which strengthens the conclusions and recommendations provided in the report.

The overall approach of using simulated model outputs in combination with observed and empirical data is to be commended. Combining the physical habitat modeling with the temperature modeling represents the state-of-the-art for carrying out these types of studies. The temperature modeling was improved by using recent (2009) empirical data along with the vegetation distribution using historical vegetation mapping results.

Intensive sampling, model calibration, and 2-D simulations of habitat were completed for both systems. Considerable detail is presented, including vegetation cover maps, habitat suitability, and reach maps illustrating ranges of hydraulic habitat suitability over a range of flows for selected species. These analyses were well done. Interfacing field data gathered by wading and by boat and with topographic data from LiDAR represents the state-of-the-art and allows for simulations of flow over the entire flow range from low flow onto the flood plain. Illustrations and information tables were clear and useful. Apparently no simulations of seasonal habitat periodicity or inter-annual habitat suitability were developed. However, it appears that all information necessary for such simulations was available.

The conclusion "that the flow regimes being considered by EARIP will provide adequate protection for aquatic resources given the underlying assumptions and the mitigation measures proposed by the EARIP have been successfully implemented" is supported for survival population levels by the data presented under apparently average climatic conditions. However, recovery after such stressful conditions cannot be assured by evidence presented thus far and should be the focus of rigorous adaptive management. Only after critical analyses comparing the proposed regimes over different seasons and under differing conditions of water supply and

climate can the conclusion that the same "minimum flow regimes" applied to all years would provide adequate protection and recovery. Applying one set of "minimum flow regimes" to future years should be considered an interim measure pending more study of the system dynamics, human impacts, and biological detail.

It appears the current report was constrained somewhat by the scope of the work. To obtain a better understanding of the probability of persistence faced by the organisms studied, additional information and analyses would be helpful. Our review team previously made recommendations relative to this needed information. See the team's previous report dated 5/10/2010 where we recommended, "Full characterization of the system hydrology: past, present, and potential including all elements: magnitude, duration, frequency, timing, and rate of change is necessary. Establishing water year categories through 1) development of annual flow duration curves, 2) delineating water year strata (e.g. dry, normal, wet), 3) classifying each water year of the period of record into a specific stratum, and 4) then using that classification in a time series analysis to develop adaptive water management strategies would help refine recommendations. Additionally, hydrologic data should be stratified for water quality analysis according to cool, normal, and hot climatic conditions."

In particular, there appear to be considerable threats posed by secondary impact mechanisms – some of which were mentioned but most of which it appears were not directly studied. Additional work is needed to address issues such as the threats posed by non-native fishes and parasites and prospects for aquatic vegetation collapse at low flows. Though vegetation disturbance associated with human recreation is logically suspected of inhibiting recovery of TWR in the San Marcos River, it is unclear if the level of impact has been directly studied or quantified. Threats posed by these and other sources at low flows may be as great as or greater than the availability of WUA and physical habitat in which organisms may live.

The report provides an appropriate level of technical documentation on the modeling approaches and evaluation of the proposed minimum flow regime targets adopted by the EARIP for a similar instance as the drought of record. We note the presumption that a drought will mirror a previous one in climatic intensity or with the same combination of factors (water quality parameters same as in 1950's, watershed conditions similar (e.g., impervious cover), connectivity constraints similar, biotic interactions similar (e.g., invasive species threats the same), demand for water and recreational demand the same, etc), does not seem probable. These facts underscore the need to look at more than WUA and physical habitat.

The analyses in the Hardy Report also focused on the potential effects of known threats that exist now or have existed in the past. A thorough assessment of future risk might look to identify potential effects of factors that appear likely to exist or increase in the future. Such factors would include the prospects for considerably more recreational use of the San Marcos River than currently occurs. Studies might also be done of potential effects of contaminated groundwater entering the systems studied here through the numerous springs that feed these environments. Clearly, it is impossible to minimize or eliminate all uncertainty associated with managing for the long-term persistence of endangered species and the reality is that for all the potential risks we can identify today, there are others that are impossible to foresee. The recommendations section of the Final Hardy Report offered appropriate suggestions for future study that should be considered to help minimize risks of persistence associated with Texas Wild Rice (TWR) and Fountain darters.

The report also limited its analysis to the lowest recorded flows of record. Because an even more severe or extended drought is possible, it would be useful to analyze lower flows for both short and longer periods. Such information would help managers deal with future pressures to allow restriction of flows to even lower levels if and when such public pressures develop. Given the rate of population growth in this part of the U.S. and state, such a scenario seems likely.

As will be discussed below under *Specific Comments*, improvements to the physical habitat modeling could have been realized through model validation (hydraulic and habitat) and time-series analysis (hydrology, suitable habitat, and temperature). Demonstrating changes to habitat through time during both the assumed drought of record and for the entire period of record would have provided better context. Also, providing additional benchmarks, such as comparing the suggested minimum flows of the Edwards Aquifer Recovery Implementation Program (EARIP) to both the historical and naturalized flows would have been beneficial. Such analyses could be particularly informative by examining the period from the late1980's to present when intensive biological monitoring has been ongoing. Comparisons between the phenology of biological species and hydrology/habitat variability over this time period should be part of any future studies.

The results contained here suggest that higher absolute minimum flows might be appropriate. Setting such conservative standards now could make it more socially acceptable to achieve needed (higher) flow levels than trying to increase the presently proposed minimum flow levels in the future if the need for such protective flows was documented. A time series analysis that looked at a series of repeated droughts over a more extended period would help clarify potential effects.

While the title of the report is, "Evaluation of the Proposed Edwards Aquifer Recovery Implementation Program", it appears the report simply demonstrates that the proposed minimum flows provide sufficient habitat (quantity and quality) for short-term survival of selected species and life stages. A true evaluation of the recovery prospects requires comparative analyses as suggested in our specific comments to meet the stated objective of recovery and long-term persistence of the species. As such, we suggest the title be modified to more accurately reflect the relatively narrow scope of the studies presented therein.

The report should address in some way all of the technical components (hydrology and hydraulics, biology, geomorphology and physical processes, water quality, connectivity) emphasized by the 2001 National Research Council review of "The Science of Instream Flows: A review of the Texas Instream Flow Program". Without some discussion of each of the components, by default the report leads to the assumption that hydraulic habitat and water temperature are the primary limiting factors in these river systems. While this may be true, the report should provide a discussion and present logical arguments as to why the other components are not limiting during recent historical times or would not be important during a narrow window of time in the future. Particular attention to seasonality and periodicity of flow events since the late 1980's when intensive monitoring started would be enlightening. In addition, evidence should be presented on the potential low dissolved oxygen levels during low flow events when combined with extremes in high ambient air temperatures. The modeling capability presented would certainly support such analyses.

Continued monitoring and an adaptive management approach is necessary if the resilience of this system is to be maintained. Hydrology is a critical aspect linking the ecology and human

systems. As such attention to flow regimes and habitat dynamics is critical for additional research, not only to establish specific habitat relationships but to establish and track habitat and population responses over time to ensure not only short-term survival but species recovery.

Specific Comments on Final Hardy Report

Page 1, Introduction

The report introduction states that it will focus evaluations on the "minimum flow regime targets adopted by the Edwards Aquifer Recovery Implementation Program during a similar instance as the drought of record". The report should clearly state the goals, objectives, and questions addressed within this report and specifically mention the time period over which the recommended flow levels will be in force. For example, "...the proposed minimum flow regime targets adopted by the Edwards Aquifer Recovery Implementation Program..." mentioned here and throughout the report, needs a concise definition, in terms of hydrology. It would be beneficial to provide a brief discussion on the minimum flow targets and the rationale for how they were derived. If this information is provided elsewhere in this text or other documents, it should be referenced here.

An excellent point is made that: *"These flow regimes cannot be sustained indefinitely (i.e., beyond the time period associated with the drought of record) without irreparable harm to the resources and/or placing these aquatic resources at unacceptable levels of risk."* This points out the need for a hydrology time series analysis to define when the drought of record (DOR) is happening versus times when flows are higher. An important piece of the recovery plan would include setting criteria indicating flows have moved into a DOR triggering implementation of the proposed minimum flow(s). The flow values used for minimums (6 months at one number, 6 months at another slightly higher number) are not flow regimes, simply two minimum flow standards, which may allow for short-term survival but not for recovery and long-term persistence of the species in question.

A quotation of the charge made to the report authors by the EARIP should be included. The report presumes that a drought will mirror a previous one in climatic intensity and with the same combination of factors (water quality parameters same as in 1950's, watershed conditions similar (e.g., impervious cover), connectivity constraints similar, biotic interactions similar (e.g., invasive species threats the same), demand for water and recreational demand the same, etc). This does not seem probable and may compromise the long-term validity of the technical analysis provided here.

The report stresses that the flow regimes modeled were specifically chosen to ensure short-term survival of the aquatic resources in the San Marcos and Comal river systems, to ultimately ensure "recovery potential". This caveat is important and is stressed in the report. Focusing on only solitary drought events is informative at a basic level but limits managers' ability to understand potential risks to survival of target organisms during extended drought periods. Given that the Edwards Aquifer Recovery Program is aimed at "recovery " and the Texas Water Plan emphasizes comprehensive instream flow studies (See Table 3-1, Sample Questions to Guide Technical Evaluations, in NRC, 2001 The Science of Instream Flows A Review of the Texas Instream Flow Program), a broader approach integrating longer term hydrologic characteristics could have been taken. The drought cycle is a part of the overall hydrologic

condition. To ensure flow regimes will provide for the long-term protection, enhancement, and recovery (where necessary) of the aquatic resources within these rivers would necessitate analysis of the habitat conditions *after* the drought cycle as well. What is important to establish is the dynamics of species survival; what conditions are necessary to restore viability, what conditions constitute a threshold? Additional hydrologic analysis (e.g., scenarios bracketing past drought flows with even more extreme events or variations) would increase the view of system behavior and the breadth of potential impacts examined. Comprehensive investigations of the variation in hydrology and water quality as well as simulated habitat variability to search for potential associations with events of high stress and conditions necessary for population recovery would be appropriate study elements for both short and long-term periods.

Page 1, Background

This section presents some basic historical flow information for both the Comal and San Marcos Rivers. Clearly there have been considerable seasonal and inter-annual variations in water flow in both systems, but the extent of this variation is not well developed. Emphasis is placed on the flow during the extreme drought periods of the 1950's. No discussion is given (pro or con) of the need to develop simulations approximating the physical habitat and water quality conditions during that period for comparison with more recent years when intensive biological monitoring has taken place. Other factors that should be included, and are at least by inference, are the need for connectivity (for organisms to escape potentially lethal habitats and re-colonize depleted areas following drought) and geomorphology (or the need to minimize or avoid fluvial geomorphic processes/bedload transport in parts of the study area) during low flow periods.

Page 2, Background - Comal River

Hydrologic information (for the Comal and San Marcos rivers) is an important element in understanding the drought flow condition and relevance of flow recommendations; however this information appears lacking in the report. A table showing the minimum, maximum, and average flow at defined points or gages on both of the streams should be included.

Clearly there is a flow level below the proposed minimum threshold at which endangered species in this system are extirpated. It would be helpful if this analysis could identify the approximate flow level at which this might occur to, at a minimum, emphasize the fine line that may exist between the proposed flow regime and the "extirpation" flow level. Such information may help the EARIP understand the need to possibly increase the minimum flow they have proposed in order to minimize the risk of permanently losing these species.

The document states, "*During the drought of record...*". This would be a good place to clearly provide criteria upon which a DOR would be based. We are unable to find the definition for the acronym "EAA". This should be provided.

Spring flows ceased for 144 consecutive days in 1956; fell below 60 cfs for more than 100 days, and also fell below 40 cfs for over 40 days. The low mean daily flow was 26 cfs; other low flows were observed in 1989 (62 cfs), 1990 (46 cfs), and 1996 (83 cfs). Comal riffle beetles and fountain darter were apparently extirpated during this drought period. Clearly, the low flow period in 1956 was substantially lower than low flows experienced subsequently. The report states that low flows after the 1956 period did not extirpate riffle beetles, fountain darter, drypoid beetles, or the Peck's cave amphipod. This is apparently the rationale for the proposed low flow thresholds of 30 cfs for no more than 6 months with increased pulse flows to 80 cfs for the

following 6 months. These proposed low flow recommendations appear to have been developed before habitat studies were done. The rationale and process for the derivation of the low flow regimes in most studies is based on hydrologic modeling or another process. As a premise for this low flow study, the basis upon which thresholds were developed should be provided in the report. Without this specific documentation, it is difficult to ascertain the real risk associated with these flow regime proposals, even qualitatively.

Page 2, Background - San Marcos River

As noted above for the Comal River, more complete hydrologic information should be provided. Criteria upon which a DOR would be based should be provided.

The lowest recorded discharge was 46 cfs in August 1956, which also had the lowest monthly average flow recorded (54cfs). Mean monthly discharges between 1955 and 1956 were between 54 and 77 cfs. Importantly, no quantitative data exist for the response of the target aquatic resources over this extended low flow period. Since the 1980's, Texas Wild Rice has sustained populations during all subsequent low flow years, even in the face of impacts from recreation, high flow scour events, and non-native species. Viable populations have been maintained during the extended low flow period in 2009. Low flows examined by the Hardy study were set for 45 cfs for no more than 6 consecutive months, with pulse flows increased to 80 cfs during the following 6 months. Without explanation for the basis of these low flows, we have the same concerns we identified for the Comal River noted above.

Page 2-4, Background - EARIP Drought of Record Low Flow Regimes

Again, it is not clear how the DOR is defined in terms of a flow value. Figure 1 is apparently showing the DOR begins sometime around the flow corresponding to January 1, 1947 and ends sometime around 1959. Is this the defined time period for the DOR? Does this mean when flows in the San Marcos River drop to 175 cfs this is the trigger for a DOR? As noted previously, there should be a section in the report that deals with hydrology and specifically there needs to be more discussion on what constitutes a DOR in terms of flow values.

Page 4, Methods

The methodological approach described in this section is very thorough and informative. The level of detail contained in these studies is exceptional and appears to facilitate the kind of analyses that are needed to effectively understand the consequences of different flow regimes. Intensive sampling, model calibration, and 2-D simulations of habitat were completed for both systems. Considerable detail is presented, including vegetation cover maps, habitat suitability, and reach maps illustrating ranges of hydraulic habitat suitability over a range of flows for selected species. These analyses were well done. Interfacing field data gathered by wading and by boat and with topographic data from LiDAR represents the state-of-the-art and allows for simulations of flow over the entire flow range from low flow onto the flood plain. Illustrations and information tables were clear and useful. Apparently no simulations of seasonal habitat periodicity or inter-annual habitat suitability were developed. However, it appears that all information necessary for such simulations was available.

Page 4, Methods - Vegetation Mapping

Mapping techniques to create vegetation polygons with dominant and subdominant species and joining with hydrodynamic modeling grids to assign roughness values and vegetation class attributes are an excellent application of the science.

Page 6, Methods - Topographic data reduction and computational mesh generation. Combining topographic maps, LiDAR, and in-channel shots is standard, thorough modeling practice. The 2nd sentence under this topic reads like LiDAR was used within the wetted channel (standard LiDAR does not penetrate through the water surface), but is resolved in the following sentence with the use of in-channel bed topography. It is common when LiDAR data and field data obtained using survey gear are combined to find inconsistencies in the elevations where data sets overlap. If there were inconsistencies in this study, then the manner in which they were resolved should be reported. Figure 4 shows the process of going from raw data points to contour map to good effect.

Page 7-9, Methods - Hydraulic Modeling

This is standard, thorough 2-D modeling practice. Figure 5 shows close match between observed and predicted water surface elevation (WSE). Table 1 shows a thorough and complete data set. The roughness values listed here all appear reasonable and within expected ranges for each vegetation or substrate type.

Page 9, Methods – Habitat Suitability Criteria (HSC)

The HSC curves for TWR, two non-natives aquatic vegetation species, and darters reflect recent research (Saunders et al. 2001, BioWest 2010a&b) and integrate additional information (empirical observations of darter depth utilization). Modifying the suitable depth criteria for darters as described here is appropriate and a credit to the authors to confirm the need for this.

The HSC curves were adopted from other studies and were well documented. No evidence is presented in this report of any testing of the adopted HSC curves as to their efficacy in describing species distribution at various simulated flows. For studies evaluating endangered species and proposed instream flows for implementation within critical water supply settings such as the Edwards Aquifer verification/validation, demonstration of habitat simulation agreement with species observations is called for (see National Research Council, 2008. Hydrology, Ecology, and Fishes of the Klamath River Basin). If such verification/validation was done by the original authors of the HSC curves then reference to the fact should be included. Academic aquatic scientists and ecosystem modelers have become quite critical of instream flow studies in recent years due to the lack of proper calibration and verification of model use in stream systems. These scientists point out that model calibration and verification/validation has become established practice in water quality modeling for over three decades and is of equal importance for hydraulic and suitability aspects of riverine habitat modeling.

When very low velocity levels (0-1fps) are within the optimum suitability range for some target species, verification of velocity data sets for simulated high flows would lend a high degree of credibility to the simulated velocity distributions produced by 2-D hydrodynamic modeling.

Page 15 -19, Methods - Physical Habitat Quantity and Quality, *Non-native vegetation Control*

Analysis of habitat for TWR and *Hydrilla verticullata* and *Hygrophila polysperma* allowed for an effective examination of non-native vegetation control areas. The basic approach for control was to, 1) remove non-native plants from existing optimal TWR stands and 2) remove non-native vegetation within a 2-meter buffer of occupied optimal TWR stands but additionally constrained by TWR having a greater suitability than the modeled non-native species.

These approaches seem reasonable given the data that exists. One caveat comes from Liebig's "law of the minimum" that states it doesn't matter how much habitat is provided, if that is not the limiting factor for the TWR plants in those areas (see http://en.wikipedia.org/wiki/Liebig's_law_of_the_minimum). There are always limits, and layers of limits; i.e., remove one limitation, and the next one becomes important. Any physical entity with multiple inputs and outputs is surrounded by layers of limits (Meadows 2008). However, what is often confounding is that the limits may shift – in other words, limits to the TWR may shift in response to stand size or some other dynamic factor. None of this argues against the approach taken, but merely expresses caution about expectations of results of the non-native vegetation control efforts. Lastly, the areal significance of *Colocasia esculenta* may suggest some further research for this species, especially if the habitat-guided control efforts for other plant species are even moderately successful.

Explanation of the analysis and accompanying graphics (Figures 10-12) were informative. As with any major field project (potentially removing over 25,000 m^2 of non-native vegetation qualifies as 'major'), converting the plans to implementation will be key. Applicability of the data, particularly under approach 2), where data accuracy is a critical element of a 'correct' decision, will likely require exploratory pilot efforts to work through field decisions before attempting targeted control work on a large scale.

Page 15, Methods - Physical Habitat Quantity and Quality, *Fountain Darters – Riverine Sections*

When carrying out flow-habitat modeling, there are several ways the HSC data can be used with the hydraulic data. In this instance the authors chose to use the geometric mean approach. This is a commonly used calculation method but it would be beneficial to provide the rationale for using this approach over other approaches. Validation of habitat model output by comparing suitable and unsuitable habitats with empirical data illustrating fish distributions would lend credibility to both the HSC and geometric mean composite suitability computations.

Habitat metrics can be expressed in a number of ways. For example, relating WUA as a percentage of the maximum observed WUA at each simulated flow would allow readers to better relate the WUA at each flow to the maximum that can be expected at a study site over the entire range of flows simulated. This may or may not change the overall conclusions of this report but would allow readers to better gauge the relative merits of the proposed minimum flow levels to other flow levels. Presenting the information as percent of total surface areas is, however, acceptable. It would be beneficial to provide the rationale for choosing this metric.

Page 15, Methods - Physical Habitat Quantity and Quality, *Fountain Darters – Lake Sections*

It is appropriate to recognize the limitations of applying flow-habitat models in lake environments and the need to use another approach, such as wetted area and depth, as used in the report. Relying on reservoir water quality models in lake systems is also commonly used.

A minor point, but use of the term "optimal" here and throughout the text is misleading and suggestive that all aspects of "habitat" have been captured. The term "habitat" can be very broad and encompassing. As a consequence, a more technically correct term might be "maximum observed suitable habitat." This change does not affect the validity of any interpretations or analyses, but would simply relate the attribute(s) being described more precisely.

Conducting analyses based on determination of WUA is widely accepted and used in virtually all instream flow studies. However, it is important to note that the relationship between the amount of WUA and numbers of target organisms is variable and imprecise between different rivers, segments, and species. The amount of WUA provides a good indication of the relative suitability of physical habitat for an organism and one would generally expect organisms to fare better and possibly expand in response to more WUA; but there is no guarantee of such outcome or steady state relationship between this factor and numbers of organisms. This is largely due to the fact that "habitat", as noted above, is comprised of a large universe of dynamic factors and processes that influence organisms. Certainly maximizing physical habitat (WUA) is a desired goal. Analyses based on the amount of WUA can help reduce or manage uncertainty, but such studies do not eliminate it or guarantee a particular outcome. It is axiomatic that physical habitat modeling is necessary but is not sufficient to provide a complete understanding of the species' ecology.

Page 16, Methods – Physical Habitat Quantity and Quality, *Texas Wild Rice – Theoretical Optimal and Suboptimal Area*

As noted above it would be beneficial to provide the rationale for using the geometric mean of the component depth over other approaches.

Overall, the approach described here is exceptional and should provide an appropriate and useful analysis.

Pages 17-19, Methods – Physical Habitat Quantity and Quality, *Non-native vegetation*

It is unclear if non-native vegetation density is constant year round or between years. Additional information about the abundance and distribution of non-native vegetation on an intra- and inter-annual basis would strengthen conclusions about the adequacy of the target flows for ensuring persistence of TWR. It would also be useful to include information on the growth and spread of these plants and TWR. This information would allow the reader more understanding of the feasibility of and need for physically controlling these plants as a way to facilitate the long-term persistence of TWR. The basic strategy and logic presented in the text is reasonable, though it is unclear why a 2 meter buffer is of greater utility than another size of buffer. Is this driven by the size of polygons used in modeling or a known life history feature of TWR or the non-native vegetation species? Clarification of these questions is needed.

The described approach for identifying most suitable areas for non-native vegetation removal and TWR expansion is a judicious and appropriate strategy that has merit over blanket removal of non-native vegetation.

Page 20, Methods - Temperature modeling

A glaring omission from this section is any discussion of the potential effects of global climate change on probabilities of achieving thermal or hydrologic conditions described in this report. Given the uncertainties associated with the effects of global climate change in both the short and long-term, a credible discussion of the probability associated with future annual thermal patterns and precipitation characteristics is warranted. At a minimum, the report should acknowledge the elevated uncertainties that may be experienced in the short (decadal) and longer terms.

Another missing component that should be included here or in an expanded water quality section would be the potential role of other water quality considerations, both surface and ground water

inputs over both the short and long-term. At the low flow levels proposed by the EARIP, even small changes in some pollutants that could enter these systems from either surface or ground water could significantly affect the persistence of the organisms studied here. The potential impact should at least be acknowledged in the final report. Future studies and monitoring should more specifically address this issue.

The last sentence of this paragraph notes that adverse thermal conditions should not exceed 6 months, but this seems based more on professional judgment than data analysis. Professional judgment is highly acceptable in many situations; however this is where a time-series analysis would be possible and beneficial.

Water quality was restricted to water temperatures. Given the sophistication of the study otherwise, it is surprising that other constituents were not addressed, especially dissolved oxygen. Average monthly and even daily time steps for this parameter are not sufficient when looking at the potential dynamics of plant stands, associated fish species (fountain darter), and sediment oxygen demand. Extreme oxygen deficits are possible at these low flows and can cause imperceptible mortalities to fishes, especially small, young life stages.

Thermal death criteria for specific life stages for all species should be provided.

Page 21, Methods – Temperature Modeling, Comal water temperature modeling, *Model Structure*

The QUAL2E model used was calibrated by the senior author and published and has been in use since. It incorporates headwater (7) and point load locations (44) to represent various springs in the system. As such it represents an established tool with adequate testing and refinement.

Page 21, Methods – Temperature Modeling, Comal water temperature modeling, *Assumed spring flows for Comal headwater and point loads*

The revision of flow rates for specific springs as a function of total Comal River discharge incorporated 8 years of field monitoring by EAA and work of Guyton Associates (2004), who analyzed historical water levels and spring flows for the 1948 to 2001 period. Assumptions and adjustments adopted within the report, based on the additional information from these sources, seem reasonable.

It is unclear why 74.51 F was used as the constant temperature on page 24 and why this level of precision (hundredth of a degree) was appropriate. Additional clarification is needed.

Page 24, Methods – Temperature Modeling, Comal water temperature modeling, *Assumed flow splits for Old and New Channel*

Table 12 - Showing the historic flow splits along with the preferred flow splits would be informative. The rationale for splitting the flows for the simulated model runs seems appropriate given the information provided. However, it would be informative to understand the historical flows in terms of differences from the flow splits being used for modeling.

Page 27, Methods – Temperature Modeling, Comal water temperature modeling, *Climate Data and Model Calibration*

Air temperatures for the 1956 meteorological year would enhance the utility of Figure 16, to show the relative similarity and differences between modeled air and water temperatures and the air temperatures occurring during the historic low flow year. Old Channel simulations (Figure

18) seemed to represent the critical excursions into or past the larval threshold differently than New Channel across from Landa Park Office (Figure 19) or the Landa Lake near Spring Island (Figure 20). There were at least 7 observed temperature readings in the Old Channel that were higher than the threshold and simulations; at least 4 of these occurred where the simulation did not reach past the threshold and the observed values did. In the New Channel, the simulations exceeded the observed values and 18 times exceeded the threshold when the observed values did not. At Landa Lake the observed high values generally exceeded the simulations but did not reach above the larval threshold temperature. The under-estimates are a concern, particularly in the Old Channel, which appears to be a critical habitat area. Additional discussion explaining these dynamics and related consequences would be helpful.

The water temperature modeling in this report relies heavily on the previous application and calibration of the QUAL2E model reported in 2009 (recalibrated from Bartsch et al. 2000). However, significant changes in the hydrology of the system have been included in this report. Therefore some discussion of recalibration of the QUAL2E model in this new setting seems appropriate. Was the model recalibrated to better fit the empirical data or simply used with new hydrology? In Figure 18, simulated high temperatures do not seem to provide a good fit to empirical data in Landa Lake.

On page 28, the report references a USGS gage on the Comal River, but the gage location is not provided here, nor is it apparent on any figures provided to this point. As noted previously, it would be helpful to include more information on and from any and all gages on the Comal River (and San Marcos).

Page 30, Methods – Temperature Modeling, *San Marcos water temperature modeling, Model Structure*

Significant changes in the hydrology of the system have been discussed in this report. Therefore discussion of recalibration of the QUAL2E model in this new setting seems appropriate. Again, was the model recalibrated to better fit the empirical data or simply used with new hydrology? An even poorer fit (both maximum and minimum) for the San Marcos Thompson Island is illustrated in Figure 28. If recalibration was done and this is the best fit that could be made considering the other sites for simulations then discussion to that effect would be appropriate. Time series simulations of water temperatures over the period of intensive biological monitoring would be informative. Recalibration should be done given the new hydrology. Time series using the recalibrated model would require additional partitioning of years and seasons of the record into periods of dry, normal/average, and wet hydrology and hot, normal/average, and cool air temperature conditions. Much of this information is apparently available from stream gage and airport weather records.

Page 30, Methods – Temperature Modeling, *San Marcos water temperature modeling, Assumed spring flows for San Marcos headwater and point loads*

There is a lack of quantitative data on individual spring flow discharges to assign specific flow rates over the range of San Marcos discharges. This mandated that individual spring flows within Spring Lake were treated as a single incremental flow and this is a straightforward treatment of the constraint posed. From Table 13: only two of the 6 headwater (1) and point load (5) discharges for the San Marcos River are assumed to vary as total discharge decreases over the range of flows studied (130-45 cfs): Spring Lake Headwater and Incremental inflow Reach 1, for

reasons noted above Interpretation of results should refer back to this limitation. This uncertainty may limit the precision of the conclusions.

The QUAL2E model is widely used and appears to have been properly calibrated and run for this study. Another model that might be considered and could offer significant benefits for other determinations discussed later in this report is the QUAL2K model (see http://www.epa.gov/athens/wwqtsc/html/qual2k.html). This model is a modernization of the former model but offers some expanded modeling features that include, among other things, use of unequally spaced reaches; simulation of attached bottom algae, light extinction as a function of algae, detritus, and inorganic solids; and simulation of pathogen removal as a function of temperature, light, and settling. Use of QUAL2K would likely not change the recommendations provided in this report but could help the authors or others address elements such as pathogen management and vegetation survival under low flow conditions in future reports.

Page 33 Methods – Temperature Modeling, *San Marcos water temperature modeling, Assumed spring flows for San Marcos headwater and point loads*

As noted above, descriptive information about the San Marcos River gage as well as more detailed hydrologic information from the gage would be helpful.

Pages 36-67, Results and Discussion

The habitat modeling results provided for the San Marcos River are impressive and thorough. Quantification of additional areas for TWR with removal of two non-native species shows the peak gain occurs at 100 cfs. Analysis of optimal and suboptimal habitat as the foundation for expansion of TWR into stable areas of unoccupied optimal habitat is a proactive application of science in an adaptive management framework. The 2-D mapped areas of TWR physical habitat provide a visual basis for relating the results and also necessary information for actually planning field operations. The report also provides quantitative information on the potential gain in TWR habitat through removal of two non-native plants, which comprise 2 of the 3 most common and abundant non-native plants documented. A conservative approach is proposed and seems prudent. The only caveat to this is obvious: proceed slowly, (spatially more isolated, smaller plots) making sure that the removal of non-native species, particularly within TWR stands, did not set up unintended conditions which exacerbate the invasive characteristics of the targeted plants. Documentation of conditions before, during, and after removal are paramount for later diagnostic efforts should something go awry.

The highest predicted suitable habitat generally occurs somewhat away from the stream margins both at 45 and 80 cfs. These results suggest that potentially high quality areas in these regions currently not occupied by TWR should be considered for planting or priorities for non-native vegetation removal as discussed below.

Another potential explanation, one that does not necessarily negate the report recommendation, is that there is another limiting factor in these areas, other than the measured habitat. For example, the distributions of the TWR may reflect unique hydraulic conditions (e.g., inside of bends), which are a function of channel shape and the helical flows of water, sediment, and nutrients.

Another explanation of the distribution of TWR could relate to the overall regime of flows; that this current distribution of TWR is an expression of longer term prevailing conditions, and that the stand itself modifies habitat when provided a range of flows within which to exist. Time

series analysis of the habitat for this species would help establish the basis for comparison of flow regimes (hydrologic time series wed with HSC curves) and an estimate of the impact on habitat conditions for any particular arrangement of flows. It would also allow diagnostic analysis of notable population events, especially when coupled with a wider array of potentially impacting factors (e.g., outbreaks of invasive species, extreme temperature events, recreation activities, sediment, nutrients, etc.). While the report is clearly addressing its stated charge, 'evaluation of the proposed minimum flow regime targets during a similar instance as the drought of record', documentation of the habitat resulting from the entire hydrologic regime, and any subsequent modifications of flows, are not provided. Adaptive management, so clearly called for and which was initiated by this substantial effort, would benefit from formal analysis of the target populations of interest and the flow/habitat time series which supports them. Gaps in understanding these systems would become clearer as well.

Page 37, Results and Discussion – San Marcos Physical Habitat Modeling, *Texas Wild Rice, Simulated TWR Optimal versus Suboptimal Physical Habitat*

Analyzing WUA data as a function of maximum WUA instead of as a function of stream surface area appears as if it would show a greater rate of change at the low flow range of interest. This presentation of the data likely would not change the overall conclusion but could strengthen it.

The word "strongly" is subjective and probably not appropriate; however, the overall conclusion that TWR may expand into areas of unoccupied suitable areas that remain suitable over a wide range of flows is a reasonable conclusion. It is unclear if expansion would occur in a short-term or longer term.

Page 40, Results and Discussion – San Marcos Physical Habitat Modeling, *Texas Wild Rice Simulated TWR Optimal versus Suboptimal Physical Habitat*

The headers for Table 15 are unclear. It appears the second column should have "simulated" added to the header and in the third column, "2009 mapped" should be added to the header. The same correction appears needed for Figure 35.

Page 42, Results and Discussion – San Marcos Physical Habitat Modeling, *Texas Wild Rice Potential TWR expansion with removal of H. verticillata and H. polysperma*

Use of the word "strongly" is subjective and unsupported. There is no information in simulations in this report that relate to the long-term persistence of TWR under any conditions, though a time series analysis of physical habitat and temperature would be helpful.

The conclusion of both providing adequate flows and removal of non-native vegetation is compelling. However, long-term monitoring is needed to confirm the indication that proactive planting and non-native vegetation removal would lead to long-term persistence of TWR. Other mechanisms may be at work influencing the growth and abundance of these organisms other than WUA as evidenced by the fact that the non-natives encroached on TWR in the past and could do so again. Though the assumption that non-native vegetation removal has a "high" potential for increasing TWR abundance, there are no data in the report that relate to this probability. This does not change the basic conclusion brought forth here that this activity may have merit and should be explored by managers. The prospects for TWR expansion are probably not an absolute, but may vary from year to year due to a variety of different environmental conditions. As such, lack of expansion in one year might not necessarily preclude success in a subsequent year and vice versa. Modeling alone is likely insufficient to resolve the potential value of this

strategy.

Pages 43-47, Results and Discussion – San Marcos Physical Habitat Modeling, *Fountain Darters - Simulated Fountain Darter Physical Habitat*

The results illustrate the value of the habitat modeling represented in this report. Potential changes of vegetation resulting from flow regime changes were not specifically included, but the results show the spatial influence of depth and velocity over the range of discharges. The sophistication of modeling analysis is evident: after providing the information indicating relatively small reductions of darter habitat between the examined flow ranges (45-80 cfs) the authors the necessity to implement adequate control measures to protect the vegetation community, to reduce potential secondary impacts on darters.

The last paragraph of this section of the report makes the appropriate point that the proposed flow regimes seem likely to provide enough WUA/habitat to ensure persistence of TWR and that other measures to control secondary impacts such as those associated with recreation and non-native fishes are equally or more important elements in a recovery program. The following section of this report addresses potential effects associated with temperature at low flow, but there may be other water quality issues to monitor and manage as well. Such impacts could conceivably arise from surface or ground water and their impacts would be greater at lower flow. If these potential secondary impacts have not yet been identified or managed, they should be the subject of future consideration and study.

Page 45, Results and Discussion – San Marcos Physical Habitat Modeling, *Fountain Darters, Simulated Fountain Darter Physical Habitat*

We agree with the conclusion that "*the combined suitability of darter habitat shows incremental increases as the discharge increases and that the spatial mosaic remains relatively constant.*" However, we do not follow the logic that it "*...is in part related to integration of vegetation in the calculation of the combined suitability which remains fixed over all ranges of simulated discharges.*" Unless the coding of the mesh is changed at each independent run of the model for each discharge, the vegetation, or substrate coding, is always constant in these models. We can't tell what actual velocities were measured at the flows of interest from the report, but suggest that if habitat remains relatively constant over a range of modeled discharges, then it is likely the velocity HSC curve is relatively constant at these low flows (see Figure 9). A sensitivity analysis can be run where vegetation is included as input to the model and then do another run of the model with the vegetation component removed. Results should be somewhat similar with the only difference being the scale on the Y axis (habitat units). The statement that "*Potential changes in vegetation as a function of flow regime within the San Marcos River were not considered in these analyses*" provides needed explanation of what was done.

It is reasonable to exclude Spring Lake from the WUA analysis since the modeled output in lakes is typically insensitive to changes in flow rate.

Whenever WUA curves show a monotypic increase in habitat relative to discharge, there should be a discussion presented to explain the shape of the WUA curve. It would be beneficial to know what the natural (no human alteration to the flow) range of discharge is for these reaches of the river. Is it reasonable to expect maximum habitat occurs at flows greater than 250 cfs? These animals evolved in the natural range of flows since the last ice age and it would helpful to

know if flows greater than 250 cfs are overbank flows, or rarely occur, etc. The known biology of the animal and the shape of the WUA should be discussed.

Pages 47 to 51, Results and Discussion – San Marcos Physical Habitat Modeling, *Fountain Darters*, *Implications of Temperature on Fountain Darters*

The temperature discussion is excellent. The detailed discussion refines the habitat suitability for fountain darters in various areas of this spring and addresses or explains the recent findings of other research. Conclusions related to the decreased viability of habitat for reproduction and recruitment in the river below Rio Vista are provided and have important implications during drought.

The graphical data presented generally support the conclusion that the flow regime being considered in the San Marcos River will provide adequate habitat quantity and quality necessary to provide protection for this species during similar instances as the drought of record. However, comparisons made with assumptions of differing climatic conditions would be valuable (e.g. dry water year and hot climate year, etc.). These comparative analyses including potential effects on dissolved oxygen are needed as well as simulations over seasons and years (short and long-term) to evaluate recovery after critical droughts.

It is widely recognized that temperature modeling of natural systems based on laboratory data is problematic but it is the standard practice. It is also common to have some observed data where temperatures exceed thresholds and the animals persist. However, given the intent is to protect species from extirpation, it is a good approach to use consistent metrics and apply a measure of precaution. There are inherent errors in models and since this exercise was designed to stay above a "thermal death" line, erring on the side of caution is warranted.

The horizontal lines in Figures 41 to 45 should have a label of "increased larval mortalities" on the graphs or supporting text in the figure caption. On page 50, reference to reaches 1 and 5 do not appear to be the subject of data presented in Figure 42. Also on page 50, the statement that ambient air temperature in the spring of 2009 was about 75F may be correct but there is no citation or other data to indicate where this number came from or whether it is the correct value to reference.

Page 51, Results and Discussion – Comal River

Physical habitat modeling again is well done and illustrated with detailed habitat maps and graphs. The general conclusion is that sufficient darter habitat will be maintained on at least a short-term basis. Many caveats are given and emphasis directed toward the need to control non-native species, ensure flow through the old channel, and protect vegetation. Indeed, survival of some, if not most, organisms during potential drought conditions similar to the 1950's appears likely under the proposed 'minimum flow regimes". Recovery following such stressful events is not demonstrated and generates uncertainty when combined with potential water quality conditions.

Page 51, Results and Discussion – Comal River – *Fountain Darters, Simulated Fountain Darter Physical Habitat in Landa Lake*

We agree that entire populations of darters (adults and juveniles) probably would not be eliminated at the temperatures shown, especially if temperatures return to favorable levels during the lifetime of these fish. If favorable temperatures do not return for several years, resident

populations may disappear though re-colonization would likely occur from upstream refugia. Recreation-related impacts and other secondary impacts (e.g. invasive species) could be severe at this time and could threaten long-term recovery. Again, this is another case where time series analysis of historic conditions and simulated worst case future conditions (that might be more severe than historic conditions), would provide important information.

Non-native fishes are a relatively new factor that may change the prospects for long-term persistence of fountain darters and the comments made here about their potential effects are valid. Other "new" or evolving factors that may change persistence prospects for darters should be identified as well. Control or removal of non-native fishes (and snails) can at least temporarily reduce pressure on small fishes like darters, but will likely require permanent monitoring and removal by humans. True recovery of endangered species should be such that species can persist on their own over time without the need for continued, regular intervention by humans. Thus non-native species removal should strive for total removal although this is a difficult goal. The uncertainties associated with this management practice speak strongly to the need to maintain the most WUA (and flow) possible to prevent non-native fishes, snails, and parasites from gaining a key advantage in terms of numbers and impacts. In consideration of the potential cascading effects of secondary impacts like these (especially on a long-term basis but also over the short and mid-term), the assessment provided by this report may be overly optimistic. Long-term monitoring and responsive action are warranted to document trends if and when they occur and enhance recovery prospects.

The second to last sentence in this section (page 58) states that "sufficient darter habitat will be maintained" but it is unclear what level of population existence is expected. It would be helpful if the authors indicated whether "sufficient habitat" relates to minimal persistence, maintaining robust populations, or some other level of abundance.

Pages 58-63, Results and Discussion – Comal River – *Fountain Darters, Implications of Temperature on Fountain Darters*

The graphical data presented generally support the conclusion that the flow levels being considered in the San Marcos River will provide adequate habitat quantity and quality necessary to provide protection for this species during similar instances as the drought of record on a short-term basis. However, comparisons made with assumptions of differing climatic conditions would be valuable (e.g., dry water year and hot climate year). These comparative analyses including potential effects of dissolved oxygen are needed as well as simulations over seasons and years to evaluate recovery after critical droughts.

Temperature modeling at 30 cfs illustrates conditions that exceeded both darter larval mortality and cessation of viable egg production thresholds in Landa Lake. At 80 cfs a few hours in late afternoon still exceed larval mortality and viable egg production threshold levels. Uncertainty about the possibility for incomplete mixing of the water column raises questions about the reliability of the QUAL2E simulations and leads the authors to believe the model over-states the thermal impacts ("likely results in an 'over-stating' of the thermal impacts in Lower Landa Lake."). This uncertainty calls for additional analyses incorporating dissolved oxygen in the water quality model simulations. This need is reinforced by reference to Figure 56 showing "that the lower extant of Landa Lake is primarily dominated by mud sediments which can have a high potential for oxygen demand under the right conditions." The cause for previous extirpations of Comal Springs riffle beetles is not known.

The horizontal line in Figures 50 to 54 should have a label of "larval mortality threshold" or text in the figure caption.

The discussion at the top of page 63 reflects an appropriate use of professional judgment.

Figure 55 shows that the river goes through a golf course, which may have or create water quality issues associated with the addition of nutrients (e.g., nitrogen, phosphorous) on an instantaneous or chronic basis. This situation provides just one example of the potential risk of water quality impacts from a variety of inputs that need to be explicitly addressed in future studies.

Pages 64, Results and Discussion – Comal River – *Implications of Flow Regime on Vegetation Dynamics*

The discussion related to all factors that can influence the aquatic ecosystem of Landa Lake is thorough and comprehensive *"...directed research on...flow regimes...residence time...velocity fields, on aquatic plant dynamics needs to be undertaken early in the adaptive management process to better inform the adequacy of the flow regimes being contemplated by the EARIP."* It is evident the tools used to date are only a subset of the effort that is required to understand the unique and complex ecosystem of Landa Lake.

Overall, this section characterizes the strength of this report, which is clearly detailed modeling and thorough examination of related factors affecting the results. Specific areas of uncertainty are noted in the report that illustrate this point:

1) Uncertainties related to vegetation response to sustained low flow regimes within Landa Lake and the fact that this represents a potentially significant unknown. The vibrancy of the current vegetation stands over the past decade is related as a positive signal for the resilience of the aquatic plant community;
2) Sediment oxygen demand within Landa Lake and uncertainties related to sediment accumulation and potential impact on the aquatic plant community. The short review of literature in this area is provided to explain this concern and is relevant and insightful;
3) A discussion of vegetation dynamics in shallow lakes, relating the complexity of interactions between dissolved inorganic carbon, periphyton, macroinvertebrates, and fish. The authors conclude, and we agree, that control of non-native species to positively impact the native aquatic vegetation in this system needs to be effective and that directed research on the implications of flow regimes on aquatic plant dynamics needs to be undertaken early as part of an adaptive management process.

The discussion on page 64 is good and adds a measure of accountability to managers to consider a potentially significant threat. Though the information needed to quantify potential effects of low flows on the survival of aquatic plants in general was apparently beyond the scope of this study, the authors make an excellent case for further developing and analyzing this potential threat.

A strong case for pursuing a conservative approach to setting long-term minimum flow levels is made. While analyses in this report suggest that WUA for target species may be acceptable on a short-term basis, the reality is that secondary factors that were not analyzed may pose a risk to the persistence of endangered species. The summary paragraph at the bottom of this page (paragraph 5) is precisely on the mark.

Page 67, Results and Discussion – Comal Springs riffle beetle

The statement, *"Our review of the water quality data do not indicate any demonstrable shift in water temperature or quality that would suggest that at these lower flow rates, impacts from water quality would be expected."* is technically correct, but what is not mentioned is that the effects of other water quality factors (pollutants) would be magnified at low flows and could have a negative effect if they were introduced. In addition to pollutants, there are likely negative consequences due potential diel swings of dissolved oxygen.

The discussion following the results shows no discernable impact to the riffle beetle. According to the report, empirical evidence of their persistence over the past two decades is evidence the proposed minimum flows provide for habitat necessary for protection of these species. Concerns expressed are: the implicit expectation of persistence of current water quality conditions, stability in water quality, stability in the surrounding watershed conditions and land use. While evidence supporting these concerns is not provided, we suggest this is not likely the case, even over the past two decades.

Pages 67- 68, Summary

The flow-habitat modeling, the temperature modeling, and the vegetation mapping are state-of-the-art (with the noted exception of a time series analysis). However, the authors very logically and correctly state there is much that is still unknown, particularly in Landa Lake with respect to dissolved oxygen and temperature regimes. While the authors conclude that the proposed flow minimums should result in the (short-term) survival of the species, there were no evaluations consisting of comparisons among alternative flow regimes. The authors appropriately caveat this conclusion stating *"...these flow regimes are not sustainable on a long term basis..."* The recommended minimums are specific to maintaining adequate habitat conditions for short-term survival of the target species during conditions similar to the drought of record. We agree these flow regimes will likely provide adequate protection for the aquatic resources but only if the underlying assumptions and proposed mitigation measures are successfully implemented.

One of the stated uncertainties is related to vegetation dynamics in Landa Lake. Other uncertainties include the degree to which the hydrodynamic velocity fields may permit cooler water to make it downstream to the old channel culvert system, and whether or not parasite and non-native fish control would be successful. The authors also note the impact of the proposed low flow regime on vegetation stand viability is unknown and this may dynamically impact darters and other species that strongly associate with the vegetation. The call for careful expansion of pilot control efforts for snails and undertaking an aggressive non-native fish program is important given the significance of this resource and the relatively small (tenuous) spatial scale of its existence. This underscores the need for systematic documentation of the population responses to flow regimes, control of non-natives, water quality parameters in addition to temperature, impacts of recreation, and small scale studies of vegetation die-offs.

To establish the theoretical and practical basis for adaptive management, sensitivity analysis of the proposed minimum flows through time series for both hydrology and habitat analyses should be undertaken not only for short-term survival during a drought of record, but of equal importance, conditions for long term recovery.

Given these uncertainties, it is problematic to then suggest *"...that darter populations will persist at reasonable numbers both within Landa Lake and upper reaches of the old channel with the*

flow regime magnitudes currently being considered." The level of uncertainty and what is known about populations of darters make it difficult to suggest persistence in perpetuity under these conditions. Clearly on-going monitoring is essential to address the uncertainties.

It is stated, *"We further reiterate the importance that these opinions assume all other mitigation measures are successfully implemented and would include non-native (fish) control, etc."* It should also be stated that given the uncertainties regarding dissolved oxygen (diel) and thermal connectivity, scientifically credible monitoring (designed to address hypotheses) is absolutely essential to address factors such as ecosystem parameters that were not included in this report, the uncertainties associated with the assumptions of the recommended mitigation measures, and the predicted outcomes of the models that were applied.

Within the San Marcos River, addressing the uncertainty related to successful recreation control for target TWR stands and removal of non-native vegetation represent substantial areas of negative feedback, in both the human and natural systems. A formal adaptive management plan, strategically stepping through modeling, research action, monitoring, and adjustment would be appropriate for all aspects of managing this system.

Pages 69-70, Recommendations

The recommendations given are certainly important. In addition, attention to additional water quality components and research on variable flow regimes and climatic conditions necessary for population recovery after the stresses brought on by critical drought conditions should be an integral component of adaptive management.

The specific recommendations follow from the results and discussion provided within the report and addressing them would generate a better understanding of the systems covered. Further, they would begin to provide information to allow a proactive approach to management – before a crisis mode is reached. For example, it seems prudent to begin implementation of recreation measures and testing the procedures, spatially, institutionally, and socially before extreme drought conditions are reached.

Use of the report results to guide direct management control activities is a logical outcome given the detail and refinement in the report and is laudable. The discussion and recommendation for future research related to vegetation dynamics and control of non-native species and control of flows in the old versus new channels is an appropriate focus of future study as part of the adaptive management strategy. However, expansion of the scale of perspective to TWR, fountain darter, and riffle beetle through time series analysis would further augment proactive management activities, further the understanding of target population dynamics, and allow science (habitat/ecology) based comparison and refinement of the low flow regime proposals. These efforts are absolutely essential in view of the uncertainty of using only flow-habitat and temperature models and the gaps in knowledge that were identified by the authors.

References

Meadows, D. H. 2008. Thinking in systems: a primer. Chelsea Green Publishing Company, White River Junction, Vermont, USA.

APPENXIX A

Review Team Members

Thomas C. Annear, Project Leader. Mr. Annear is the water management and instream flow program coordinator for the Wyoming Game and Fish Department. He has worked for the department since 1981 and helped develop and implement their instream flow program from its inception. He has directed or assisted with studies that led to filing over 100 instream flow water rights and conducted or coordinated aquatic impact assessments for every major water development project in the state since 1983. From 1992 to 1994 he chaired the instream flow technical subcommittee for the Colorado River Endangered Fishes Recovery Program. In 2003 he helped form an inter-divisional water rights management team to address water rights issues associated with the acquisition, disposal, and management of Game and Fish commission lands and has served continuously as team chairman. Mr. Annear assembled and chaired a steering committee in 1996 that led to formation of the Instream Flow Council (IFC), served as that organization's first president, and is an active member of the Executive Committee. He was project manager and senior author of the IFC book *Instream Flows for Riverine Resource Stewardship* (2002 and a revised edition in 2004), is a co-author of the IFC book *Integrated Approaches to Riverine Resource Stewardship: Case Studies, Science, Law, People, and Policy* (2008), and was project leader for the IFC's International Instream Flow Program Initiative (2009) that assessed the status and effectiveness of state and provincial fish and wildlife agency instream flow programs in the U.S. and Canada and opportunities for improvement. He has written over 150 scientific reports, numerous publications and popular articles on river management; been an invited speaker at national and international symposia; and helped address instream flow issues on a variety of projects in the U.S., Canada, and Europe.

Ian M. Chisholm is the Supervisor of the Minnesota Department of Natural Resources' Stream Habitat Program. He has developed the program since its inception in 1989, shortly after he began work for the MN DNR's Division of Ecological Resources. The primary focus of this team of eleven scientists is to understand river and stream systems, increase the appreciation and understanding of ecosystems, and promote the use of science in decisions affecting natural ecosystems. He has worked with instream flow issues since 1983 and has been an active founding member of the Instream Flow Council since 1995. Mr. Chisholm chaired the science subcommittee that produced the IFC's book, *Instream Flows for Riverine Resource Stewardship*. Current research and work includes: creating, developing and delivering a GIS-based watershed assessment tool for Minnesota's major watersheds; developing a calibrated and validated erosion index for Minnesota rivers; conducting a watershed-wide (HUC 8 scale) assessment of river stability and sediment supply; continuing to develop and maintain a HSC library for Minnesota fishes, now covering 102 species and 257 species life-stages (162,500 individual fish observations); maintaining long-term biological monitoring sites on five (5) rivers, first sampled in 1987; administering a stream restoration priority list for capital bonding funding; conducting review and comments on FERC-licensed hydropower projects for the Minnesota DNR's divisions of Fish and Wildlife and Ecological Resources; surveying, designing and supervising stream restoration projects (over 100 completed statewide) following a natural channel design approach; and, providing training and materials on river systems, including 4 week-long courses on fluvial geomorphology.

Dr. Clair B. Stalnaker has been a key player in the instream flow arena for over 30 years – in research, method development and implementation, and policy. He organized and served as leader of the Cooperative Instream Flow Service Group (and various subsequent titles) under the U. S. Fish and Wildlife Service and Geological Survey. This program brought together an interagency group of multidisciplinary scientists for the purpose of advancing state-of-the-art science and elevating the field of instream flow management to national and international prominence. The primary focus of this group was toward a more holistic view of river science addressing the major components of instream flow management, namely hydrology, geomorphology, water quality, and aquatic biology and promoting instream flow regimes (incorporating intra- and inter-annual variability) rather than "minimum flows". He retired as a senior scientist with the U.S.G.S. where he was chief of the River Systems Management Section, Midcontinent Ecological Science Center, Fort Collins Colorado. He earlier served as Assistant Professor, Fisheries and Wildlife Science (1966 to 1976) and as Adjunct Professor in the Department of Civil Engineering at Utah State University and more recently as Adjunct Professor in the Departments of Earth Resources and Fisheries and Wildlife at Colorado State University. He has served on national and international technical advisory committees and task forces and authored numerous publications focusing on the instream flow aspects of water allocation and river management. He served on the Water Science and Technology Board of the National Research Council committee report on "Water Transfers in the West: Efficiency, Equity, and the Environment" and the National Research Council, Board on Environmental Studies and Toxicology report on "Hydrology, Ecology, and Fishes of the Klamath River Basin". He is an Honorary Life Member of the Instream Flow Council and was awarded the Instream Flow Council's Lifetime Achievement Award in 2008. Since 2004 he has served as a member of the Science Advisory Board for the Trinity River Restoration Program, California.

Allan Locke has worked as a fish habitat protection biologist in Ontario and Alberta over the past 30 years. His work has encompassed the fields of fish habitat restoration, habitat protection, conservation biology, river, wetland and lake ecology and most recently, instream flow needs. In 1981, Allan joined the Alberta Fish and Wildlife Division as the Provincial Aquatic Habitat Protection Biologist. His responsibilities were to develop fisheries habitat protection guidelines with the intent to provide industry, governments, resource managers, and the public with an understanding of fisheries concerns regarding specific land use activities. Gaining knowledge and experience in the science of instream flow needs, Mr. Locke went on to develop a provincial program to address the important issue of protecting Alberta's rivers and creeks with respect to water use. In 1998, Mr. Locke succeeded in getting Alberta to become a founding member of the Instream Flow Council. From 1998 to 2000, he served on the Instream Flow Council Executive Committee as the first Director of Region 5 (Canadian Provinces). From 2004 to 2006, he was president of the Instream Flow Council. As a member of the Instream Flow Council, Allan volunteered his time as a co-author on the Council's first book, *Instream Flows for Riverine Resource Stewardship* and the second revised edition. Mr. Locke was the project manager and senior author for the Council's third book, *Integrated Approaches to Riverine Resource Stewardship: Case Studies, Science, Law, People, and Policy.*

July 13, 2010

Dr. Robert Gulley, Program Director
Edwards Aquifer Recovery Implementation Program

Delivered via email

Re: Responses to comments on our j-charge report

Dear Dr. Gulley:

Attached are the Expert Science Subcommittee's responses to the comments by Annear Associates, LLC on our j-charge report "Analysis of species requirements in relation to spring discharge rates and associated withdrawal reductions and stages for critical period management of the Edwards Aquifer". The subcommittee met on May 17, 2010, to respond to the comments and exchanged emails over the past few weeks to finalize our responses after receiving clarifications from Annear Associates, LLC on several comments.

Please let me know if you have any questions or comments.

Sincerely,

Robert E. Mace, Ph.D., P.G.
Chair, Edwards Aquifer Area Expert Science Subcommittee

Responses of the Edwards Aquifer Area Expert Science Subcommittee to the Peer Review Team Comments on "Analysis of Species Requirements in Relation to Spring Discharge Rates and Associated Withdrawal Reductions and Stages for Critical Period Management of the Edwards Aquifer" aka the "j-Charge" Report

Responses to the overarching comments:

"The review team agrees that pumping reductions to meet these trigger criteria is a positive interim strategy. However, this is a reactive approach and is bound to be difficult to implement in a way that maintains and enhances the species and habitat conditions in the springs."

- ***To clarify, the Expert Science Subcommittee was tasked with providing triggers and associated pumping reductions in response to species requirement, but we did not call for pumping reductions. The Steering Committee will ultimately be making those recommendations. The critical period management approach could be described as reactive rather than proactive, but note that it is not expected to be the entire solution to the problem.***

Responses to comments on: Task 1 Analyze species requirements in relation to spring discharge rates

P. 3 – The flow criteria in the table do not make any distinction as to time of year. In most other aquatic systems, different flow rates or levels at different times of year are needed to maintain or restore aquatic species.

- ***In comparison to in-stream flow analysis for rivers, seasonal variations in these spring systems are minor.***

P. 4; It is legitimate to assume that adequate flows for surface dwelling aquatic organisms will likely address needs of aquifer-dwelling species. This is intuitive because the species are "pool" species that key on lentic habitats more characteristic of aquifer conditions even if they exist in flowing portions of the aquifer. The list of environmental attributes should also include longitudinal and vertical connectivity. Longitudinal connectivity refers to connectivity processes over space within the existing channel (and springs) of a water body. Vertical connectivity is a reference to the manner in which a surface water is connected to ground water. Connectivity is multi-faceted and can relate to the ability of organisms to actively or passively move up or downstream or through gravel from groundwater to channel bed, as affected by the presence of barriers or features that impede (or facilitate) their movements. Barriers to the movement of biota can include physical, thermal, or chemical obstructions. Impervious cover over a landscape can constitute a barrier for vertical connectivity, impeding water and nutrient flow from the surface to groundwater. Connectivity can also relate to non-biotic elements such as water quality elements (pollutants or sediment) and geomorphic processes (bed load transport). It is

clear that the authors of the "j charges" report recognize the importance of this diverse concept, but we felt that because of its importance in affecting the distribution and abundance of the endangered species, it would be effective to specifically mention and address this key ecosystem attribute. Connectivity can be a key driver in determining the distribution and colonization of species throughout a system and directly affect their ability to re-populate areas that may have become temporarily unusable.

- ***As long as flow is sustained, we are assuming connectivity of the habitat of the subsurface species is maintained at each spring system. Additionally, we recommended that lower flows occur over a much shorter time period than historically experienced during the drought of record. As such, we are assuming that habitat connectivity for the Comal Springs Riffle Beetle would be maintained at a level suitable to meet the stated goal of survival and recovery.***

Approach

P. 6; The "workgroup" approach described at the top of this page, as well as the "subcommittee" approach used to develop this report, are strengths of the approach taken to develop the spring flow recommendations and indicative of the application of the best available science.

- ***We agree.***

P. 6-10; This list of monitoring reports and programs is unique and provides this study with much more information upon which to analyze model outputs and apply professional judgment than exists for the great majority of other flow studies. The wealth of information described on pages 6 - 11 further attests to the best available science being applied.

- ***Thank you.***

Natural Flow Theory

P. 11; It is a reasonable assertion to suggest that a recommendation to restore the natural flow regime would be impractical. These species have survived, to some degree for the last 150 years in altered flows, so it is imperative that this entire period of record be used for describing hydrologic variability and making flow recommendations.

- ***To clarify, "150 years" generally refers to human alterations over time in the spring ecosystems. Continuous gage data only goes back to the 1930s for Comal Springs and to the 1950s for San Marcos Springs.***

P. 11, last paragraph; A conservative strategy should be no less than the lowest observed flow especially considering that these species are endangered for the very reason that such low flows are part of the reason for their classification. A more appropriate conservative strategy would be to pick some higher

flow with less duration than was observed historically. The complexity of stream ecosystems makes setting an absolute low number very difficult but those closer to the river and issues doubtless have a sense of a proper range based on their professional judgment.

- ***We agree.***

Professional Judgment

P. 12. This approach, including use of professional judgment, represents the state of the art / science for these type of studies. There are no models that provide precise answers without the application of some degree of interpretation and professional judgment. The team is to be commended for clearly articulating the process and the very real fact that professional judgement must be used.

- ***Thank you.***

Analysis Assumptions and Recommendations

P. 12 – 13; The approach of using metrics defining thresholds for loss of habitat and an instantaneous threshold below which no water should be taken is consistent with similar studies throughout North America. The review team had difficulty understanding how seasonal and inter-annual adjustments would be made and when these adjustments would be implemented in a real time operational sense. There is no evidence, such as a time series analysis of any hydrologic period or periods against which these criteria have been overlain or plotted to show how these metrics will support necessary intra- and inter-annual variability.

- ***Once developed, critical period management for the aquifer is in place all the time in this system which addresses the need for seasonal and inter-annual adjustments. We agree that a time-series analysis will be valuable for the habitat conservation plan and/or the final critical period management plan.***

P. 13; The report notes, *"...the frequency and duration of these extreme events are of critical importance and, if extended beyond the natural tendency of the system, can be detrimental to the resident ecological community."* The assumption being made here that the variability of the flow record of the past 150 years is a reasonable representation of the longer term record may not be reasonable given the declining nature of the endangered species in this system.

- ***We agree; that's why we considered other factors other than historical hydrology.***

P. 13; The use of average statistics is risky. While the various time intervals have merit in terms of maintaining flow regime characteristics, most species are affected by instantaneous low or high flows. The use of average statistics can mask potentially serious bottlenecks associated with short-term low (or high) flows.

- ***We agree.***

The allowed or expected frequency of the minimum 6 month average flow and 1 month minimum average is unclear. Certainly the authors do not anticipate back-to-back periods of these conditions but it would be good to clarify what they think allowable limits might be.

- ***We agree; an analysis of these values in the context of a habitat conservation plan will need to be done.***

The authors' logic about natural precipitation events providing for higher flow pulses may be acceptable however future studies should address the potential for additional water development in the region that might capture additional surface flow and alter spring flows. In addition, future reports should offer recommendations about how much additional water development is allowable within various parts of the watershed.

- ***We concur.***

The issue of seasonality should be more specifically addressed – the report should at least acknowledge the level of natural seasonal variability that existed prior to development to support the statement that the specified strategy will approximate those conditions. This was a major point of discussion in the review team's overall comments.

- ***See our response to the comment for Task 1, page 3.***

P. 14; The report notes, *"...high flow pulses are very important . . . in both . . . ecosystems to flush the system, remove vegetation mats, move sediment, and occasionally scour out vegetation . . . We evaluated high flow pulses within the context of each of the threatened and endangered species and made the determination that as these events are driven by precipitation, they would occur naturally."* The team is to be commended for not just focussing on the average to low flow range but including the higher flow ranges as well. Many studies overlook this very important aspect of river ecology. We caution, however, that a simple assumption that pulses will occur naturally is not a means of ensuring these events will occur. An additional, higher statistic than those listed is needed to address this flow level.

- ***We believe that this would be difficult to achieve in an aquifer system; a karst aquifer responds differently than a riverine environment.***

P. 14, last paragraph; The process of analysis omits mention of historic / natural conditions and appears to use existing conditions as a starting point. This approach accepts the existing condition as the default standard which seems like a tenuous perspective given the fact that the species have become endangered under these conditions and return to flow patterns and processes closer to historic levels would seem necessary.

- ***These species are endangered because of geographic isolation and risk associated with drought and pumping; therefore, using existing conditions in the absence of historical biological data is a reasonable starting point.***

P. 14; A seasonality component is necessary and should be included.

- ***See our response to the comment for Task 1, page 3.***

Comal Springs Analysis and Assumptions

P. 15; The fact that fountain darters had to be reintroduced here from San Marcos Spring clearly indicates that connectivity is important. Connectivity to habitat that could sustain them under drought conditions (thermal refugia) was a function of water flow from the spring, which was affected by pumping. Since being reintroduced, the fountain darters have flourished. In terms of zoogeography, we assume that the same fish species in a region were distributed through hydrologic connections that may or may not be apparent today. In essence, the reintroduction established a population by (artificial) connection to a fountain darter refuge (San Marcos Springs). We make the point that insuring conditions that allowed habitat refugia, and the connectivity to them, to exist within the springs, would go a long way towards ensuring fountain darter persistence. Meaningful, or full, recovery should involve the ability of organisms to re-colonize any areas of suitable, historic habitat without human intervention.

- ***The flows recommended at Comal Springs were established to prevent the need for reintroduction (human intervention) of fountain darters from San Marcos as was required following the drought of record.***

P. 18, paragraph 4; Given the status of this organism and the expressed goal as stated on page vii, paragraph 3 of this report that says "*Our interpretation of a protective flow regime is one that will ensure the "survival and recovery of the species in the wild". To accomplish this goal, the subcommittee determined that the recommended flow regime must sustain an overall trend of maintaining or increasing the populations of the threatened and endangered species*", acceptance of up to a 40% reduction in habitat seems too high.

- ***The important component of this reduction is that it will only be temporary in nature. A temporary reduction (1 month or 6 month average) that occurs infrequently is not considered to contradict our goal.***

P. 20 last paragraph; Discussion about the reduction in parasite prevalence following flood events suggests that such events are important. Flow management strategies to address this issue should be included in recommendations regardless of potential conflicts with any other endangered species. Because the range of flows during studies of cercarial abundance were relatively limited (no more than 441 cfs) it is unclear if higher pulses of flows would indeed have the speculated effect of reducing their numbers.

- ***We agree.***

P. 21, last paragraph; Simply monitoring Ramshorn snails will not ensure protection or enhancement of habitat for fountain darters. If this species really does pose a threat, their populations should not only be monitored, but strategies and efforts to control their abundance and distribution should be identified and adopted.

- ***We agree.***

P 22, second full paragraph; This discussion of potential effects associated with recreation suggests that some level of habitat degradation is acceptable in Comal Springs, which is a questionable position when dealing with recovery of endangered species. In many cases like this there is zero tolerance for takings unless specific levels are identified and justified in recovery plans.

- ***Because of the current condition of endangered species in the Comal Springs system, some level of habitat degradation over short periods of time will not contradict our goal of an overall trend of maintaining or increasing populations.***

P. 25 first two paragraphs re: Comal Springs Riffle Beetle; These observations about the ability of this organism to survive natural drought periods are logical. However, it would not be prudent to prescribe or allow those conditions any more frequently than they occur naturally. Sometimes when water managers accept or recommend an instream flow level that is substantially lower than existing flows (or is based on

the lowest flow on record), the result is in essence the same as a prescribed drought. Managers should be careful not to indicate an acceptance of low flows that approximate historic low flow levels on the basis that organisms have survived those conditions in the past.

- ***We agree, and thus the rationale behind us using multiple approaches (not just historic hydrology) in the development of our recommendations.***

We appreciate that the Science Subcommittee is sensitive to this fact and offer encouragement to implement flow regimes that exceed drought levels. Prescribed drought is never an acceptable condition for perpetuating aquatic organisms. The recommendations provided by Hardy (2009) seem defensible and acceptable for this species.

- ***We agree.***

P. 25, Comal Springs dryopid beetle; Comments about the habitat and flows needed to perpetuate this organism are logical and defensible. Additional data collection would be helpful to affirm these observations.

- ***We agree.***

P. 26, Peck's Cave Amphipod; It is not uncommon for invertebrates like this and the beetles to experience wide swings in population numbers within or between years. Flow is probably only one of the drivers behind these swings. Water quality is likely also involved. It is unclear to this point in the report how or if water quality in spring flow is affected by surface management practices in the Edwards Aquifer drainage area. If there are input areas of concern these should be identified.

- ***We agree that water quality needs to be addressed in the HCP.***

Comal Springs Flow Regime Recommendations

P 26-27, Figure 5; Final recommendations deviate from the long-term average, 6 month minimum, and 1 month minimum statistics. The process details resulting in the recommendations of 225, 75, and 30 cfs are not completely clear and undoubtedly relied on professional judgement. We support professional judgment but descriptions of the logic and decisions that led to these changes must be documented more thoroughly. We can envision how these recommendations could be used as reactive strategies but it is unclear how these recommendations could be used to pro-actively manage the system. This issue is addressed in more detail under the review team's comments for Task 2.

- ***Best professional judgment was used to interpret the information in Figure 5 and develop the recommendations. The development of an habitat conservation plan and/or a critical period management plan is a proactive approach to managing the system.***

No biological rationale is given for allowing the absolute minimum to go down to 5cfs except for the implication that this flow is greater than 0 cfs. In the absence of additional information or discussion about the basis for this prescription, this flow level does not support the goal for survival and increasing populations of the fountain darter in Comal Springs.

- ***We agree; we used 5 cubic feet per second to simply ensure that a monthly (~30-day) mean flow did not allow springs to stop flowing. We expect that any flow at 5 cubic feet per second would be momentary. A monthly mean flow was used to accommodate the stress periods in the aquifer model.***

There are many unknowns that could affect the actual achievement of species recovery and this is an excellent example where continued monitoring and study is warranted. Monitoring alone is not enough as water managers should also put in place authority and financing to implement emergency protective actions if future study shows it necessary. Of course, criteria should be developed to define the meaning of "necessary".

- ***We agree.***

P. 28, 2nd paragraph; the goal should be not just be "survival", but "recovery".

- ***Our goal was to support an overall trend to maintain or increase populations instead of survival.***

P 29, Next to last paragraph; " . . . *we have elected to recommend flows higher than the historically observed low flow statistics at Comal Springs because of the extirpation of the fountain darter following the 1950' drought* . . ." This statement is in contrast with the information on page 28 regarding the selected absolute minimum of 5cfs discussed above. Additional discussion is needed to clarify this apparent discrepancy.

- ***Comal Springs stopped flowing for 144 consecutive days; therefore, 5 cubic feet per second is higher than historically observed values.***

P. 30; As stated previously, it is interesting the Subcommittee made the decision not to incorporate a margin of safety. The EARIP should ensure the legal and institutional capacity allows for changes that may be necessary in the future if it is determined that flow regimes need to be more conservative.

- ***This comment is directed to the EARIP.***

P 30, 2nd paragraph; The recommendation for monitoring should not be just for study at critical low flow periods, but for other flow levels as well so that suitable comparisons can be made and conclusions drawn.

- ***We agree.***

San Marcos Spring Analysis and Assumptions

P 32, 3rd paragraph; Future studies should document the level of recreation use between years.

- ***We agree.***

P. 34, 2nd paragraph; The review team agrees that consideration should be given first to monitoring data, then to model results. This is a strength of the approach used.

- ***Thank you.***

P. 35, paragraph 1; SNTEMP is a useful tool for assessing thermal dynamics in streams and is generally known to be relatively insensitive to air temperature. More influential drivers are shading and groundwater inputs. It is important to include the most accurate data possible for all sensitive drivers.

- ***We agree.***

P. 36, 1st paragraph; A short explanation of how Saunders et al. determined "importance in the ecosystem" would be helpful.

- ***Our interpretation is that it was based on the native vegetation's abundance in the ecosystem.***

Page 39-40, Figure 9; The Subcommittee should use a finer scale of flow increments between 30 and 80 cfs to see if there is a discernable inflection or change in the slope of the curve over this range of flows.

- ***We agree.***

P. 41, line 5; Reference to the effect of flood retention dams on fluvial geomorphic processes (siltation) is an important factor. Hydrologic events that have led to this condition are just as important as those processes that perpetuate vegetative growth and physical habitat for endangered species. It would be appropriate to develop recommendations that relate to this trend and construction of additional flood retention dams in the future.

- ***We agree.***

P. 48-50; It is obvious that recreational use of the river is having an impact on wild rice and other aquatic vegetation. Studies to quantify these effects at different times of year are needed to incorporate in

development of flow regime recommendations. Based on the outcome of these studies, specific management measures may need to be developed.

- ***We agree.***

P. 50, 1st paragraph and P. 51; Data are not provided to determine whether the differences between years and seasons are statistically significant. Also, if there is a natural late-season die-back of Texas wild rice that might contribute to seasonal changes, this aspect of the species' life history should be described.

- ***See earlier comment. Note that there is no late season die-back of Texas wild rice.***

P. 53, 3rd paragraph; The percent reductions in WUA do not appear to be substantial given the changes in flow, especially given the inherent measurement error in both flow measurement and hydraulic modeling. Our reference to "substantial" relates to numeric changes and the relatively small change in WUA with change in flow. We appreciate that WUA is only a relative indicator of physical habitat suitability and the relationship between that metric and organism abundance is unique for each stream or system. As a consequence, even a small change in WUA in some streams could result in a relatively large impact (or benefit) for some species. In light of this fact, additional discussion would help explain why the relationship between flow and WUA may or may not be an important consideration as opposed to simply another piece of evidence.

- ***We acknowledge that in certain instances there were only slight changes in WUA relative to changes in flow. As such, additional approaches, including professional judgment, were used for decision making to supplement the WUA assessment.***

P. 55; If the WUA estimates are credible, over time one would reasonably expect the plants to become established in more than 9 and 17% of the habitat. A time-series analysis would be helpful here to further investigate this linkage.

- ***There are other species already occupying (and competing for) potential habitat.***

P. 55; This discussion provides additional indication of the need to consider connectivity of habitats and time series analyses when analyzing or setting flow recommendations. In this instance, we affirm that in addition to longitudinal, vertical, and lateral connectivity, it is important to also consider the temporal aspect of this attribute per time series analysis. The importance of addressing and managing for appropriate intra- and inter-annual connectivity patterns and processes is well established and can be a major driver for many aquatic organisms.

- ***We agree that a time series analysis should be conducted during the alternatives analysis for the habitat conservation plan.***

P. 56, 1st paragraph; These statements provide a compelling basis for placing an emphasis on the human component of biotic effects as it relates to habitat needs for the endangered species. Not many instream flow studies rely on this kind of criteria but it seems clear that human-caused degradation is a significant driver here. Professional judgment would be a useful tool to set a flow regime recommendation on this basis.

- ***We agree.***

Pp 56-59; The assumptions in this section are scientifically valid.

- ***We agree.***

Historical Flows at San Marcos Springs

P. 60; It is not clear what is meant by "*rarely be experienced*". Perhaps the long term average flow target of 140 cfs could be presented graphically so that the frequency and duration for an appropriate time step, say monthly or whatever best suits the assemblage of flora and fauna, can be seen to better illustrate the point.

- ***Flows are presented in Appendix G. Figure 27 shows how often the 1 month and 6 month targets are exceeded. The phrase "rarely be experienced" will need to be addressed in the habitat conservation plan; it wasn't necessary with the critical period management plan.***

P. 60, 4th paragraph; The goal should be recovery as well as survival. In the last paragraph, the WUA-flow relations developed by Hardy (2009) for fountain darter do not support the claim made in the 2nd sentence about the 140 cfs flow. More detail regarding the professional judgment that went into this recommendation would be helpful.

- ***See comment above on recovery/survival. Professional judgment was used to balance the needs of all endangered species, not just the fountain darter. We believe the report adequately documents the professional judgment used.***

P. 61; The review team notes that the overall strategies used by the Subcommittee for recommending flows is to pick statistical values as the flow limit and then use habitat modeling and other information to justify the highest value without going above the statistic. This is an acceptable strategy but it does not appear that this protocol was consistently followed. The review team thinks the present recommendations are acceptable interim guidelines but additional information is needed to explain the deviations.

- ***We disagree that this was the main strategy used. We used data, modeling, natural flow, and professional judgment at varying degrees depending on what information was available.***

P. 62, Table 11; As suggested above, more detail regarding professional judgment would be helpful to explain how specific recommendations were derived. Results presented by Hardy (2009) and Saunders et al. (2000) by themselves do not appear to be supportive of the 140 cfs recommendation for the Long-term Average flow prescription.

- ***Based on the occupied area of Texas wild rice and professional judgment, we made adjustments to balance the needs of all species.***

The Subcommittee chose to exceed the historically observed flow statistics at San Marcos because of uncertainty associated with stochastic events that might significantly impact species. Of particular note is the 1-month average minimum of 60cfs with an absolute minimum of 52 cfs. This contrasts with the low flow recommendation for the Comal Springs where the lowest flow reached since reintroduction of the darter has been 26cfs.

- ***See previous comment.***

P. 64; Additional rationale is needed to explain why this calculation was used, as opposed to other methods to set the 1-day minimum flow.

- ***See both previous comments.***

P. 65- 66; As with our previous comments, it is clear the Subcommittee thoroughly discussed this issue and it is clear they chose not to factor in a safety margin in view of the uncertainty. And to reiterate, it is not known if the legal and institutional setting will allow for changes to the water management plan if it is later revealed that impacts are occurring and the flow needs to be increased. Ultimately, this is a decision about how the Subcommittee wants to manage risk.

- ***This comment is really directed to the EARIP.***

P. 66-68; The Subcommittee's recommendations for future study are certainly appropriate for developing a better understanding of the system and should be pursued. Increased sedimentation and recreational pressure are confounding issues that need to be specifically addressed during future study of the San Marcos Springs.

- ***We agree.***

Response to comments on: Task 2 Analyze withdrawal reductions and stages for critical period management

P 69-74; The MODFLOW-NR represents the state-of-the-art and is appropriate for evaluating Task 1 minimum flows and stages. Accounting for groundwater and surface water is a very complex undertaking

and the Subcommittee outlined very clearly how this was done in the context of evaluating a number of flow alternatives. The Subcommittee is to be commended for addressing this complexity in a comprehensive and reasonable fashion. The review team found that conducting the 40-odd runs was a useful exercise that illustrated how the present management model can be used in meeting Task 1 flow recommendations.

- ***We concur. Thank you for the acknowledgment.***

P. 75; The report clearly shows the Subcommittee attempted to address the very uncertain topic of climate change. If the climate models show the possibility of decreased flows in the future, the Subcommittee could create simulation runs representing a range of possible flow conditions and examine the effect on flow recommendations. Addressing climate change when making flow recommendations presents an enormous challenge and is not unique to this basin. We suggest the Subcommittee consider looking at a number of climate change models and once they agree to one that predicts less water in the future, they could calculate the return intervals for whatever time period is most appropriate.

- ***We are assuming that there is a margin of error in the analysis and that this is an adaptive management process which will be updated in the future when more information is available. We also recognize in the recommendations for future work that global climate modeling can be used to look at effects of climate in the future.***

P. 79; The sensitivity analysis is a good scientific tool for examining possible scenarios.

- ***We concur. Thank you for the acknowledgment.***

P. 81-84, Table 13 and Figures 22 to 24; The various pumping scenarios and how the various runs do or do not meet Task 1 flow recommendations are logically presented. Figure 24 is particularly informative as it shows how the operating criteria would influence flow statistics.

- ***We concur. Thank you for the acknowledgment.***

P. 85; The recommendations would reduce pumping only during Stage I. It is unfortunate that changes in other stages could not be evaluated due to lack of time, though this is understandable given the manner in which Task 2 was conducted. We agree that additional evaluations are needed, especially for Stages II and III.

- ***We agree that additional evaluation needs to be done.***

P. 89; These "real time" operational issues should be addressed in the next phase. These operational issues however, are valid and we agree with the Subcommitte's assessment. We assume that real time operational issues will be addressed including possible adjustment by forecasting, water year, and season.

- ***We agree as we mentioned in the recommendations that the management module needs to be refined to better represent the aquifer management especially at the large potential cutbacks.***

P. 89, last paragraph; Comments about the need to understand the effects of rapid flow fluctuations may be warranted as all of the endangered species appear to have an affinity for stable conditions of a spring flow environment. It would seem that Texas wild rice is the species that would benefit most from specific studies of the effects of higher than average flows.

- ***We concur that Texas wild rice would benefit from studies of the effects of higher than average flows.***

P. 90; Further studies; computer models all have limits and the current analysis is no exception. There are many unknowns in how this system really works and how pumping at various levels from a variety of locations really affects spring flow. In fact, the relationship between groundwater level, pumping, and spring flow likely exhibit naturally dynamic characteristics associated with a variety of factors that are beyond the ability of managers to accurately measure. That said, most of the additional studies mentioned in this section are all appropriate and would help develop a better understanding of how to manage pumping processes over time. These recommendations are well thought out and appear to be consistent with modern scientific opinion regarding the use of modeling in water planning and management as is discussed by the National Research Council (2008).

Specific recommendations for the next generation of water quality and physical habitat modeling and guidance for addressing seasonal and inter-annual variability through improvements in modeling and time series analyses are outlined in our review of the Hardy 2009 report. The continued integration of these modeling efforts as improved by ongoing and future monitoring would provide a firm foundation for producing conservation plans in support of the Endangered Species Act. Depending on how these studies are conducted and the legal and institutional constructs within which they occur, we perceive a very good opportunity to refine flow regime recommendations using a scientifically based adaptive management approach. We acknowledge that this kind of approach is probably not yet in place, but we suggest that such a program, if properly designed and implemented, could be effective.

- ***We concur.***

P 94; There appears to be a critical shortcoming between how the water consumption licences are administered and what it means to flows in the system. The recommendation that *". . . .the Edwards Aquifer Authority . . . consider modification of its rules to provide for more immediate responses to critical period management triggers."* is reasonable and needed.

- ***We concur.***

Appendix G.

The utility of the graphs of scenario runs would be greatly improved by plotting a reference condition (for example Run 2) with each run. This would provide a direct comparison of the magnitude and pattern of change each scenario relative to a common base line.

- ***We don't feel that there is a consensus reference case to show on the plots.***

APPENDIX J:

BIO-WEST, INC., "ENVIRONMENTAL RESTORATION AND PROTECTION AREAS FEASIBILITY STUDY: COMAL SPRINGS," FEBRUARY 2011

DRAFT

Environmental Restoration and Protection Areas Feasibility Study: Comal Springs

Prepared for:

Edwards Aquifer Recovery Implementation Program
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February 2011

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1.0 INTRODUCTION

The Edwards Aquifer Recovery Implementation Program (EARIP) is pursuing a Habitat Conservation Plan (HCP) for the protection of the threatened and endangered species in the Comal and San Marcos springs/river ecosystems. To ensure the protection of these species in the wild, EARIP will likely need to consider measures above and beyond currently established practices. One such measure is Environmental Restoration and Protection Areas (ERPAs) within the Comal and San Marcos springs/river ecosystems. Formerly termed "Intensive Management Areas (IMAs)", the name was changed to be more representative of the function of the measure. An ERPA consists of both restoration and protection activities pursuant to the threatened and endangered species and their habitats in these aquatic ecosystems.

Guyton (2004) took a cursory look at several measures for maintaining habitat for the threatened and endangered species during times of severely reduced recharge. Several strategies appeared promising but the response of the biological community is often unpredictable, and thus without adequate study it was not possible based on Guyton (2004) to determine the impacts and benefits of such alternatives to protect habitat for these species. This feasibility study evaluates several alternatives in greater detail with a focus on the following three key components that are imperative in the EARIP decision making process.

1) *In-situ* refugia – maintain habitat and endangered species within the springs/river ecosystem(s) under severely reduced recharge conditions;
2) Adaptive management – conduct applied research to explore low and high flow responses of the endangered species and their habitats, in order to better inform future (adaptive) management decisions; and
3) Mitigation – restore and maintain habitats that will be or have been historically reduced for some reason, as a trade-off for some level of take that may occur as part of the proposed HCP action.

Unless considerable reductions in groundwater withdrawal can be accomplished during extensive drought periods, *in-situ* refugia may provide one of the best measures for protection of the species and their habitat in the wild during these extreme conditions. Applied research will prove extremely valuable and informative for the EARIP adaptive management plan and continued re-evaluation of HCP measures and groundwater withdrawal requirements. The low-flow response of the threatened and endangered species and their habitat in the wild is a critical question that remains unanswered because biological data under extremely low-flow conditions in these systems are non-existent. Restoration of habitat in particular areas of these systems in advance of any extreme periods is a form of mitigation that will enhance the opportunity for habitat maintenance and survival of the species in the wild when such extreme periods occur. Therefore, ERPAs are directly applicable to EARIP decision making as it is evident that under the proposed bottom-up approach additional measures (beyond springflow reductions) will be required to protect species and their habitat in the wild.

The purpose of this feasibility study is not to implement a pilot project or research effort, but to conduct the necessary steps to evaluate an ERPAs probability of success both biologically and economically. As groundwater modeling results continue to demonstrate that the most severe

reductions to flow under the current Senate Bill 3 (SB3) legislation will occur at Comal Springs, the focus of the feasibility study is on the Comal Springs/River ecosystem. However, during the EARIP process it was also determined that a cursory evaluation of potential ERPAs at San Marcos Springs/River would be conducted in this assessment and included as a separate section. The Comal Springs/River detailed evaluation focuses on existing conditions (Section 2); stakeholder interaction (Section 3); system-wide evaluation (Section 4); component description and conceptual design (Section 5); alternatives formulation and evaluation (Section 6); and concludes with recommendations (Section 7). Section 8 presents a cursory evaluation of the potential for ERPAs in the San Marcos Springs/River ecosystem with the focus on need and biological feasibility.

All analysis and recommendations presented in this feasibility study are based on the proposed EARIP flow regime as follows. The EARIP flow regime is presented as an overlay on historical flow conditions with permitted pumping which is forced to maintain a 30 cubic feet per second (cfs) daily minimum not to exceed 6 months with 80 cfs daily minimum flows for 2 to 3 months following each extended low-flow event. Additionally, this overlay assumes that these low-flow conditions would only happen periodically over time and not be repeated every few years. We are also making the assumption that to balance this minimum flow condition, a long-term average flow condition (yet to be determined) will be incorporated into the flow regime with the goal of maintaining or increasing populations or habitat over time. This long-term average is not the EARIP Science Subcommittee (SSC) long-term average recommendation at this time, as the SSC recommendation did not include any management or mitigation measures beyond the status quo (SSC 2009). Finally, the evaluated EARIP flow regime in this analysis is NOT the EARIP bottom-up approach discussed at the January 2011 EARIP Steering Committee meeting. The EARIP bottom-up approach when modeled using historical hydrology and fully authorized pumping does create a hydrological time series over the period of record, which could be considered a flow regime. HDR has modeled this scenario and provided monthly results to the EARIP. Additional analysis is currently underway to assess the bottom-up approach and resulting hydrological time series and will be reported on in the EARIP HCP.

2.0 ENVIRONMENTAL BACKGROUND

Comal Springs gush forth from the Edwards Aquifer through a series of spring openings located along the Balcones Escarpment near New Braunfels, Texas. Collectively, Comal Springs represent the largest spring system in Texas, and have the greatest mean discharge of any springs in the southwestern United States with an average annual discharge of approximately 284 cfs (USFWS 1996). Comal Springs has stopped flowing only one time in recorded history, from June 13 to November 4, 1956, during the most severe drought recorded for this region (USFWS 1996). The perennial flow of constant temperature water (≈23˚C) emanating from these springs has created a diverse and unique ecosystem in the relatively arid environment of central Texas. Due to the island-like uniqueness of this habitat, many of the species found in Comal Springs are not found elsewhere. In fact, four Federally-listed endangered species and an endemic salamander are found within the Comal Springs/River ecosystem.

2.1 FOUNTAIN DARTER - ENDANGERED

The fountain darter *Etheostoma fonticola* is a small fish endemic to the upper San Marcos and Comal Rivers. Fountain darters are one of the smallest darter species, with adults averaging approximately one inch (25 mm) in standard length. They feed on small aquatic insects and crustaceans. Fountain darters spawn adhesive eggs which are attached to submerged vegetation. Spawning occurs year around with peaks in reproduction occurring seasonally. Fountain darters are thought to have been extirpated from the Comal River when the springs ceased flowing during the 1950's. However, 457 individuals from the San Marcos River population were reintroduced in the mid 1970's (Schenck and Whiteside 1976, Linam et al. 1993). Currently, fountain darters occupy the entire Comal River from its headwaters near Landa Lake to its confluence with the Guadalupe River. However, habitat conditions vary throughout the system, with certain areas harboring higher densities of fountain darters than others. Substantial information on habitat use of fountain darters has been gained during the 10-year ongoing Edwards Aquifer Authority (EAA) Variable Flow Study (BIO-WEST 2000a,b – 2010a,b).

In the Comal Springs/River ecosystem, fountain darter populations are largely influenced by aquatic vegetation. Density of fountain darters varies widely across vegetation types. Native vegetation such as bryophytes and filamentous algae which provide thick cover near the substrate tend to yield the highest fountain darter densities (Figure 1). These vegetation types also harbor high densities of amphipods and other aquatic invertebrates, which are the main food source of fountain darters. Fountain darters are also common in other native vegetation types with complex leaf structures such as *Ludwigia* and *Cabomba*. Exotic vegetation types (*Hygrophila* and *Ceratopteris*), and native plants with simple leaf structures (*Vallisneria* and *Sagittaria*) harbor fewer darters. Fountain darters are seldom found over open substrate with no aquatic vegetation.

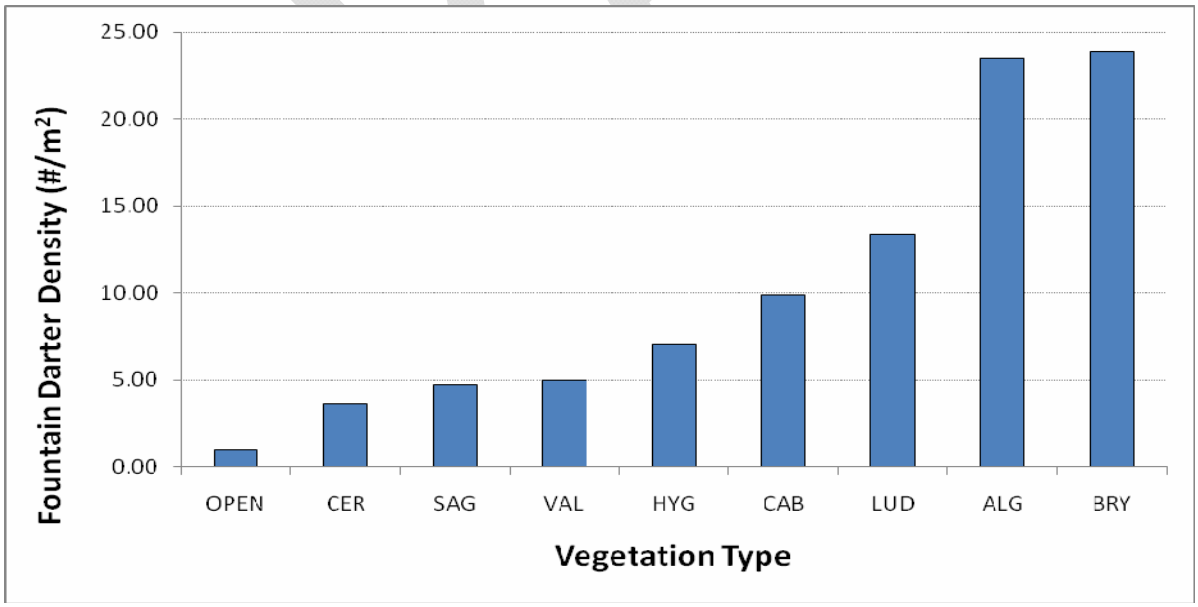

Figure 1. Density of fountain darters collected by vegetation type in the Comal Springs/River ecosystem from 2000-2009. CER – *Ceratopteris*, SAG – *Sagittaria,* VAL – *Vallisneria*, , HYG – *Hygrophila*, CAB – *Cabomba*, LUD – *Ludwigia*, ALG – Filamentous Algae, BRY – Bryophytes.

Throughout the 10-year EAA Variable Flow study, aquatic vegetation has remained abundant in most study reaches, with the largest impacts resulting from scouring associated with sporadic flood events. This scouring is intensified in areas where the channel is constricted (i.e., Upper Spring Run and New Channel), and is less severe in areas where flow is dispersed laterally (i.e., Landa Lake). The vegetation types that are the most susceptible to scouring are those that are not strongly rooted, such as filamentous algae and bryophytes. Unfortunately, these vegetation types also support the highest densities of fountain darters. However, scouring typically results in a temporary reduction in total aquatic vegetation coverage after which many plant types quickly respond with rapid re-growth during the period of higher flows following a flood event.

Low flows have been uncommon during the 10-year study period. However, from 2007 to 2009 central Texas experienced an extreme drought that resulted in a Critical Period Low Flow sampling event on the Comal River in 2009. The lowest total discharge recorded during 2009 was 158 cfs, and flows were below 200 cfs for 83 consecutive days. This resulted in the lowest flows experienced since late summer 2000. The most obvious effect of sustained low springflows on fountain darter habitat conditions was the proliferation of green algae in the Upper Spring Run reach. Areas typically occupied by bryophytes under higher flows became blanketed by green algae. Despite the less-than-optimal habitat conditions observed in summer 2009, no drastic changes in fountain darter abundance or density were noted (BIO-WEST 2010a).

2.2 COMAL SPRINGS RIFFLE BEETLE

The Comal Springs riffle beetle *Heterelmis comalensis* is a small (≈ 1/8 inch long) aquatic beetle in the family Elmidae found at Comal Springs and San Marcos Springs (Arsuffi 1993). It inhabits gravel and cobble substrates within and around spring openings, where it is thought to feed on periphyton and attached algae. Larvae of the Elmidae family create terrestrial pupal chambers in soil and detritus. After emergence adults reenter the water and reproduction usually occurs subsequently (Arsuffi 1993). Other genera in this family are able to tolerate environmental extremes (low dissolved oxygen and high temperature). Such tolerance may have contributed to survival of the Comal Springs riffle beetle during the drought of the 1950's, when Comal Springs stopped flowing for several months (Arsuffi 1993). Based on laboratory observations, Comal Springs riffle beetles are also known to retreat into interstitial spaces within the substratum as upwelling flows decrease (BIO-WEST 2002c). This may have also contributed to their survival during the drought of record.

As part of the EAA Variable Flow study, the Comal Springs riffle beetle population is monitored at three spring upwelling areas in and around Landa Lake. Riffle beetle monitoring occurs in spring seeps within Spring Run 3, in several springs along the western shoreline of Landa Lake, and near springs upstream of Spring Island. To monitor riffle beetles, a cotton lure is placed near spring upwellings, covered with several large rocks, and left out for four weeks. Attached algae and various microorganisms which grow on the lure attract riffle beetles and other invertebrates. After four weeks, the lures are removed and invertebrates are identified. Table 1 shows the total number of Comal Springs riffle beetles captured per cotton lure during each sampling event from 2004 through 2010. Similar to fountain darter abundance data, this data is variable across sampling events. However, data suggests a relatively stable long-term trend in abundance.

Table 1. Total number of Comal Springs riffle beetles (*Heterelmis comalensis*) collected with cotton lures (adults and larvae) for each EAA Variable Flow sampling date from 2004 – 2010.

Sample Period	Spring Run 3	Western Shore	Spring Island	Total
May-June 2004	88	83	122	**293**
August 2004	169	143	90	**402**
Nov-Dec 2004	170	175	146	**491**
April 2005	119	121	121	**361**
Nov-Dec 2005	262	201	185	**648**
May-June 2006	256	195	160	**611**
Nov-Dec 2006	185	92	125	**402**
May-June 2007	59	161	119	**339**
Nov-Dec 2007	204	83	132	**419**
May-June 2008	155	139	156	**450**
Nov-Dec 2008	144	133	227	**504**
May-June 2009	136	226	74	**436**
Nov-Dec 2009	72	56	198	**326**
May-June 2010	53	110	20	**183**
Nov-Dec 2010	298	264	104	**666**
Total	**2,370**	**2,182**	**1,979**	**6,531**
Average	158.0	145.5	131.9	458.3

2.3 COMAL SPRINGS DRYOPID BEETLE

The Comal Springs dryopid beetle *Stygoparnus comalensis* is the only stygobiontic (subterranean aquatic) beetle in the Dryopidae (long-toed water beetles) family. They are small weakly pigmented beetles (≈ 1/8 inch long) with non-functional eyes and thin skin. Comal Springs dryopid beetles have been collected from Comal Springs, Comal County and Fern Bank Springs in Hays County. The feeding and reproductive habits of this organism are unknown. Adults are thought to feed on biofilms scraped from various surfaces. The extent of their range in the subterranean realm of the aquifer is not well understood, but based on the fact that the beetles have not been collected from deep wells, they may be confined to small areas of the aquifer near spring openings. These beetles use atmospheric oxygen to produce a bubble that is used to breathe (act as a gill) underwater. Dissolved oxygen (DO) from the water diffuses into this bubble allowing the beetles to remain underwater for extended periods of time (Arsuffi 1993). As a result, DO levels in the water can have an impact on their survival. The surrounding terrestrial environment may also be important because the larvae are thought to inhabit soil and debris near the subterranean orifices (Arsuffi 1993). Since this species is subterranean and the EARIP flow regime being considered maintains springflow at all times, proposed ERPA's are not designed to influence Comal Springs dryopid beetle habitat or populations. Although uncertainty exists in dealing with rare subterranean species, maintenance of sufficient springflow and protection of aquifer water quality is thought to provide sufficient subterranean aquatic habitat for persistence of this species (SSC 2008, 2009).

2.4 PECK'S CAVE AMPHIPOD

Peck's cave amphipod *Stygobromus pecki* is a subterranean aquatic crustacean in the family Crangonyctidae. This species, which has no eyes and no pigment, has only been collected from Comal Springs and nearby Hueco Springs. Similar to the Comal Springs dryopid beetle, the extent of their habitat in the subterranean realm of the aquifer is unknown, but they have only

been collected near spring openings. There is very little data on this species, but some things may be inferred from other species of amphipods with a subterranean life cycle. Although its feeding habits are unknown, it likely feeds on dead organic matter transported from above ground areas (Arsuffi 1993). Cold-water species of amphipods exhibit long life cycles and reduced fecundity (Thorp and Covich 1991) and do not likely survive for long, once outside the aquifer. Since this is a subterranean species, ERPA's are not designed to influence the Peck's Cave amphipod. Although uncertainty exists in dealing with rare subterranean species, maintenance of sufficient springflow and protection of aquifer water quality is thought to provide sufficient subterranean aquatic habitat for persistence of this species (SSC 2008, 2009).

2.5 COMAL SPRINGS SALAMANDER

Although not Federally-listed, the Comal Springs salamander *Eurycea* sp. is a small (adults are approximately 60 mm [2.4 inches]) aquatic salamander species endemic to Comal Springs. Like other species of *Eurycea*, they are neotenic, meaning that they remain in the larval condition with external gills throughout their life, and never metamorphose into a lunged terrestrial form. The Comal Springs salamander was once considered the same species as the endangered San Marcos salamander *Eurycea nana*. Comal Springs salamanders are only found in close proximity to spring upwellings in the vicinity of Landa Lake, and in the spring runs above Landa Lake. They are typically found hiding under larger rocks, and are most abundant in spring areas containing attached bryophytes. Siltation of spring areas usually leads to a decrease in the number of salamanders observed. Although no detailed life history studies have been conducted on the Comal Springs salamander, the closely related San Marcos salamander feeds on aquatic insect larvae, small crustaceans, and small snails, and is thought to reproduce year around with a possible peak in the spring. Although manipulating habitat for the Comal Springs salamander is not the direct focus of ERPAs, this species occupies habitats in close association with the Comal Springs riffle beetle. During opportunities to create habitat or research opportunities for the Comal Springs riffle beetle, the requirements for the Comal Springs salamander should also be explored.

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3.0 STAKEHOLDER INTERACTION

As part of the ERPA feasibility study, BIO-WEST was charged with informing, seeking input from, and updating EARIP stakeholders as the feasibility study was conducted. Stakeholder meetings were held, site visits were conducted, and several presentations were given to a variety of EARIP stakeholders as summarized in Table 2. At each initial stakeholder meeting, the project team presented a description of what the feasibility project entailed, answered questions to the degree possible, and sought input regarding existing conditions or additional items for consideration.

The activities in Table 2 led to excellent discussions, information being provided to the project team and questions being asked that guided the overall analysis of feasibility. Examples of some specific concerns and questions brought to the project team's attention at these meetings included:

- Could water be supplemented from wells during prolonged drought periods?
- Concern about the potential for increased gill parasite concentrations within the ERPAs during periods of low-flow.
- How would security for any constructed structures be addressed?
- How could the experimental component of ERPAs be used to guide adaptive management decisions both before and after experimentation?
- What water rights permits, if any, would be needed for ERPAs?
- How would ERPAs potentially affect population genetics of the endangered species?
- How would the endangered invertebrates be protected during times of extreme drought?
- Would water temperatures significantly increase in any pipelines used?
- Would carbon dioxide (CO_2) need to be added to any re-circulated water for aquatic vegetation growth?
- What damage would flooding as experienced in June 2010 cause to the proposed ERPAs?

During meetings with the City of New Braunfels and New Braunfels Utilities important information was gathered regarding the existing property, management of flows, and structures within the project area that might be used for future supplementation or manipulation of spring flows in the Comal system.

3.1 UPPER SPRING RUN HEADWATERS

New Braunfels Utilities owns a parcel of land at the headwaters of the Comal River that is being considered for education outreach purposes. This site also contains 3 wells with a cumulative pumping capacity of a few cfs.

Table 2. List of Stakeholder meetings, site visits, and presentations during the Study Period.

Stakeholders	Activity	Date	Location
Schlitterbahn	Stakeholder Meeting	September 18, 2009	New Braunfels
U.S. Fish and Wildlife Service - National Fish Hatchery and Technology Center	Site Visit	January 26, 2010	New Braunfels
San Antonio Water System	Stakeholder Meeting	February 17, 2010	San Antonio
U.S. Fish and Wildlife Service Texas Parks and Wildlife Department Habitat Conservation Plan Project Team San Antonio Water System Guadalupe/Blanco River Authority San Marcos River Foundation	Discussion following Habitat Conservation Plan Biological Modeling Group Meeting	February 18, 2010	San Marcos
City of New Braunfels	Site Visit / Stakeholder Meeting	February 25, 2010	New Braunfels
Guadalupe/Blanco River Authority	Stakeholder Meeting	March 8, 2010	Seguin
New Braunfels Utilities	Stakeholder Meeting	March 26, 2010	New Braunfels
Edwards Aquifer Authority	Stakeholder Meeting	April 13, 2010	San Antonio
City of New Braunfels	Stakeholder Meeting	July 19, 2010	New Braunfels
EARIP Steering Committee	Presentation	March 11, 2010	San Antonio
EARIP Steering Committee	Discussion	June 29, 2010	Kerrville
EARIP Steering Committee	Presentation	July 28, 2010	San Antonio
EARIP Science Subcommittee	Presentation	September 1, 2010	San Marcos
Technical Advisory Group	Presentation	September 2, 2010	San Antonio
U.S. Fish and Wildlife Service Texas Parks and Wildlife Department	Site Visit / Stakeholder Meeting	October 13, 2010	New Braunfels
U.S. Fish and Wildlife Service Texas Parks and Wildlife Department	Stakeholder Meeting	November 30, 2010	San Marcos

3.2 SWIMMING POOLS NEAR LANDA LAKE

The City of New Braunfels operates two swimming pools near Landa Lake at the head of the Old Channel. One pool is supplied with water from the City system, while the other uses spring water sourced from Landa Lake. Both pools have a typical annual operating period between May 1 and October 1. Once filled, the spring fed pool maintains approximately 5 cfs of flow-through during normal operations. Water is discharged from the spring fed pool through a 36" diameter culvert with gate valve directly into the Old Channel. The natural unlined pool bottom often leads to the pool water getting turbid during periods of heavy use. Water temperature because of solar insolation is affected by the wide shallow geometry of the water body. During once-per-week (Tuesday or Wednesday) pool draining and cleaning operations, the pool is drained (over the course of a couple hours), scrubbed, filled, drained, and re-filled for use on the following day. The pool is not chlorinated and approved chemicals/neutralizers are used in the cleaning operation. Some consideration of unknown levels of components in the pool discharge water (e.g., suntan lotion or other products used by outdoor swimmers) may be warranted as part of the future permitting-level environmental assessment.

3.3 OLD CHANNEL CULVERTS

Landa Lake is connected to the Old Channel by a 48-inch culvert (Figure 2), and two 24-inch Culverts (Figure 3). The lake-side invert elevation of the 48-inch culvert is approximately 611.4 feet (ft) and the two 24-inch culverts are installed at a lake-side invert elevation of approximately 618 ft (Guyton 2004). A fourth smaller culvert directs flow into the flowthrough swimming pool, and ultimately into Old Channel as described above. The dual 24-inch culverts were the sole source of water directly into the Old Channel until the late 1990's and have a capacity of approximately 40-50 cfs. The new 48-inch culvert was installed at upstream invert 614.00 ft and downstream invert of 611.14 ft. The additional capacity (Figure 2) of the new culverts allows for considerably higher flows to the Old Channel. At this time, no active flow management occurs except for cleaning of culvert inlet screens. Flow through the culverts can be impacted by vegetation accumulation on upstream grates. The City of New Braunfels clears vegetation and trash from the culvert gates approximately once per week from March through October and on an as needed basis the remainder of the year. The June 2010 flooding has caused considerable erosion around the culvert openings that will need attention to ensure the proper continued operation of these structures (Figure 4).

Figure 2. New 48-inch culvert from Landa Lake to the Old Channel

Figure 3. Old set of 24-inch culverts with limited capacity in the Old Channel.

Figure 4. Damage to new culvert from June 2010 flood (photo courtesy of Nathan Pence).

3.4 NEW CHANNEL STRUCTURES

The LCRA weir (Figure 5) which includes a bypass culvert is located across from the City of New Braunfels Park office. The elevation of the weir is 619.28 ft and no active flow management occurs at the weir and gate valve. The gate valve does have 80-90 cfs capacity to pass water but the valve is typically closed. As the lake stage becomes lower, flow is naturally controlled by these outlet elevations in the Old and New Channels. Comal spring flow would stop at New Channel dam first (at 619.28 ft) and then flow would be directed towards the lower Old Channel culverts (Guyton 2004).

New Braunfels Utilities own the dam/hydropower unit in the old mill race (just above the confluence with Dry Comal Creek). If managed, this facility can back up water in the New Channel to the LCRA weir. The hydropower facility was taken offline during the 1980s primarily because pulling weeds off of intake rake was too labor intensive compared to generation capacity. The facility needs approximately 100 cfs to generate with a capacity of 300 cfs at full operation.

Figure 5. Reconstructed LCRA weir across from Landa Park office.

3.5 EARIP ERPA FUTURE SUBCOMMITTEE OR REVIEW TEAM

During the October 13th site visit with USFWS and TPWD agency personnel, BIO-WEST proposed the concept of an EARIP ERPA subcommittee or review team to oversee ERPA activities. A concern repeatedly raised since the concept of *in-situ* refugia, IMAs, and ERPAs was first proposed, and raised again during the October 13th site visit is: If ERPAs are established and proven to be successful, what would keep the water users from pumping down to these levels at all times? First of all, if ERPAs were established and proven to be successful, the added protection to the species and knowledge learned through applied research would both greatly benefit the very species the EARIP stakeholders are charged with protecting. Secondly, the concern regarding massive water withdrawals following such establishment and proof of success is completely unwarranted for the following reasons. In order for the USFWS to approve an HCP, one would assume that a flow regime that would "protect" the threatened and endangered species and their habitat would need to be obtainable. One would also assume based on EARIP SSC guidance that this flow regime would be a regime and not just a minimum flow. Additionally, allowing some sort of maximum pumping at all times completely contradicts the reason that ERPAs are being developed in the first place. ERPAs are additional protection measures during periods of extreme conditions to allow a measure of safety. They are not designed, nor proposed as a continuous measure.

Additionally, concerns have been raised by EARIP stakeholders and reiterated at the site visit regarding the nature of the studies, who would do the work, and who would interpret the results.

It is anticipated that the HCP applicant(s) would be responsible for the implementation of the HCP components and adaptive management plan. It is also anticipated that the EARIP SSC would remain in some fashion to peer review future work being conducted or proposed associated with the HCP and adaptive management plan. In addition to those entities, it may be valuable to have an ERPA subcommittee or third-party independent review team consisting of scientists thoroughly familiar with the specific systems and the scientific process of applied research. Anticipated roles for this group would include overseeing activities/studies to be conducted at any implemented ERPAs as well as being the first entity to review and interpret study results from any applied research activities. Subsequently, this subcommittee was discussed at the November 11, 2010 Steering Committee meeting but was not formally established. An informal gathering of stakeholders interested in discussing the potential ERPA subcommittee or review team met with BIO-WEST on November 30, 2010.

4.0 ERPA SYSTEM EVALUATION

Determining the best locations for placement of potential ERPAs or various ERPA components in the complex and highly modified Comal Springs/River ecosystem required careful consideration of numerous factors. Before design details could be discussed, a systematic process for evaluating feasible locations of various ERPA components included a system-wide analysis of several key factors including but not limited to habitat abundance and quality, recreation, flooding, land ownership, and security. The Comal system ERPA analysis focuses on habitat restoration and protection for the fountain darter and Comal Springs riffle beetle. Habitat conditions for each species in each major section of the system are discussed below, along with notes regarding recreational impacts and flooding.

4.1 COMAL SPRINGS/RIVER SECTIONS

4.1.1 Upper Spring Run Reach

At times, large numbers of fountain darters inhabit the Upper Spring Run Reach, which extends from the mouth of Blieders Creek to the Spring Island area (Figure 6). Bryophytes located in the upper portion of this reach often contain relatively high densities of fountain darters under typical flow conditions. However, the springs at the top of this reach are at the highest elevation of any of the major springs, and are the first to stop flowing as aquifer levels decline. Since these springs are the first to be affected, habitat conditions can suffer during lower than average flow periods, as witnessed in summer 2009 when most of the high-quality bryophyte habitat within this reach was covered with green algae. No Comal Springs riffle beetles have been collected from this reach.

Flooding resulting from localized runoff rushing down Blieders Creek can also significantly alter habitat conditions within this reach. During the June 2010 flood event, high flows from Blieders Creek resulted in intense scouring within this reach. All aquatic vegetation (except for a few small patches of strongly-rooted *Sagittaria*) was removed during this event, leaving only bare gravel substrate. Low to moderate amounts of recreational activity (mainly swimming and fishing) occur within this reach. Heidelberg Lodges, located at the junction of Blieders Creek and the Upper Spring Run Reach allows swimming and fishing, and local homeowners are often

seen canoeing, kayaking, or fishing. However, since there is no public access to this reach, recreational impacts are relatively minor compared to areas further downstream.

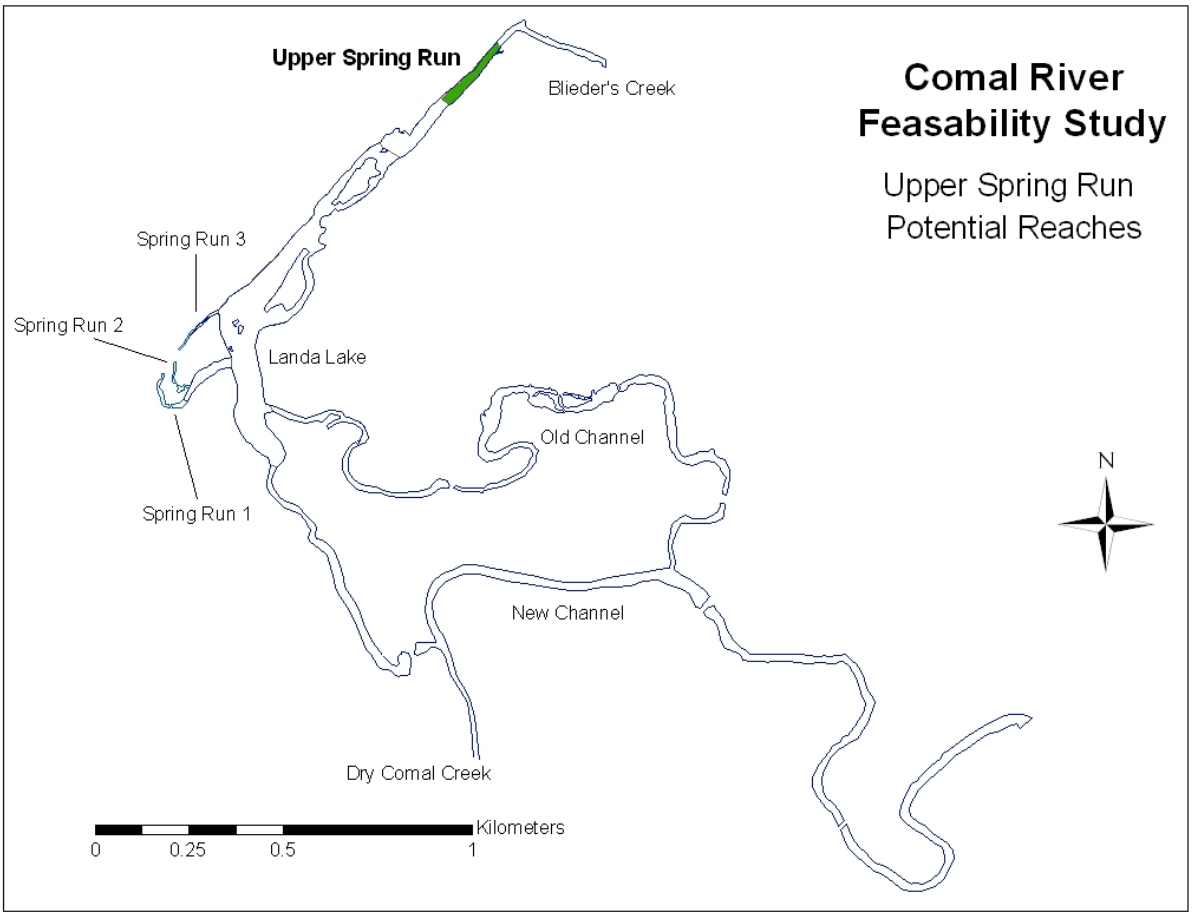

Figure 6. Upper Spring Run Reach – Comal System

4.1.2 Landa Lake (Spring Island Area to Landa Lake)

The upper portion of Landa Lake is labeled Spring Island with the main portion of the lake being labeled Landa Lake (Figure 7). The Spring Island area contains high-quality habitat for both fountain darters and Comal Springs riffle beetles. Although fountain darters are found throughout this area, the highest densities are found in the bryophyte covered gravel immediately upstream of Spring Island. Several spring upwellings are located on the stream bed in this location, which also provide habitat for Comal Springs riffle beetles and Comal Springs salamanders. Spring upwellings are also located in the eastern channel of the river, and two small spring runs emerge from a spring located on the main island. Although habitat quality will likely decline in this reach under critically low flows, the additional springs and upwellings in this area will maintain quality conditions longer than in the Upper Spring Run Reach.

Flooding from Blieders Creek can also have significant impacts on the Spring Island area. During the June 2010 flood event, significant scouring occurred in the area upstream of Spring Island, and debris washing down from Blieders Creek resulted in significant damage to the

recreational area on the island. Recreational activity is moderately high in this area. Although there is no public access, Spring Island serves as a park for local homeowners, and the eastern channel of the river is used as a wading/swimming area. Canoes are available for homeowners to access the area around Spring Island.

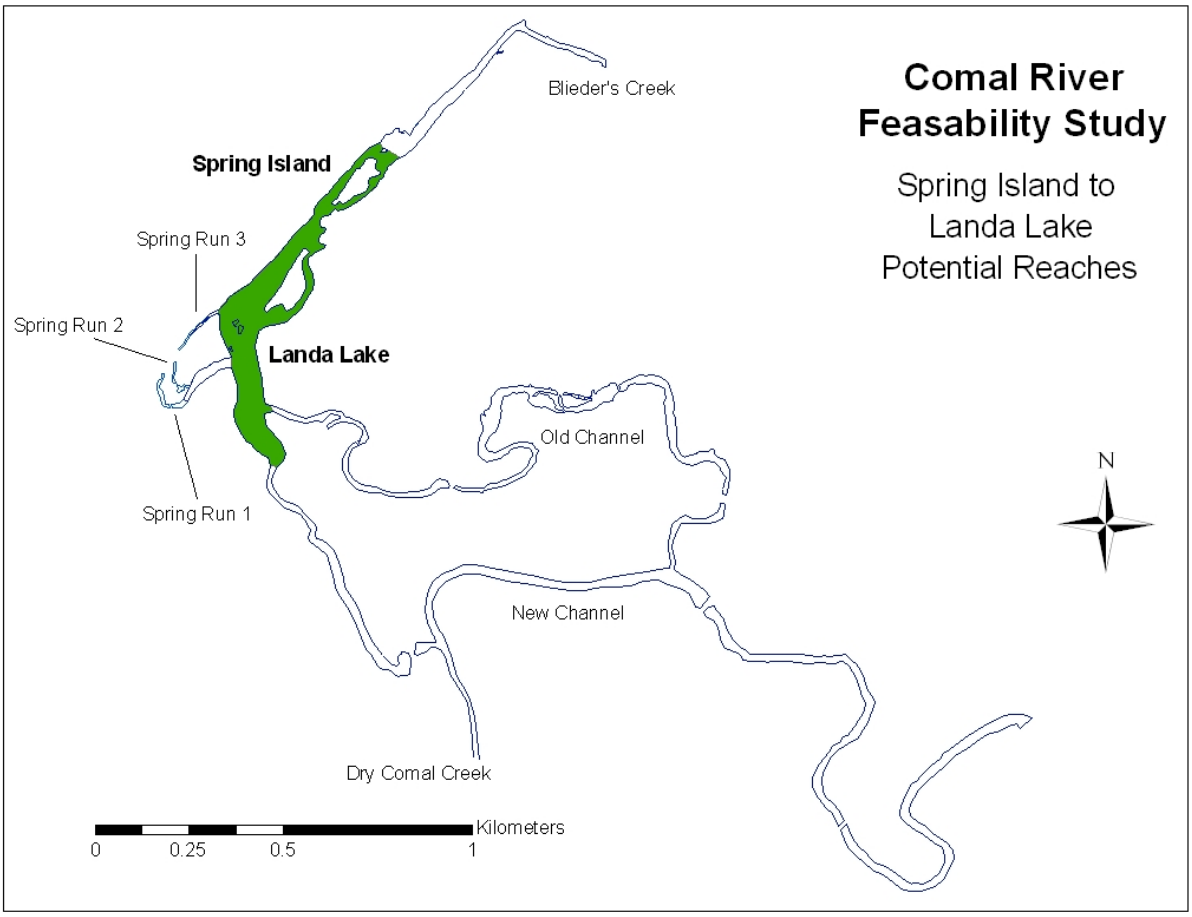

Figure 7. Landa Lake proper and Spring Island area – Comal System

Landa Lake proper provides a large area of high quality habitat for fountain darters. Although it is variable across vegetation type, overall density of darters here is greater than in any other sample reach. Due to the abundance of springs along the lake bottom and flow entering the lake from the various spring runs, annual temperature variation in Landa Lake is less than 1˚C. A diverse vegetation community exists in Landa Lake, including large expanses of bryophytes near the upper end of the lake which harbor large numbers of fountain darters. Comal Springs riffle beetles are routinely captured at several small springs located along the western shoreline of Landa Lake. Due to the hydraulic control of the dam, the width of the wetted channel, and the relatively low and flat nature of the terrain surrounding Landa Lake, scouring as a result of flood waters from Blieders Creek have minimal impact to habitats within the lake. During the June 2010 flood event, only minimal scouring of bryophytes along the upper east side of Landa Lake was evident, despite extreme scouring of vegetation in the more channelized Upper Spring Run and Spring Island areas.

Landa Lake is designated as an environmentally sensitive area, and therefore, no swimming or kayaking is allowed in the lake. The only recreational watercraft allowed on Landa Lake are paddle-boats available for rent from the City of New Braunfels. Fishing is allowed from the banks. However, neither of these activities has a significant impact to endangered species habitats, and therefore, recreation is currently not an issue in Landa Lake proper.

4.1.3 Spring Runs

Three major spring runs occur along the western edge of Landa Lake (Figure 8). Spring Run 1 is supported by a large spring that erupts on the west side of Landa Park Drive. Spring Run 2 emerges a few yards east of Spring Run 1 along the east side of Landa Park Drive, flows through a small wading pool, and merges with Spring Run 1 before it enters Landa Lake. Spring Run 3 emerges a few yards northeast of Spring Run 2, and follows a separate course to its juncture with Landa Lake near the gazebo in Landa Park. Spring Run 1 is the highest elevation, and the first spring run to go subsurface under critically low flows, whereas, Spring Run 3 is the last spring run to go subsurface. Localized rainfall can cause flooding in the area of the spring runs. In the June 2010 flood event, flood waters moving down the steep terrain of Panther Canyon caused significant damage to bridges and other structures near Spring Runs 1 and 2, whereas impacts to Spring Run 3 were relatively minor. Comal Springs riffle beetles are known to occur in all three spring runs, however, long-term monitoring has focused on Spring Run 3. Fountain darters are occasionally seen in all three Spring Runs, however, they are not particularly abundant in the swift rocky habitats of the spring runs. No swimming or wading is legal in Spring runs 1 or 3 (although frequently observed). Spring Run 2 has a small wading pool just above the confluence with Spring Run 1 where wading is allowed resulting in heavy recreational use of this area.

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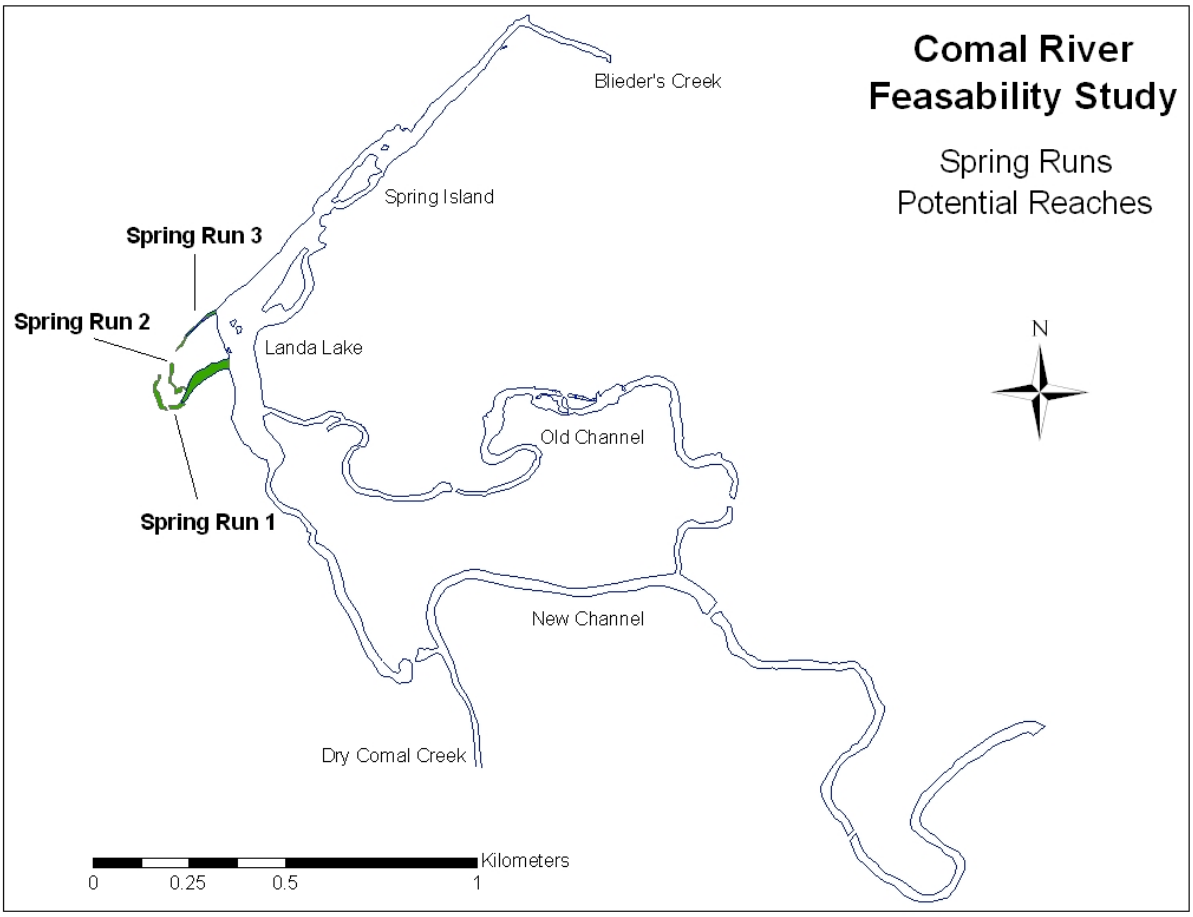

Figure 8. Three main Spring Runs – Comal System

4.1.4 New Channel (Above and below Dry Comal Creek

The new channel emerges from the southern end of Landa Lake near the Landa Park Drive bridge and flows several hundred yards downstream before it merges with Dry Comal Creek immediately past the old NBU Hydrogeneration facility (Figure 9). This artificially dredged channel is deep (>6 ft. in most areas) and highly channelized. There are substantial amounts of aquatic vegetation here (mainly *Sagittaria* and *Vallisneria*), which provide limited fountain darter habitat. The deep nature of the channel here would make any kind of experimentation difficult without major channel modifications. Comal Springs riffle beetles have not been collected from this reach. Vegetation within this upper area is not routinely mapped, and therefore, information on scouring after flood events is primarily anecdotal.

After the confluence of Dry Comal Creek, the New Channel flows past the Wurstfest grounds, under the Union Pacific Railroad bridge, and by Hinman Island Park before its confluence with the Old Channel immediately above the tube chute. This section of the New Channel is extremely channelized with concrete walls or bulkheads on both sides in many places. The lower portion of this section is greater than six feet deep in most places. Aquatic vegetation in this reach includes primarily *Cabomba*, *Hygrophila*, and *Ludwigia* which does provide habitat for fountain darters. Comal Springs riffle beetles have not been collected from this area.

Coverage of vegetation within this reach is extremely variable due to significant scouring after sporadic large flood events coming down Dry Comal Creek. Due to the intense flows coming from the steep watershed of Dry Comal Creek during rainfall events, this reach witnesses the worst scouring of any of the sample reaches. This area is also the put-in location for several local tubing businesses, and receives intense recreational pressure, especially on summer weekends.

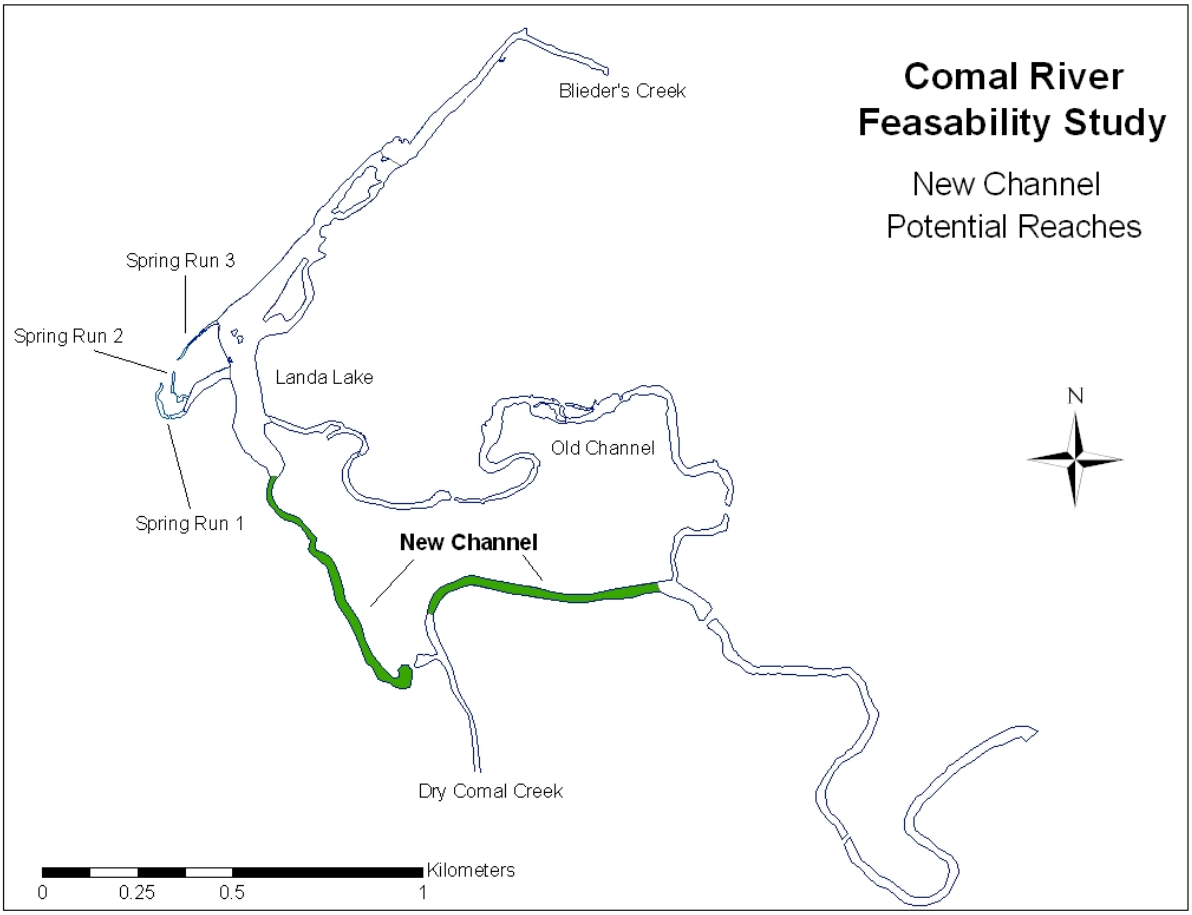

Figure 9. New Channel – Comal System

4.1.5 Old Channel (Reach 1 [below Landa Lake], Reach 2 [near Schlitterbahn], and Reach 3 [below Hinman Island Drive])

The old channel emerges from the southeastern portion of Landa Lake (Figure 10) through three sets of culverts. Two sets of culvert send water directly into the old channel near tee box #2 on the city golf course. An additional culvert directs water through the City of New Braunfels swimming pool before rejoining the old channel below the pool area. The Old Channel below Landa Lake is a fairly natural channel with a diversity of habitat for aquatic organisms. Fountain darters are moderately abundant throughout the majority of the Old Channel. Prior to the installation of the new, higher capacity culvert and subsequent high flow period, fountain darter habitat was outstanding throughout sections of the Old Channel. However, the removing of native vegetation from higher flow conditions, followed by the establishment of non-native

aquatic vegetation species have led to reduced habitat conditions in the Old Channel at this time relative to what it had been in the early 2000s. Although many aquatic invertebrates including a species of riffle beetle are present in the Old Channel, no Comal Springs riffle beetles have been documented in the Old Channel below Landa Lake. The three reaches shown in Figure 10 were evaluated because they maintain quality fountain darter habitat and relatively high numbers of darters. Reach 1 (just below Landa Lake) is tucked between the City swimming pool and the riparian zone that separates the river from the golf course. As such, Reach 1 is very protected and not used for recreational purposes. Reach 2 is located downstream below Elizabeth Street and encompasses one of the long-term monitoring reaches of the EAA Variable Flow study. This area is located on City of New Braunfels property and is adjacent to the golf course on the south. As such, this reach is also well protected and not heavily used for recreation. Schlitterbahn does use the adjacent area to the north of the river for a parking lot when the park is open. The third reach is located downstream of Hinman Island. This area maintains quality fountain darter habitat but is not well protected and heavily used for recreational purposes. This reach also experiences the highest level of disturbance following flood events that come down Dry Comal Creek and back water up into this area.

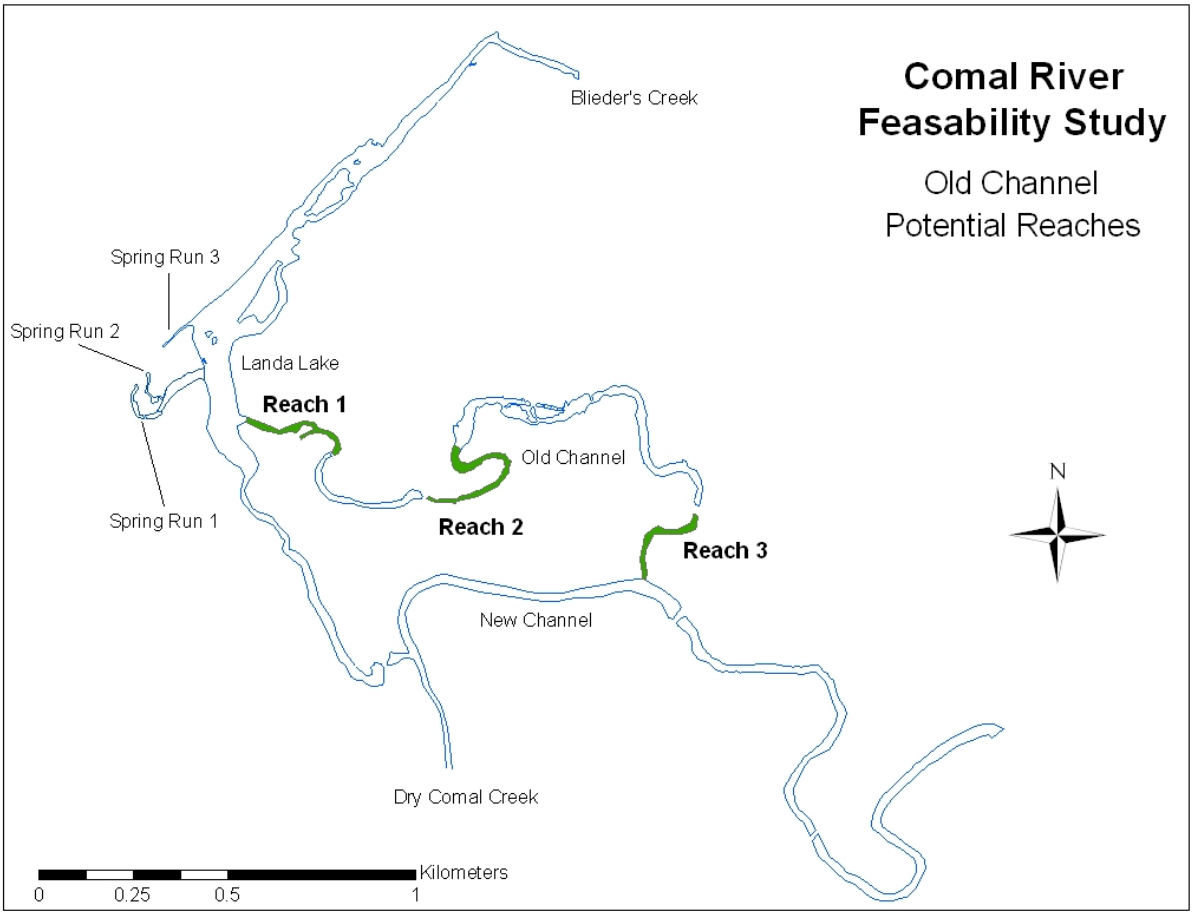

Figure 10. Old Channel Reaches – Comal System

4.1.6 Comal River below confluence

Below the confluence of the Old and New channels (Figure 11), the amount and quality of fountain darter habitat decreases although darters are still collected in this section. There has been no Comal Springs riffle beetles documented in this reach. This area is also highly recreated and routinely scoured by high flow events.

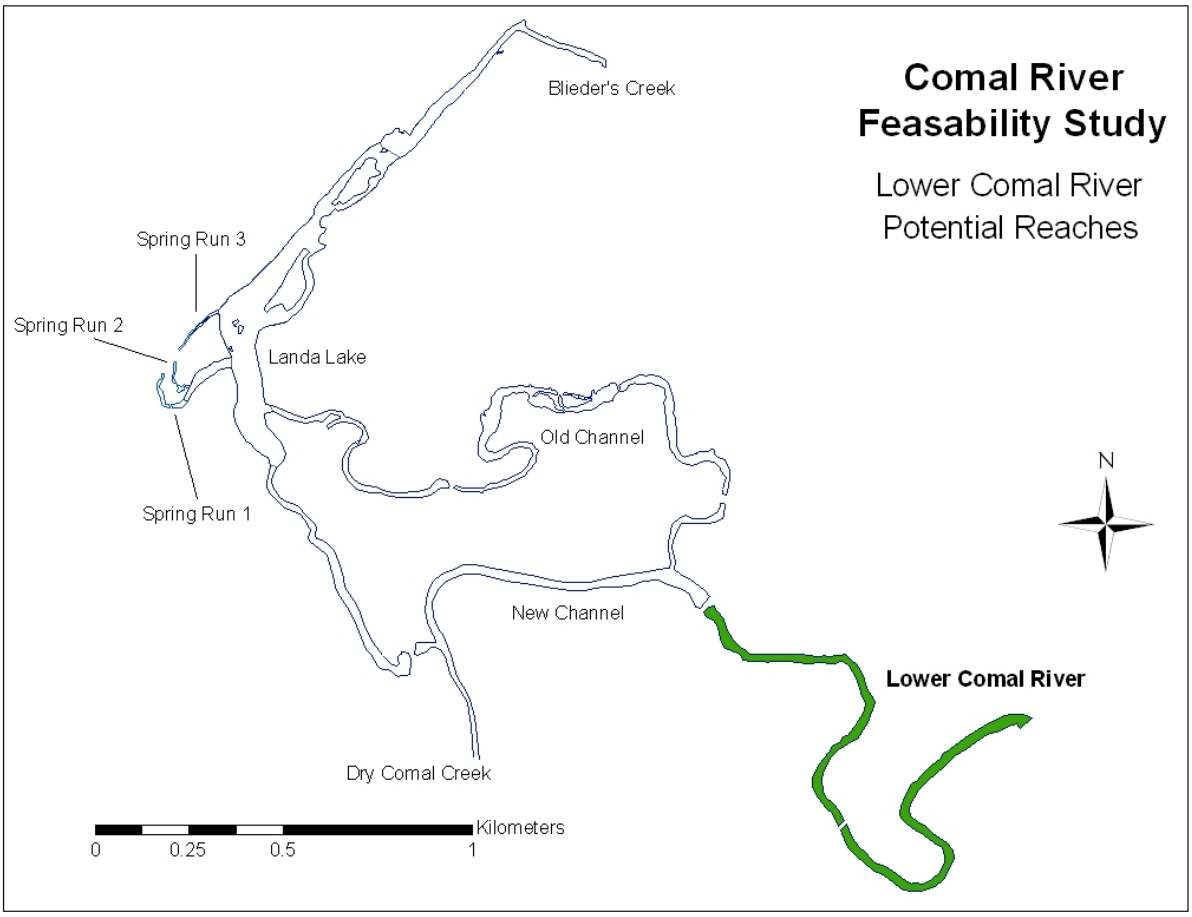

Figure 11. Comal River below confluence of Old and New channels

4.2 STUDY REACH EVALUATION

Table 3 provides a summary of several key evaluation measures for the reaches described above. Key biological measures evaluated were whether or not fountain darters and Comal Springs riffle beetles are present and if so, what quality of habitat is found in these areas. Life history data and habitat requirements of the unique biological communities within the Comal Springs/River ecosystem indicate certain locations that are important to the survival of these species during severe low recharge to the aquifer. Additionally, elevation and hydrology information was evaluated to assess at what total Comal springflow these reaches maintain surface water flow. Finally, additional items were evaluated including potential recreational, flooding, and security risks that might be associated with each of these locations.

Table 3. Reach Selection Evaluation Matrix

Comal River Section	*Fountain Darter Presence / Habitat Quality*		*Comal Springs Riffle Beetle Presence / Habitat Quality*		*Maintain surface flow during drought (Total Comal Springflow cfs)*					*Recreation Activity*	*Flooding impacts*	*Security Risk*
	Pres.	*Qual.*	*Pres.*	*Qual.*	*30 cfs*	*60 cfs*	*90 cfs*	*120 cfs*	*150 cfs*			
Upper Spring Run												
Blieders Creek to above Spring Island	√	*Mod*							√	*Low*	*High*	*Mod*
Landa Lake												
Spring Island	√	*High*	√	*High*	√	√	√	√	√	*Mod*	*Mod*	*Mod*
Landa Lake proper	√	*High*	√	*High*	√	√	√	√	√	*Low*	*Low*	*Low*
Spring Runs												
Run 1	√	*Low*	√	*High*				√	√	*Low*	*Mod*	*Mod*
Run 2	√	*Low*	√	*Mod*				√	√	*High*	*High*	*High*
Run 3	√	*Low*	√	*High*			√	√	√	*Low*	*Low*	*Mod*
New Channel												
Lake to NBU hydro	√	*Mod*			√	√	√	√	√	*Low*	*Low*	*High*
Below NBU hydro	√	*Low*			√	√	√	√	√	*High*	*High*	*High*
Old Channel												
Reach 1 (below Landa Lake)	√	*Mod*			√	√	√	√	√	*Low*	*Low*	*Low*
Reach 2 (near Schlitterbahn)	√	*Mod*			√	√	√	√	√	*Low*	*Low*	*Low*
Reach 3 (Hinman Island)	√	*Mod*			√	√	√	√	√	*High*	*High*	*High*
Comal River												
(below confluence)	√	*Low*			√	√	√	√	√	*High*	*High*	*High*

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When total Comal Springs flow falls below approximately 150 cfs, the springs upstream of Spring Island cease to flow and that area may become stagnant resulting in elevated water temperatures and a higher potential for decreased dissolved oxygen (DO) levels. As a result, fountain darters will likely move downstream to where the springs are still flowing and water quality is more suitable. In addition, the Comal Springs riffle beetle is not found in the Upper Spring Run Reach (length of river upstream of Spring Island), therefore at low recharge this area is not considered crucial for the survival of any endangered species. As mentioned in Section 3.1, New Braunfels Utilities owns a parcel of land at the headwaters of the Comal River that is being considered for education outreach purposes. This site contains 3 wells with a cumulative pumping capacity of a few cfs that could be used to support a research facility. This property might be considered for further evaluation if no other feasible locations are identified for the Comal system. At this time, this location was not carried further in the analysis since a completely new research facility would need to be constructed at this location requiring significant costs. Also, being located at the headwaters of the Comal Springs/River ecosystem might prove problematic if unexpected flooding or unforeseen accidents caused spills or exotic species (being used in applied research) releases at this most upstream locale.

All three spring runs provide Comal Springs riffle beetle habitat to varying degrees but limited fountain darter habitat. Spring Run 1 is the highest elevation and the first spring run to go subsurface under critically low flows while also being susceptible to intense flooding coming down Panther Canyon. Spring Run 2 is highly susceptible to flooding coming down Panther Canyon, has the lowest quality riffle beetle habitat and is highly recreated in the kiddie pool. Spring Run 3 is the last spring run to go subsurface, less impacted by flooding, and has the highest quality riffle beetle habitat. As such, Spring Run 3 was selected for further evaluation.

The areas with the highest quality habitat for fountain darters and potential for protecting habitat during severely low-flows are Landa Lake and the Spring Island area. These areas also maintain high quality riffle beetle habitat along the western shoreline of Landa Lake and in the Spring Island area. However, for this feasibility study we are not evaluating measures that could be used below 30 cfs total Comal Springflow because that minimum has preliminarily been determined necessary for threatened and endangered species survival (SSC 2009, Hardy 2011). Modeling suggests that at 30 cfs total Comal Springflow, Landa Lake and Spring Island area will remain wetted with sufficient springflow to support aquatic habitat and water quality parameters. As such, these areas were only selected to evaluate for restoration activities and potential water quality improvements, but not selected for specific ERPA project evaluation.

Although DO and water temperatures may remain suitable in the New Channel downstream of Landa Lake during a period of low recharge, physical conditions within this reach results in lower quality habitat for fountain darters. In addition, no Comal Springs riffle beetles are found in the New Channel. As such, the new channel was not carried forward for evaluation. For the Old Channel, Reaches 1, 2, and 3 all provide quality fountain darter habitat but varying levels of other conditions. During the site visit, Nathan Pence of the City of New Braunfels requested that Reach 3 be removed from consideration as it is too impacted by recreation during the summer months (most likely time of low recharge) to make this reach feasible. Therefore, in the Old Channel only Reaches 1 and 2 were carried forward for evaluation.

In summary, based on the evaluation, Landa Lake (including Spring Island and Landa Lake proper), Spring Run 3, and the Old Channel (reaches 1 and 2) were carried forward for additional analysis.

5.0 ERPA COMPONENT DESCRIPTION AND CONCEPTUAL DESIGN

To preserve endangered riffle beetle and fountain darter populations and habitat during low-flow drought conditions, ERPAs or specific drought management measures are proposed for the area encompassing Comal Springs, Landa Lake and the Old Channel of the Comal River. These measures would be implemented to protect endangered species populations and habitat as spring flow drops below threshold levels. The impetus for this project is concern for species survival in the wild during an extreme drought condition similar to that exhibited in the 1950s. Of particular concern are conditions similar to those in 1956 where aquifer levels in the Landa Park well dropped below 622 ft causing Spring Runs 1 and 2 to cease surface flow and then continued to drop below 620 ft causing Spring Run 3 to cease surface flow (total spring flows were approximately 35 cfs). In 1956, aquifer levels continued to drop below 619 feet, causing springs emitting into the lake to cease resulting in total spring flows of zero. This last stage is outside the bounds of the ERPA analysis as the underlying assumption for all ERPA analyses herein is that a minimum 30 cfs daily average total Comal discharge will be maintained.

The objective of this feasibility study is to identify more specifically what structures or practices are needed to implement potential management measures, then to evaluate benefits, concerns, and constraints for each measure. Considering the reaches carried forward there are several measures to be evaluated that could potentially provide sufficient habitat for fountain darters and Comal Springs riffle beetles during extremely low recharge within the Comal Springs/River ecosystem.

The key components to any ERPA include Restoration, Protection, and Applied Research. The following outline provides a guide for each component:

- Restoration
  - Re-establishment of native vegetation
- Protection
  - Native aquatic vegetation maintenance
  - Flow Split Management
  - Decaying Vegetation Removal for maintenance of dissolved oxygen at low-flow (if necessary)
  - Spring Run 3 connectivity
  - Old channel ERPA
  - Landa Lake Barriers for water temperature control
- Applied Research
  - Old Channel ERPA – channel creation and establishment of Comal Springs riffle beetle habitat
  - Spring Run 3 – observation well

5.1 RESTORATION

It has been documented over the past decade of EAA Variable Flow study monitoring that native aquatic vegetation plays a key role in supporting the native fish assemblages including the fountain darter. Native vegetation restoration consists of the establishment of native aquatic vegetation within key, sustainable reaches of the Comal River. This includes planting native vegetation in unoccupied areas and the establishment of native vegetation in previously occupied non-native aquatic vegetation, with the latter obviously requiring non-native vegetation removal first. In either instance, the 2-D models developed for the EARIP should be used to evaluate the potential for success of the native vegetation establishment. This evaluation should consider the depth, velocity, and substrate conditions present in the proposed areas along with what non-native vegetation is thriving in these areas. If the area is bare, is there a reason it is bare? (i.e. recent flood scour, or unsuitable depth, velocity or substrate conditions). Following an evaluation of the physical habitat model, an evaluation of water quality conditions should also be conducted. In particular, understanding whether the native plant being considered for establishment is a carbon dioxide (CO_2) obligate species and if so, what are the CO_2 concentrations in the water column under varying flow conditions at the proposed establishment locations? Additionally, restoration will involve acquiring local, disease and pathogen-free plant material that will either be removed from adjacent habitat or propagated off-site with material removed from the Comal system. When non-native species are removed, they will need to be disposed of properly. Finally, federal and state permits will be required for potential "take" of fountain darters and for removal of non-native species that are on the TPWD prohibited list.

The EARIP has established restoration subcommittees for both the Comal and San Marcos Rivers and as such, this report will not go into specifics regarding native vegetation establishment or costs associated with these activities. In general, however, it is recommended that the focus be on key, sustainable areas. For the Comal system, this includes Landa Lake and the Old Channel. As positive as it sounds to conduct restoration activities throughout the entire system, the factors that shape these areas (floods, recreation, etc) discussed above need to be factored into the cost/benefit and potential success component of this decision. A few examples that should prove valuable would be replacing the non-native *Hygrophila* with native *Ludwidgia* in Landa Lake and the Old Channel. This would be a positive step in habitat creation/enhancement in both areas. Establishing additional *Cabomba* along the eastern shoreline area of Landa Lake would also create valuable fountain darter habitat.

5.2 PROTECTION

Restoring native vegetation within the Comal system is likely to have benefits to the aquatic species, but will be unsuccessful or likely very limited if it is not monitored and protected over time. Similarly, any restoration activities or ERPA components that are simply constructed and left unattended will likely fail. One-time restoration contradicts the purpose for these activities which is to provide better habitat conditions for the ecological community over time and in particular, upon entering into critical low-flow periods. To maintain these conditions prior to entering into these periods both native aquatic vegetation maintenance in Landa Lake and the Old Channel, along with a flow-split management for the Old and New channels are recommended for implementation.

5.2.1 Native aquatic vegetation maintenance**.**

Native aquatic vegetation maintenance consists of actively monitoring and maintaining planted stands of native vegetation. Temporal monitoring should incorporate some form of quantitative measurement system to assess whether plantings are increasing, decreasing or remaining stable. Additionally, intensive non-native vegetation control in the adjacent areas may be required until the native vegetation is well-established. Maintenance will also likely include additional activities following natural disturbances such as floods, periods of limited recharge, and/or herbivory, as well as anthropogenic disturbances such as recreation or vandalism. Anytime a disturbance is observed the monitoring/maintenance schedule may need to be increased temporarily in order to provide the stability for the native vegetation re-establishment. Regardless of how successful the initial establishment of native aquatic vegetation may seem to have gone, the continued maintenance/control of non-native vegetation will likely be required in order to protect the restoration efforts and keep them viable over time.

5.2.2 Flow-split management in the Old and New channels.

Flow-split management using the culverts at the head of the Old Channel is also a key tool for the protection of native aquatic vegetation proposed for re-establishment in the Old Channel. A second, but possibly more important function of flow-split management is to maximize (to the extent possible) the quality of habitat in the Old Channel. This could be accomplished by 1) providing a level of flow variability during average to high flow conditions, and 2) allowing proportionally more water to go through the Old Channel versus the New Channel during periods of critically low-flow with the ultimate goal of preserving high quality fountain darter habitat within the Old Channel in wait of the rains necessary to recharge the aquifer.

Table 4 presents the amount of available fountain darter habitat in the Old Channel relative to flow as predicted by the 2-D modeling conducted by the River Systems Institute (Hardy 2011). The physical habitat information along with the temperature modeling conducted during this project and confirmed by the update temperature modeling in Hardy (2011), and professional judgment of the authors who have spent the last decade monitoring the changes within the Old Channel were used to formulate the proposed flow-split recommendation.

Table 4. Fountain Darter Weighted Usable Area in Old Channel (Hardy 2011)

Old Channel Flow (cfs)	Proposed Old Channel ERPA WUA (m^2)	Total Old Channel WUA (m^2)
10	777	18,471
20	833	19,931
30	879	21,837
40	908	22,595
45	924	22,984
50	935	23,291
55	949	23,902
60	956	24,287
70	975	27,109
80	987	27,783

Hardy (2011) describes that from 40 cfs to 80 cfs in the top section of the Old Channel (proposed Old Channel ERPA) greater than 90% of the total available habitat is maintained and water temperature conditions in this reach are not projected to exceed threshold levels. Based on our experience with this reach over the past decade, flows over 80 cfs start to initiate scour of native vegetation (BIO-WEST 2007c). Therefore, the desired goal for maximizing fountain darter habitat in the Old Channel ERPA at all time is to maintain 40-80 cfs of flow. Extremely uniform suitable habitat is present in the New Channel under modeled (10 to 300 cfs) flows (Hardy 2011). Table 5 describes a proposed flow-split for total Comal springflow conditions. During average to high flow conditions (200 to 350+ cfs) the focus is on a seasonal flow split in order to optimize habitat conditions in the Old Channel over time. Slightly higher flows during the fall and winter should provide some channel maintenance benefit while not hindering overall fountain darter habitat. Optimal habitat conditions are proposed for spring and summer to provide the best opportunity for fountain darter recruitment.

Table 5. Proposed Flow-split management for Old and New channels.

Total Comal Springflow (cfs)	Old Channel (cfs)		New Channel (cfs)	
	Fall, Winter	Spring, Summer	Fall, Winter	Spring, Summer
350+	80	60	270+	290+
300	80	60	220	240
250	80	60	170	190
200	70	60	130	140
150	60		90	
100	60		40	
80	50		30	
70	50		20	
60	40		20	
50	40 / (30*)		10 / (20)	
40	30 / (30*)		10	
30	20 / (20*)		10	

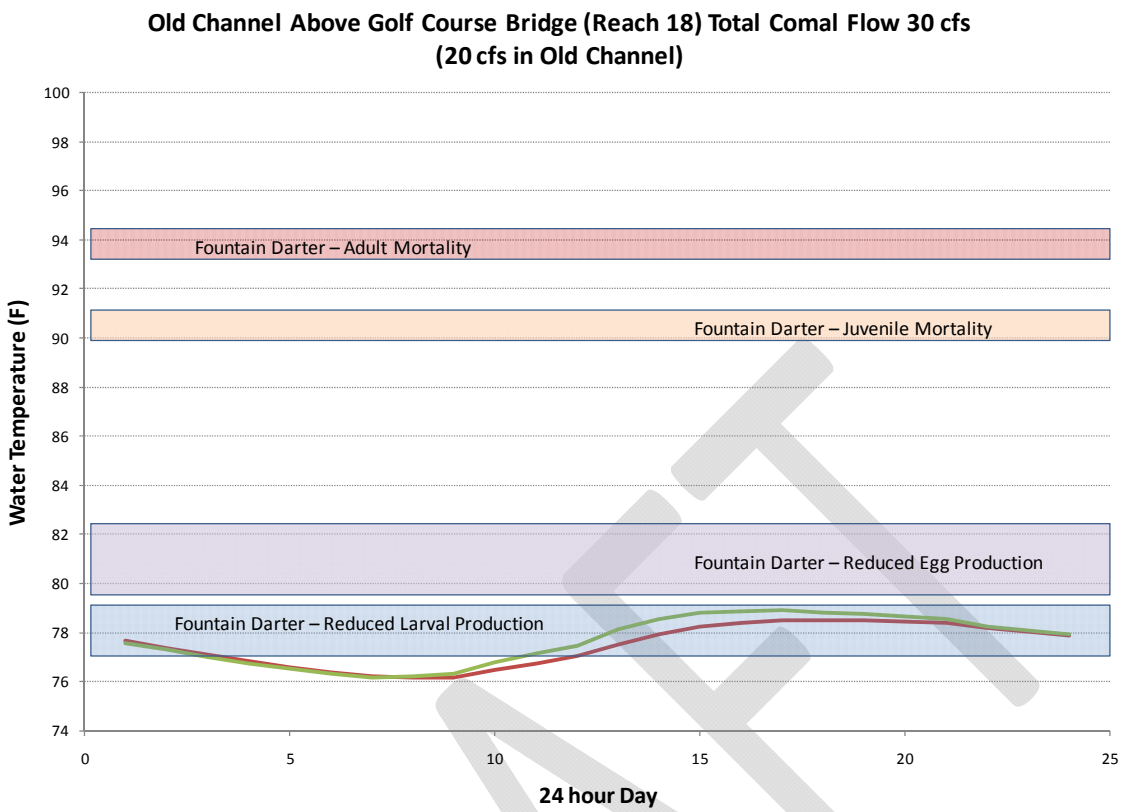
(*) Potentially supplemented to 40 cfs with ERPA recirculation

When total Comal springflow flows drops to 150 cfs the flow split is shifted to protecting the maximum amount of habitat within the Old Channel year round, while continuing to provide flow in the New Channel at all times (Table 5). As discussed in Hardy (2011), 20 cfs in the Old Channel will provide approximately 75% of the maximum available fountain darter habitat in the Old Channel from a physical habitat perspective. In addition to physical habitat, four checkpoint temperature ranges have been identified as critical to the fountain darter life cycle: at and above 77 to 79 (°F) there is reduction in fountain darter larval production; between 79 and 82 (°F) and above there is a reduction in egg production, and at approximately 91 (°F) and 94 (°F) larval and adult thermal death can be expected based on laboratory studies (Brandt et al. 1993, Bonner et al. 1998, McDonald et al. 2007). At 20 cfs, under the extreme ambient temperature conditions modeled in Hardy (2011), the proposed Old Channel ERPA area (Landa Lake to Golf Course Road, [Model Segment 18 – Hardy 2011], Figure 12) is projected (model results) to maintain water temperature below three of the four temperature threshold ranges at all times. Reduced

larval production (up to 63%) has the potential to occur for portions of the day based on laboratory results from McDonald et al (2007). Hardy (2011) shows that the lower portion of the next modeled segment downstream (Reach 19 – Old Channel above Elizabeth Street – Figure 12) is projected to have water temperatures high enough during portions of the day to cause reduction in egg production as well, as do all subsequent downstream Old Channel segments. However, it should be reiterated that even at 20 cfs, nowhere in the Old Channel during the extreme conditions modeled, are water temperatures projected to exceed levels necessary for adult or juvenile survival (Hardy 2011).

5.2.3 Decaying Vegetation removal.

Hardy (2011) highlights the uncertainty surrounding the potential effect of extended low-flow periods on aquatic vegetation dynamics within the Comal system as neither the hydraulic and habitat modeling, nor water quality modeling conducted address this issue. As such, Hardy (2011) recommends further study (for which we support) of this important topic. The main concern is that dying vegetation will start to decay subsequently requiring a large amount of dissolved oxygen (DO) during the decay process. This in turn could cause large swings in the DO concentration within Landa Lake which depending on the severity could affect the biological community including the endangered species. The concern is likely limited to the lake portions of the system as the culverts and weirs present at the upper most portions of the Old and New channels would likely provide sufficient re-aeration to compensate most events. However, within the lake environment problems could occur. A possible solution is to establish water quality monitoring stations within the lake where 24-hour probes could be placed and monitored as flow conditions fall below 80 cfs (total Comal springflow). The focus would be to closely monitor the DO (and other water quality parameters) as flows start to decrease to these flow conditions that have been infrequent in history. Should aquatic vegetation start to die-off and DO concentrations start to show large swings, a vegetation removal program should be initiated. The program would identify areas of dying and/or decaying vegetation and remove the vegetation from the lake with the minimal amount of disturbance possible. This would likely entail using rakes/pitch forks and a jon boat to transfer material to the banks for subsequent disposal.



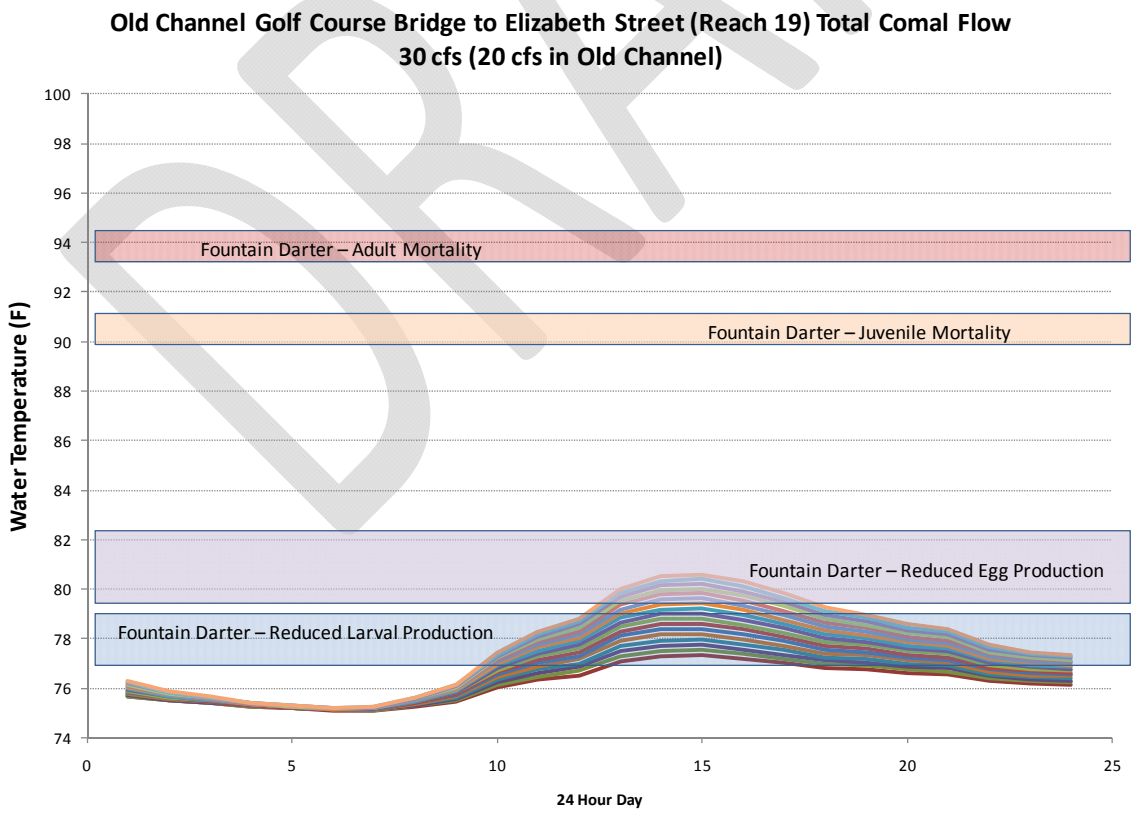


Figure 12. Modeled water temperatures in Reach 18 (top) and Reach 19 (bottom) (Hardy 2011)

5.2.4 Spring Run 3 connectivity

Hardy (2011) states, "We believe the empirical data on riffle beetles demonstrates their persistence within the Landa Lake and spring runs over the past two decades strongly supports that they should be adequately protected over the proposed flow regime being considered by the EARIP." As introduced in Section 1.0, the proposed EARIP flow regime is described as an overlay on historical flow conditions with permitted pumping which is forced to maintain a 30 cfs daily minimum not to exceed 6 months with 80 cfs daily minimum flows for 2 to 3 months following each extended low-flow event. Additionally, this overlay assumes that these low-flow conditions would only happen periodically over time and not be repeated every few years. We concur that the Comal Springs riffle beetle would be protected with the described EARIP flow regime as described in Hardy (2011) and presented throughout this document, as long as it is balanced with a long-term average flow condition suitable for maintaining or increasing populations and habitat over time.

Comal Springs riffle beetles (adults and larvae) have been collected at least semi-annually over the past 7 years via a cotton lure methodology employed for the EAA Variable Flow study. The details of the sampling protocol and results can be found in BIO-WEST 2005a – 2010a). In summary, three main areas are sampled in the Comal Springs system including Spring Run 3, a portion of the western shoreline of Landa Lake, and the Spring Island area. Table 1 (Section 2.0) shows the total number of Comal Springs riffle beetles (adult and larvae) collected per event over this time period. Figure 13 shows the breakdown of Comal Springs riffle beetle density (#/lure) collected during this same time period for the three locations and overlaid on the total Comal springflow observed over this period. Table 1 and Figure 13 show that the total numbers collected and density's observed has been similar across all three locations. However, the difference is that the area sampled along the western shoreline and Spring Island area are smaller areas in proportion to the total available habitat in those areas, as compared to the proportion of sample area to total available habitat in Spring Run 3. Figures 14 through 16 are intended to put the size of the areas into perspective with approximate sampling locations laid over aerial photography.

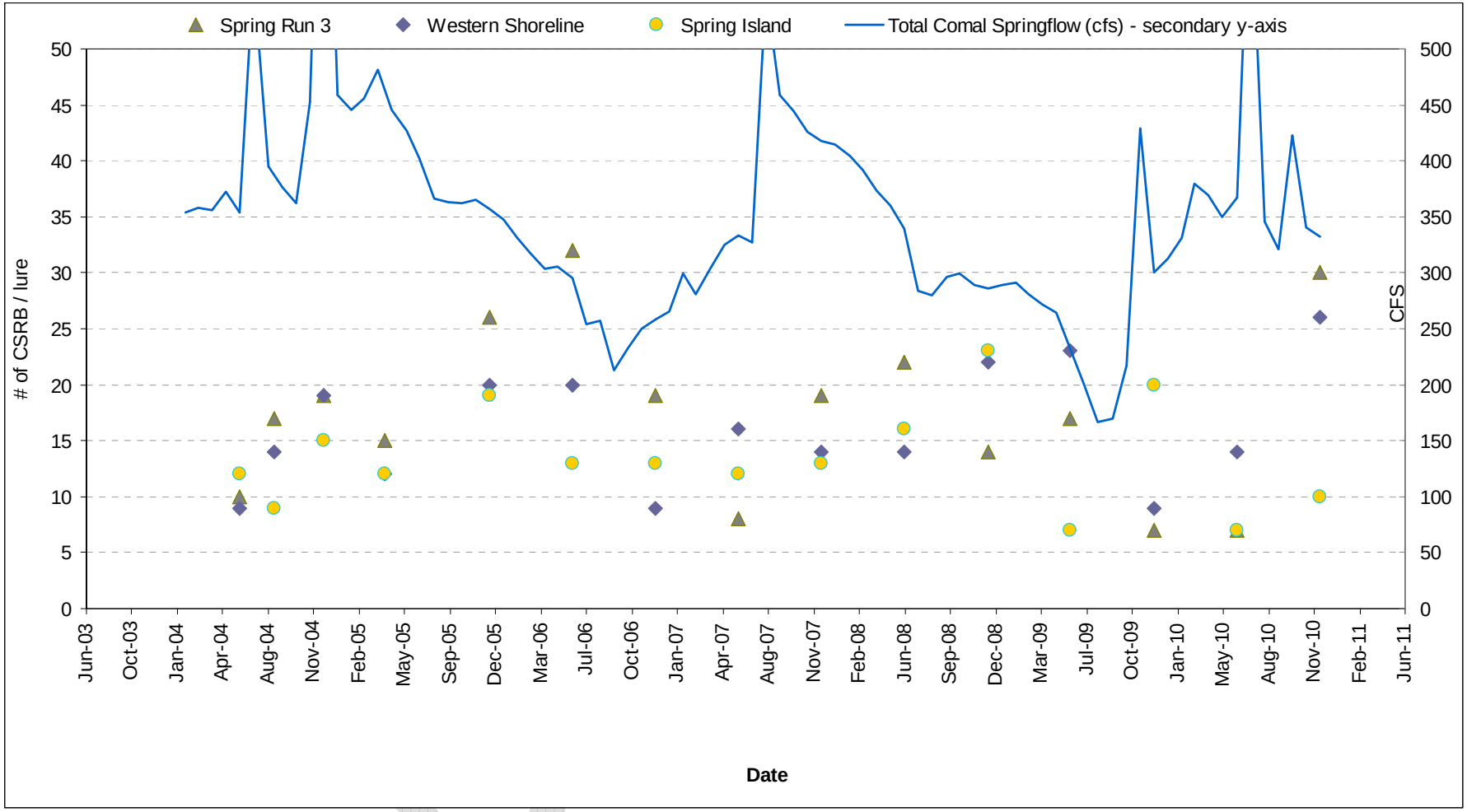


Figure 13. Density of Comal Springs riffle beetles (#/cotton lure) from 2004 to 2010 – EAA Variable Flow Study.

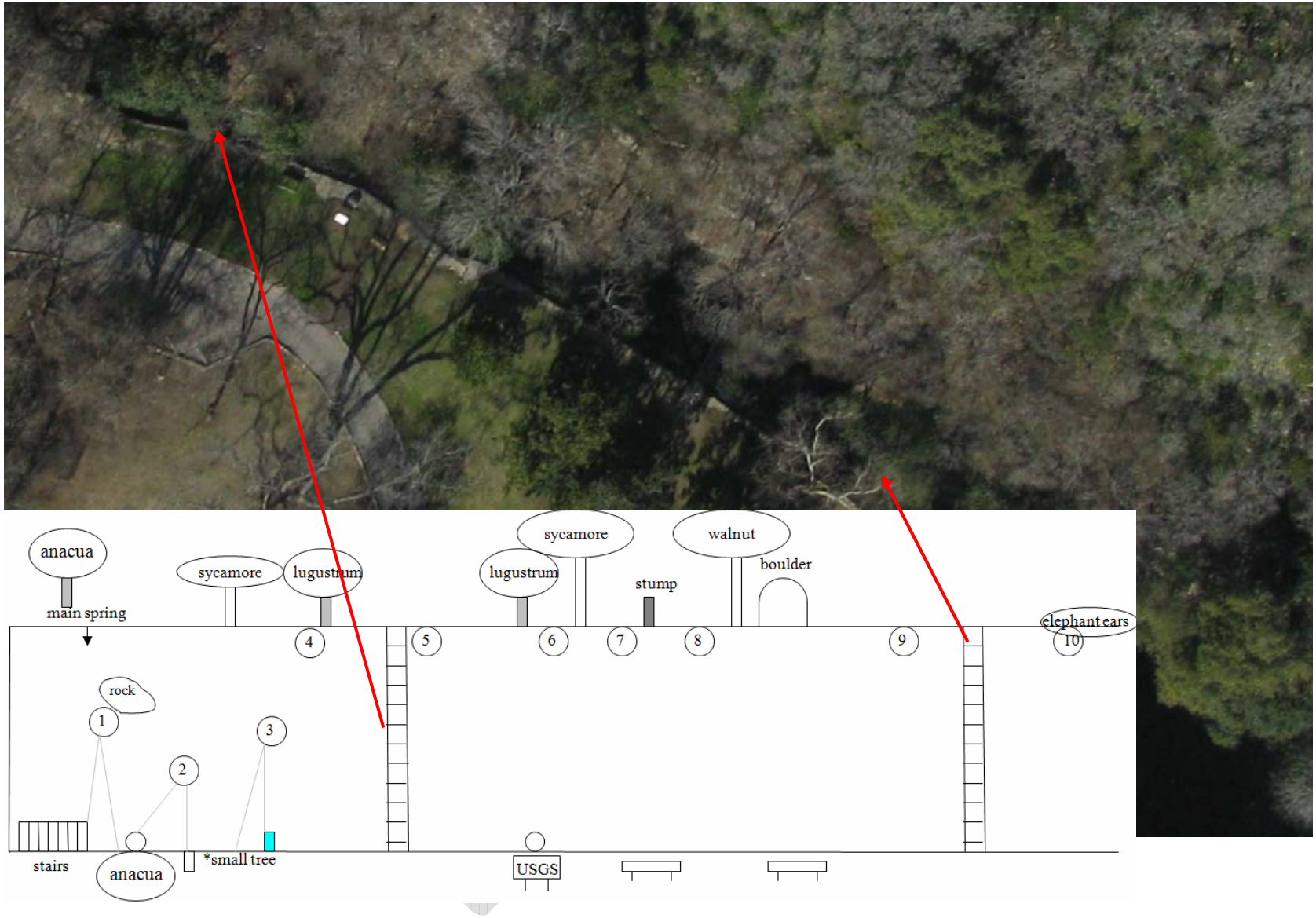


Figure 14. Spring Run 3 Cotton Lure sampling area – EAA Variable Flow Study

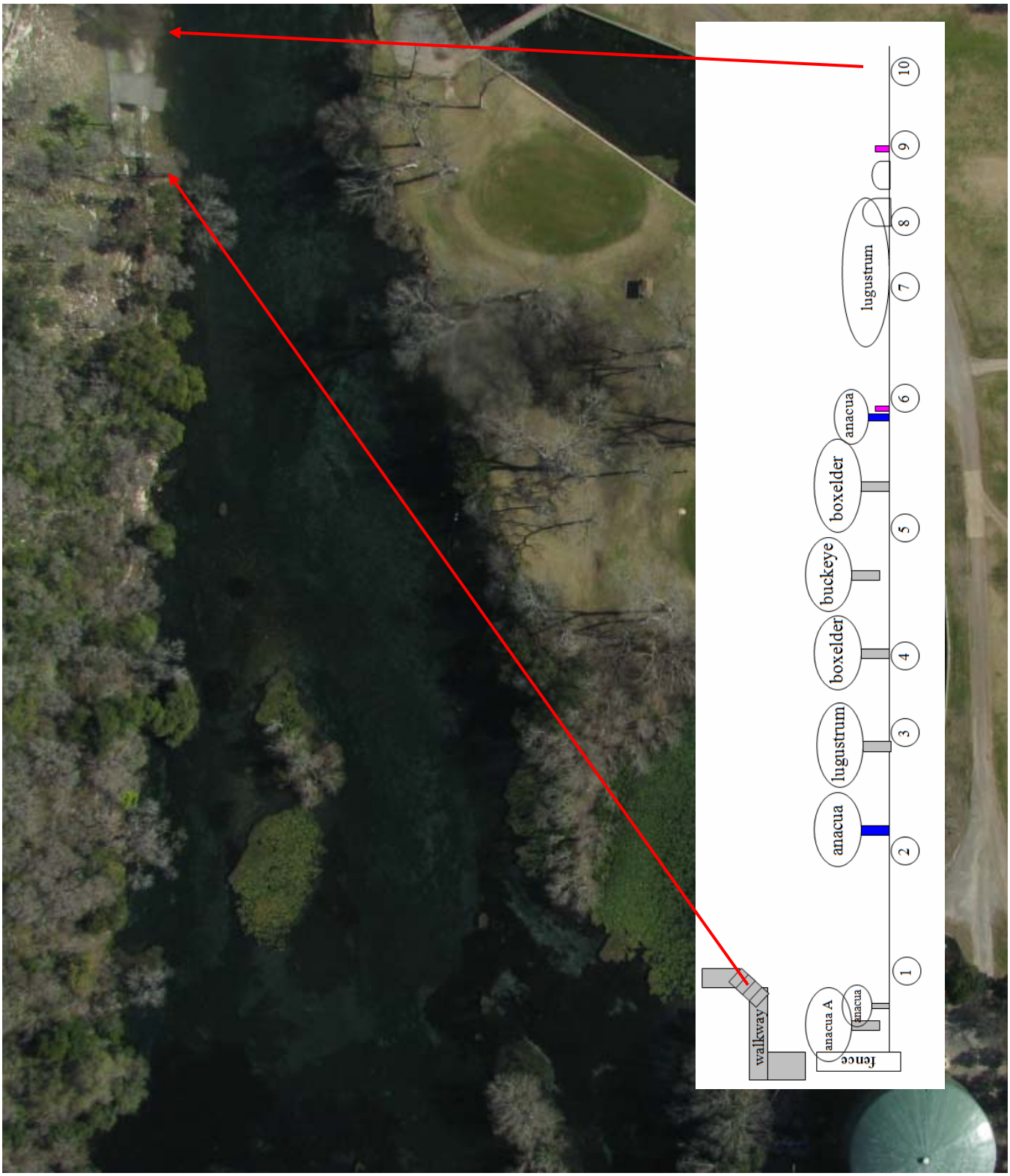


Figure 15. Western Shoreline of Landa Lake Cotton Lure sampling area – EAA Variable Flow Study

Figure 16. Spring Island Cotton Lure sample locations (red circles) – EAA Variable Flow Study

A close examination of Figure 13 shows that a lagged response to total Comal springflow appears evident at all three locations. Why this is happening has not been determined. A closer look at 2009 shows fewer riffle beetles were collected at Spring Run 3 and the Western Shoreline in December as compared to June, but more riffle beetles were collected at Spring Island in December compared to June. One explanation might be that the riffle beetle population fluctuates with total springflow. Most of the springs sampled in the Spring Island area are upwellings on the lake bottom and possibly less susceptible to the effects of drought than seeps along the margins of the lake; some of which had no measurable flow in June. However, many *Heterelmis* were collected on the lures along the Western Shoreline in June 2009. Another possible explanation is that riffle beetles in edge habitat retreat further into the lake or spring run or go subsurface during lower flow conditions. This would also explain fewer numbers recorded during lower flow conditions. During 2010, increases in Comal Springs riffle beetle densities were recorded at all sites as flows returned above historical average conditions.

Hardy (2011) states that the Spring Island portions of Landa Lake and the Western Shoreline will remain inundated at 30 cfs whereas Spring Run 3 would likely go subsurface except for near the terminus into Landa Lake. This is shown in Figure 17 which was provided by Dr. Hardy upon request of the project team. Overall, during 30 cfs total Comal springflow approximately 2/3 of these three main (sampled) areas would likely sustain riffle beetle habitat. Based on this amount of remaining habitat, coupled with the ability of the beetles to use subsurface habitat in the spring runs and increased flows to 80 cfs for a few months following each low-flow event (re-wetting surface water habitat in Spring Run 3 (Hardy 2011), and the fact that the Comal Springs riffle beetle survived after 6 months of zero flow in the 1950s, we have confidence that the Comal Springs riffle beetle should survive the described EARIP flow regime.

Although confident in the statement concerning the described EARIP flow regime, there remains considerable uncertainty regarding the ability to meet the flow targets specified. Additionally, there is very little known about the Comal Spring riffle beetle response to low-flow events in the wild. As such, we propose an ERPA within Spring Run 3 that would maintain spring run connectivity to surface water flow during the periods of minimum flow (30 cfs) in the system. The following is a description of a proposed ERPA to evaluate the concept of spring run connectivity.

The goal of the proposed measure is to provide a constant source of water to flow over the Spring Run 3 edge habitat used by riffle beetles during times when the surface flow in Spring Run 3 ceases. The concept for testing is whether a constant flow of water over detritus and other surface materials might provide a continued food source to riffle beetles that had retreated to subsurface habitats. It would also allow edge habitat to remain wet or moist which in of itself may sustain riffle beetles for some period of time. For instance, during the Spring 2009 EAA Variable Flow study sampling (May 21 to June 19 – standard 4 week retrieval period), total Comal springflow dropped from 223 to 199 cfs and the lake depth lowered slightly around Site 1 (Figure 15, Western Shoreline) leaving the cotton lure in just a moist spot along the bank. Additionally, Site 2 (Figure 15, Western Shoreline) was located in an area with no detectible flow at the conclusion of the survey. However, at the conclusion of the survey, the Site 1 lure contained 26 adult Comal Springs riffle beetles and 5 larvae, while the Site 2 lure contained 25 adults.

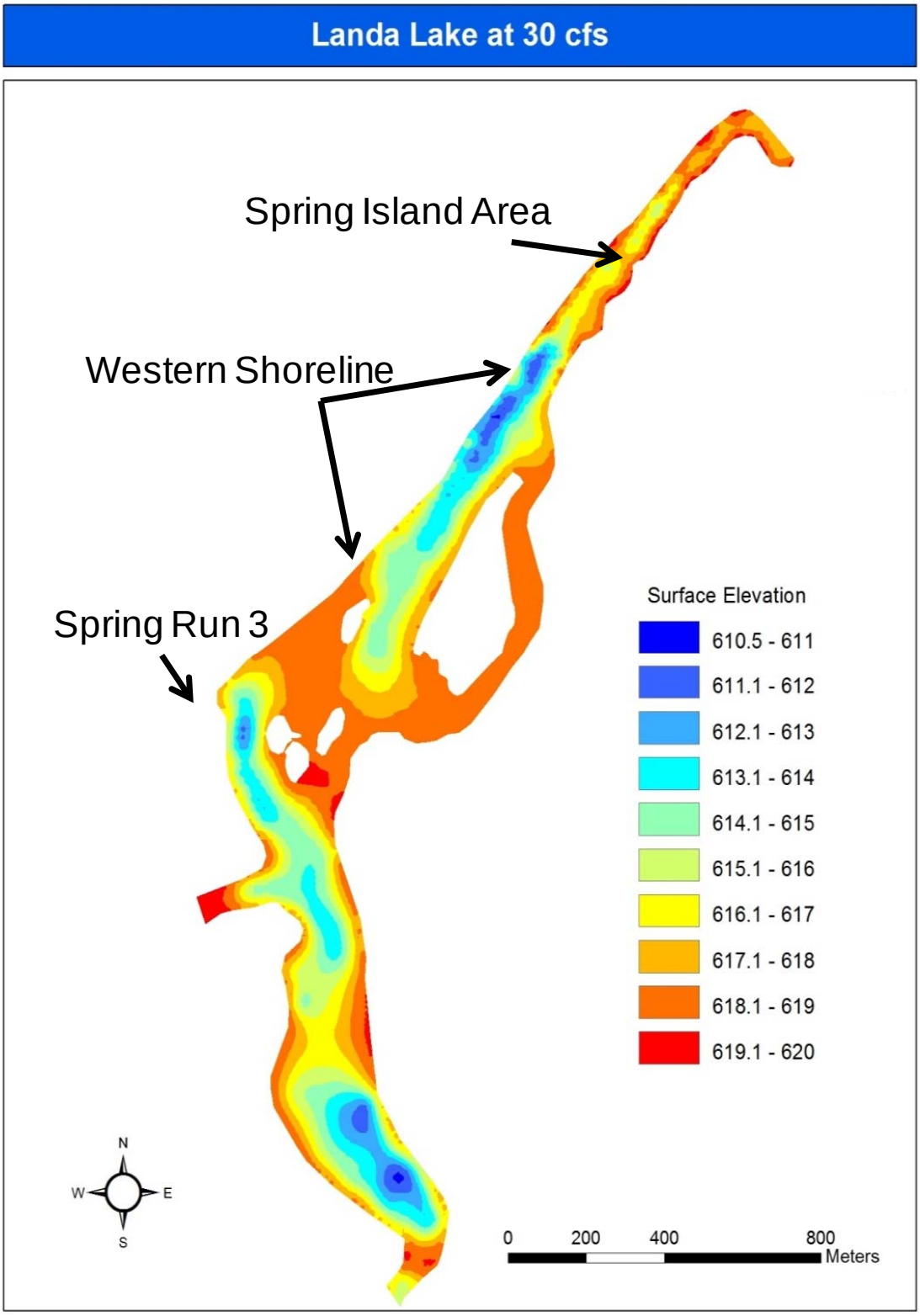


Figure 17. Inundation of Landa Lake at 30 cfs model flow (Hardy 2011)

The proposed ERPA would involve taking Landa Lake water from the immediate terminus of Spring Run 3 and recirculating that water to Spring Run 3 during times when aquifer levels decrease below 620 feet (Landa Park Well) (Figure 18). As aquifer levels decrease to 620 feet, spring flow decreases then ceases surface flow in the spring runs. Temporary wetting of surface areas and connectivity to the subsurface water at documented riffle beetle habitat would be provided along the river left edge of Spring Run 3 (Figure 18) by trickling water from the ground surface down through riffle beetle habitat areas. A temporary submersible pump (or a pump with submersible intake screen) would be deployed across from the existing gazebo. The pump (estimated to have capacity of approximately 2 cfs) would draw water from the lake and discharge into a pipe along the length of the north shoreline of Spring Run 3. Diffusers attached or integral to the pipe would be used to supplement riffle beetle habitat (Figure 19 shows a simple, conceptual perforated pipe design) that would emit water through existing high quality riffle beetle habitat (Figure 20). If implemented, a means for testing the success of the measure would also need to be developed. This would likely include the presence of riffle beetles (adult and larvae) but may also involve some form of habitat assessment.

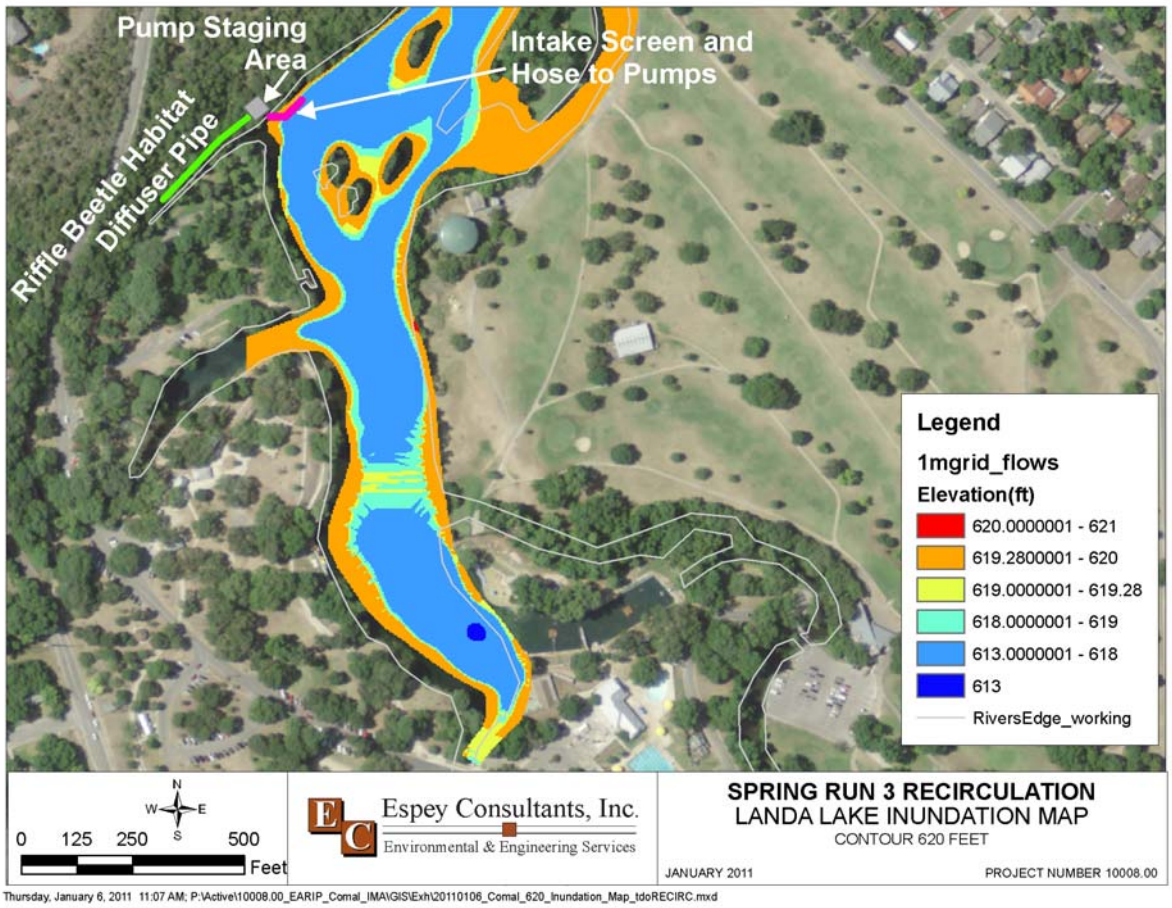


Figure 18. Spring Run 3 Connectivity conceptual design

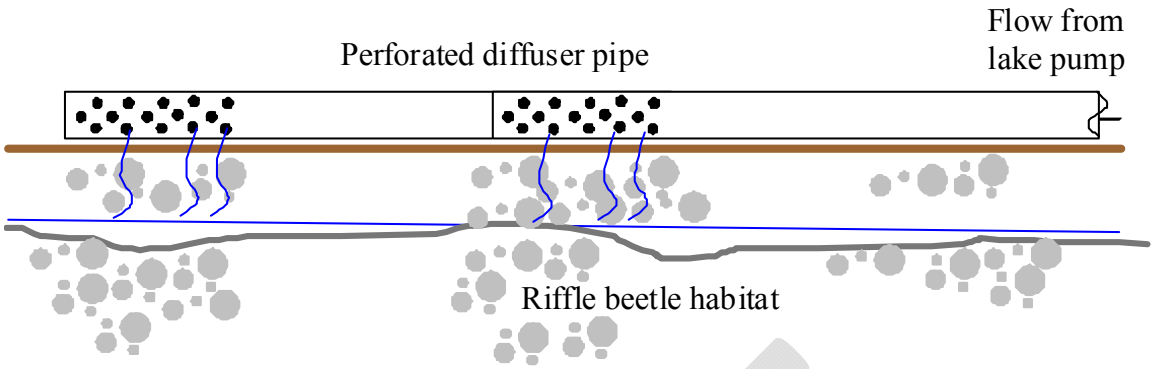


Figure 19. Spring Run 3 - Riffle Beetle diffuser pipe

Figure 20. Picture of Riffle Beetle edge habitat in Spring Run 3.

Since use of a gas or diesel pump in this sensitive area is not preferred, installation of a 480v 3-phase electrical service would be needed to run an electric 1,000-2,000 gpm pump. Rather than using a permanently installed pump within a pump-house, a temporary rental pump is recommended to avoid maintenance costs associated with cleaning and servicing a pump used irregularly (e.g, once every 10+ years). Similarly, piping and intakes are envisioned as temporary. Any temporary equipment would need to be secured and/or anchored to prevent theft, vandalism and/or disturbance during weather events. However, permanent structures could be constructed to house temporary pumps rented during an operational event.

Consideration to the aesthetics of the system is critical since the area is visited for its natural beauty. An outlet box placed on the northern shoreline (across the channel) with a temporary submersible pump and camouflaged perforated pipe along the northern shoreline is proposed to minimize any aesthetic issues. An informational kiosk is also proposed near the Gazebo across the channel from the outlet box that describes the purpose and goal of the Spring Run 3 connectivity project. It must be remembered that during these very infrequent events, all three main spring runs will be mostly dry, causing an aesthetically unpleasing scene for park visitors. Observing an attempt to protect endangered species habitat during these time periods might even

be considered a positive aesthetic appeal. Permanent structures may offer more benefits to aesthetics despite being infrequently used and more expensive than temporary installations. Construction of a permanent intake structure and pump house is possible but with increased costs. However, attempting to bury the diffuser pipe along the northern edge is NOT recommended as this would involve considerable disturbance to the existing Comal Springs riffle beetle habitat and/or flow patterns that this project would be trying to protect.

Spring Run 3 ceases surface flow at park well level 620 ft (approx 35 cfs total spring flow), so operationally, this measure should begin operation in advance at approximately 50-60 cfs total spring flows. Permitting of the recirculation component would need to be further evaluated if this option is chosen. Texas Commission of Environmental Quality (TCEQ) water rights permitting staff have indicated the possibility that Spring Run 3 could be designated as a water course where a bed and banks permit may be needed to withdraw and discharge. Additionally, permitting for construction of permanent facilities may need approval of regulatory entities including the city of New Braunfels or TCEQ.

Estimated cost for purchase of necessary site equipment and installation is $87,000, which includes installation of a 480V 3-phase service at $32,500 (Table 6). Estimated monthly operations cost totals $12,600 per month (Table 7) for a rental pump and hoses ($7,300) and for electrical power ($5,300).

Table 6. Spring Run 3 - Construction and materials cost estimate

Infrastructure and Purchased Equipment

Description	Quantity	Unit	Unit Price	Total
Mobilization	1	LS	$2,000	$2,000
Pipe Manifold Structure	1	LS	$2,000	$2,000
12" Gate Valve	1	EA	$1,500	$1,500
12" 20-slot SS Well Screen, 20-ft Joint	1	EA	$2,500	$2,500
Screen Assembly	1	EA	$750	$750
12" PVC Pipe and Installation	300	LF	$90	$27,000
Diffuser assemblies	10	EA	$250	$2,500
Revegetation	1200	SY	$1.50	$1,800
Electrical Service Line	500	LF	$65	$32,500
Subtotal				$72,550
Contingencies	20	%		$14,510
Total				**$87,000**

Table 7. Spring Run 3 - Monthly operations cost estimate

Rental Equipment

Description	Quantity	Unit	Unit Price	Total
100-hp Trailer-Mounter Pump with Noise Abatement	1	Mo	$7,000	$7,000
12-in Flexible Suction Hose	50	LF/Mo	$6	$300
12-in Flexible Discharge Hose	20	LF/Mo	$2	$40
Total per month				**$7,300**

Electric Power Cost

Description	Quantity	Unit	Unit Price	Total
Electricity	40267.8	kWh	$0.084	$3,400
Demand Charge (3 months)	168	kW	$3.75	$1,888
Total per month				**$5,300**

5.2.5 Old Channel ERPA.

As discussed in Section 4.0 and highlighted in Table 3, the Old Channel below Landa Lake is a suitable location to construct and maintain an ERPA for the protection and enhancement of fountain darter and potentially riffle beetle habitat during extended drought conditions. Similar to the Comal Springs riffle beetle conclusions presented, Hardy (2011) also concludes that the fountain darter in the Comal system will be protected by the EARIP flow regime as previously described. We concur with the Hardy analysis for the fountain darter relative to the described EARIP flow regime, but again are concerned with several components of ecological uncertainty raised by the EARIP SSC, and the uncertainty surrounding any management approach to truly meet the flow requirements as specified in the described regime. An Old Channel ERPA, as described below, would provide an additional measure of safety in the event that all does not go as planned or that some of the underlying assumptions founding the Hardy (2011) analysis are proven to be not completely accurate. Additionally, the Old Channel ERPA presented below would serve as an on-site facility to conduct applied research on the concerning assumptions and many unknowns that continue to cloud our judgment on what is truly necessary to protect the ecological community (including the endangered species) within the Comal Springs/River ecosystem. The applied research component is discussed in detail in Section 5.3.1.

To summarize the Hardy (2011) findings, at 30 cfs total Comal springflow (20 cfs – Old Channel, 10 cfs – New Channel), physical habitat and water quality conditions throughout Landa Lake proper, the Old Channel and New Channel are sufficient to support adult and juvenile fountain darters and recruitment in key but limited areas. At 80 cfs, which are the flows prescribed for a few months following a maximum 6-month flow of 30 cfs minimum daily flows, suitable conditions are extended into the spring runs and further downstream in the Old and New Channels (Hardy 2011). Three main concerns noted in Hardy (2011) regarding this flow regime were 1) the potential for aquatic vegetation die-off and subsequent dissolved oxygen (DO) problems in Landa Lake, 2) the reduction in larval production of fountain darters that would likely be experienced, and 3) the potential for cool water inflows from springs along the western margin of Landa Lake flowing down the New Channel instead of entering the Old Channel. As supported in Hardy (2011), the aquatic vegetation question remains unanswered and we agree it should be explored further through applied research on-site (see Section 5.3.1). The reduction in larval production has been thoroughly documented in laboratory studies (Bonner et al. 1998, McDonald et al. 2007) and can be assumed to occur at these flow conditions in the wild based on

temperature modeling (as no water quality data is available at 30 cfs total Comal springflow). Therefore, based on the temperature modeling, at 30 cfs total Comal springflow, only the upper portion of the Old Channel (proposed Old Channel ERPA and the upper portion of Hardy 2011 – Reach 19) (Figure 12) and possibly pockets of cooler water along the bottom of Landa Lake (Hardy 2011) are projected to remain below three of the four temperature threshold ranges at all times. At this flow level, reduction in larval fountain darter production is possible in these segments during portions of the day (Figure 12). All other areas of the system are projected to experience reductions in fountain darter larval and egg production (Hardy 2011). It needs to be clear, that at these flow levels, temperatures throughout most all of the Comal system are still below conditions necessary for survival of adult and juvenile fountain darters and a reduction in larval production within the threshold range (77 to 79 °F) does not equivocate to "total" larval mortality (projected as up to 63% in McDonald et al. 2007). The third concern is directly related to uncertainty associated with the temperature modeling and will require additional hydrodynamic modeling with follow-up water temperature modeling in addition to intensified spatial monitoring during low-flow events. These activities are all supported and will be proposed in the HCP.

At 80 cfs, the majority of Landa Lake proper and an extended portion of the Old Channel (Hardy 2011) are not predicted to experience any reductions in fountain darter larval production. Based on the maximum 6-month duration at 30 cfs daily flows, the few months at 80cfs following the minimum periods, and the available darter habitat and reproduction availability within the system, we concur with Hardy (2011) that under the described EARIP flow regime, the fountain darter population and habitat will be supported in a condition that can recover to pre-drought conditions. With this said, it is easy to start asking what if questions, such as what if aquatic vegetation in the Lake does crash?; Would we come to the same conclusion if fountain darter habitat going into the drought is in really poor condition because of a recent flood or human disturbance?; What if predation and competition in the remaining high quality habitat is so great that fountain darters are drastically reduced by this biological pressure?; What if the proposed EARIP flow regime cannot be met for whatever reason?, etc. etc. These are the types of questions asked in the development of the proposed Old Channel ERPA. The primary function of the Old Channel ERPA (as described below) will be to maintain high quality fountain darter habitat within the main channel through restoration and protection, in order to ensure that habitat quality going into a drought is always high in this area. Should model assumptions relative to the biology and/or hydrology be wrong, this area could be operated with the goal of protecting the fountain darter population and habitat in the wild for some period of time. The phrase "some period of time" is used because at this time, this concept is only at the feasibility stage and would need to be implemented, tested, and no doubt adjusted and improved over time to maximize its ability to sustain fountain darters and their habitat in the wild.

Figure 21 shows the proposed Old Channel ERPA location. As discussed in Section 4.0, flow from Landa Lake into the swimming pool and the Old Channel can be controlled by existing culverts in the system (Figure 22). Figure 23 shows the topography for the proposed Old Channel ERPA which extends from Landa Lake to the Golf Course road. One alternative is that the flow in this area be controlled by the existing culverts and actively restoring and maintaining fountain darter habitat within this reach. Figure 24 shows the aquatic vegetation communities within this reach in Spring 2010, prior to the June flood. If one simply takes the average

fountain darter densities per aquatic vegetation type (recorded over the past 10 years of the EAA Variable Flow study) and multiplies that number by the amount of each type of vegetation in this reach and then sums it up, one would predict that at that particular time, that reach maintained a fountain darter population of approximately 8,500 fountain darters.

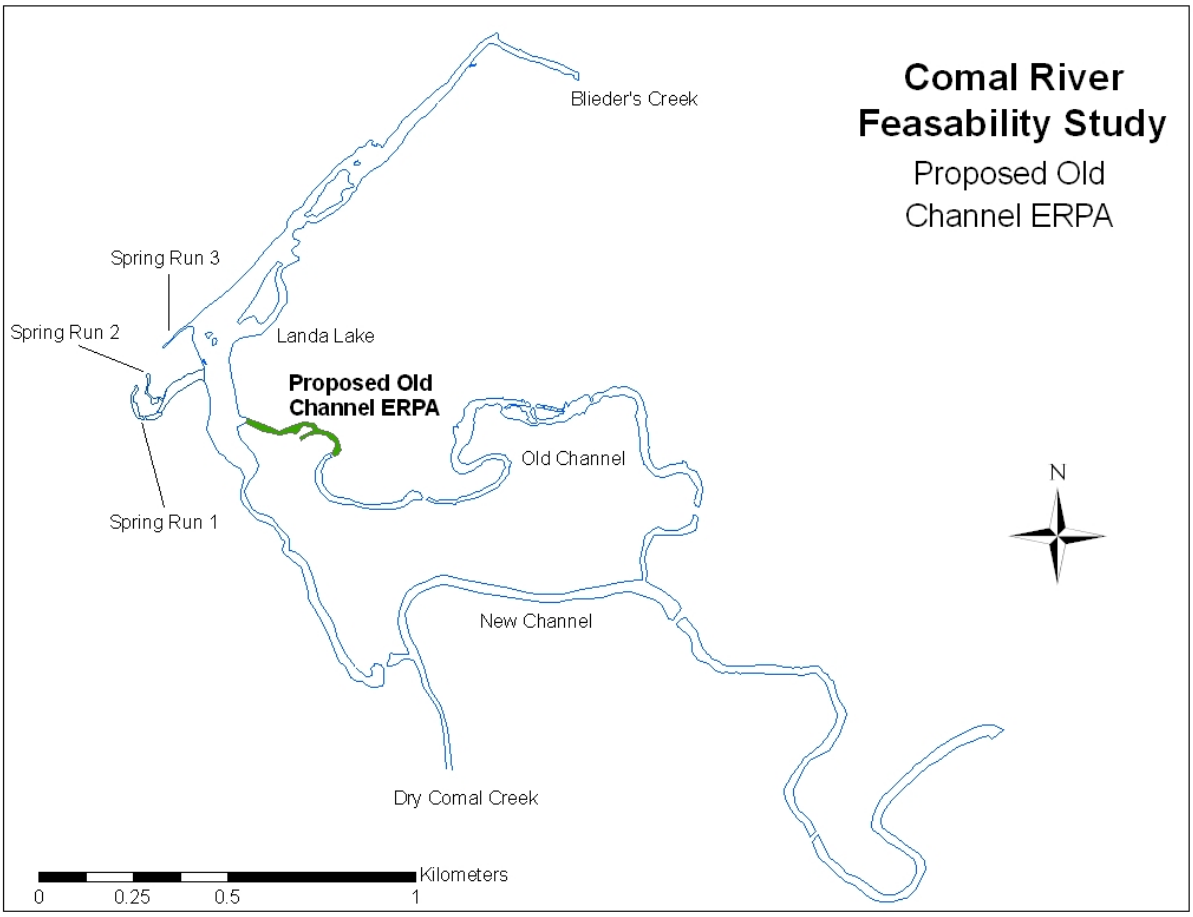


Figure 21. Proposed Old Channel ERPA location.

Figure 22. Landa Lake and culverts going to swimming pool and Old Channel

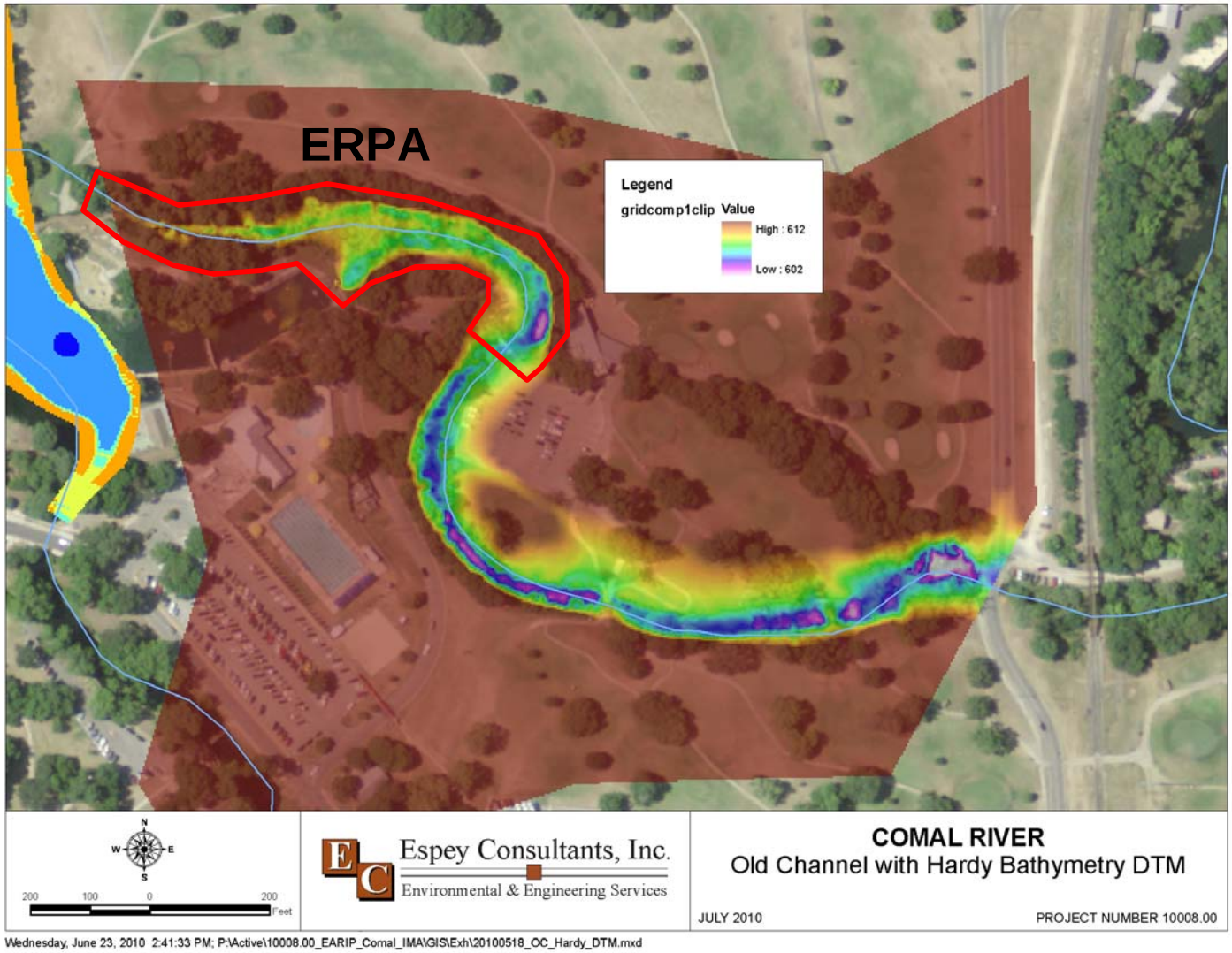


Figure 23. Old Channel ERPA below Landa Lake. Data sources: Topography – City of New Braunfels two-foot topographic contours from LIDAR data Bathymetry – (Hardy 2009)

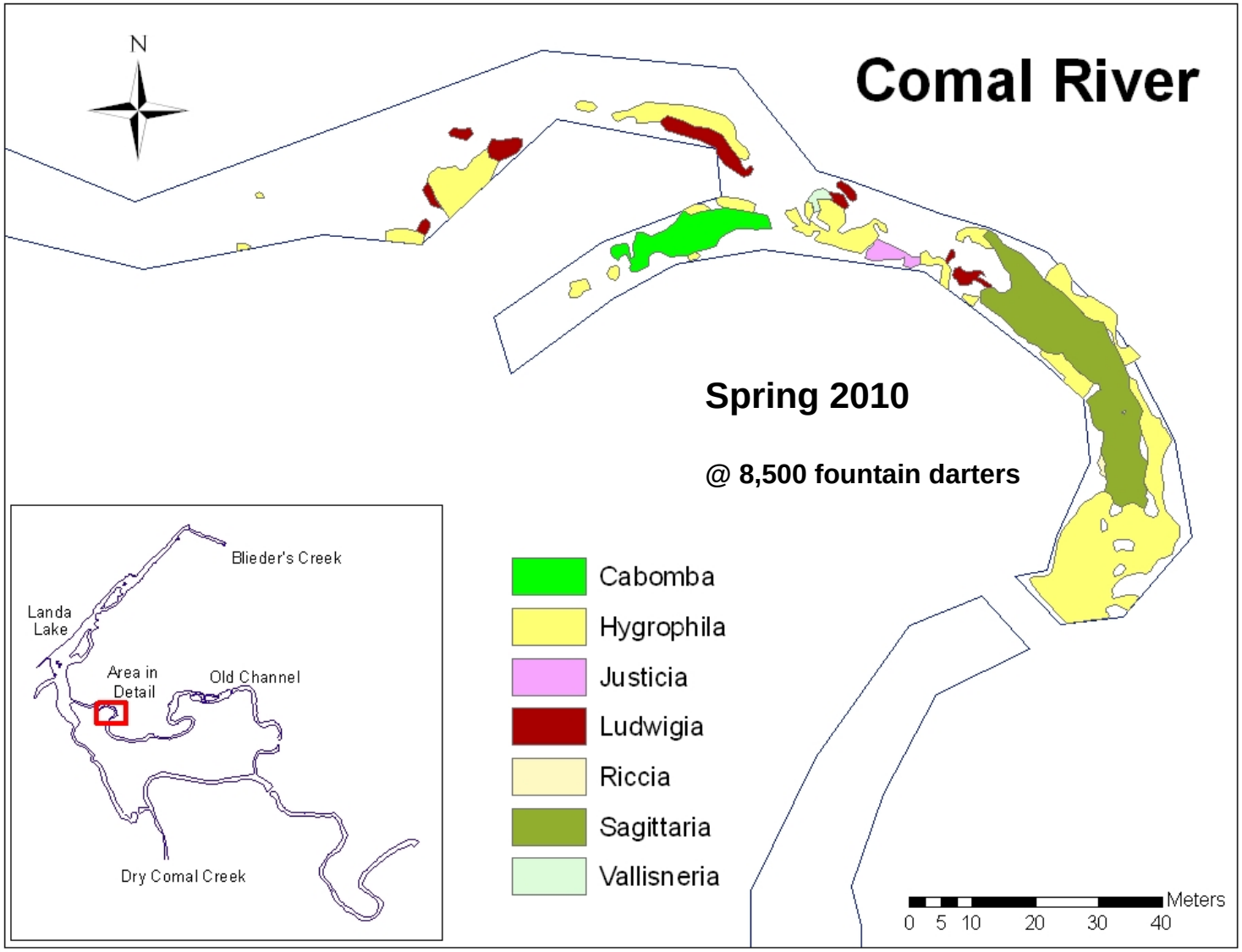


Figure 24. Aquatic vegetation in proposed Old Channel ERPA – Spring 2010

Figure 25 shows the same area with an example of a recommended aquatic vegetation restoration and maintenance effort. Under this scenario, the same fountain darter population calculation as presented above would yield approximately 28,000 fountain darters within this reach. Clearly this is an oversimplification, but is used to provide an example of what might be possible to maintain within this reach under high quality habitat conditions. Based on the habitat modeling conducted by Hardy (2011), Old Channel flows between 40 and 80 cfs support high quality habitat conditions. By only operating the culverts at Landa Lake, maintaining these conditions at all times would be impossible for the following reasons. At higher total Comal spring flows, the amount of water coming through the Old Channel is often in the 80 to 110 cfs range in order to alleviate the pressure on the dam above the swimming pool, and thus, would be anticipated to continue unless dam improvements were made or a flow by-pass around the ERPA was constructed. Secondly, the EARIP described flow regime proposes flow to go as low as 20 cfs within the Old Channel which again strays from a high quality habitat condition, should only the culverts be used to control flow. In order to increase flows back to more optimal conditions within the Old Channel ERPA, some sort of recirculation scheme would need to be implemented. Bottom-line, it is currently not possible to maintain optimal conditions in the Old Channel via the existing culvert operation and restoration of aquatic vegetation alone.

Figure 26 shows the conceptual design for the complete ERPA package being discussed in this report. The design incorporates a diversion structure used to take water from the main channel and either bypass the ERPA (blue line, Figure 26) or divert water into the experimental channel (described later in this section). To accommodate the significant slope in the Old Channel and to facilitate diversion, a control structure similar to a cross-vane weir (Figure 27) is proposed to provide head to deliver water to the bypass or experimental channel while controlling impact to the existing Old Channel. Rock cross vane weirs have been used for this similar purpose in the South Fork of the Platte River in Colorado (Figure 28) and elsewhere to provide head for an irrigation diversion. With the inclusion of the experimental channel, this structure would be located at the presented location, whereas if the experimental channel was not constructed, this structure would be better suited closer to the main portion of the ERPA. For this discussion, the entire package including the experimental channel is described.

Having the ability to bypass water around the ERPA during higher flow conditions is only one part of the protection necessary to allow the continued maintenance of high quality fountain darter habitat conditions at all times. The second component is the ability to recirculate up to 20 cfs in the same pipeline (blue line, Figure 26). While the experimental channels would be permanently installed (discussed later) and likely used continuously, the recirculation appurtenances are anticipated to be used only during severe drought conditions. Recirculated water would be used to augment flow within the ERPA area. For example, under the 30 cfs EARIP minimum total Comal springflow (20 cfs in the Old Channel) approximately 40 cfs flow (20 cfs continually coming from Landa Lake plus 20 cfs being recirculated) could be maintained within the Old Channel ERPA despite only 20 cfs flowing into the ERPA from Landa Lake and discharging out of the downstream end. Water volume necessary to augment flow within the ERPA would start to be withdrawn (smaller quantities at first) from the river and recirculated at around 50 to 60 cfs to minimize impact to downstream water users.

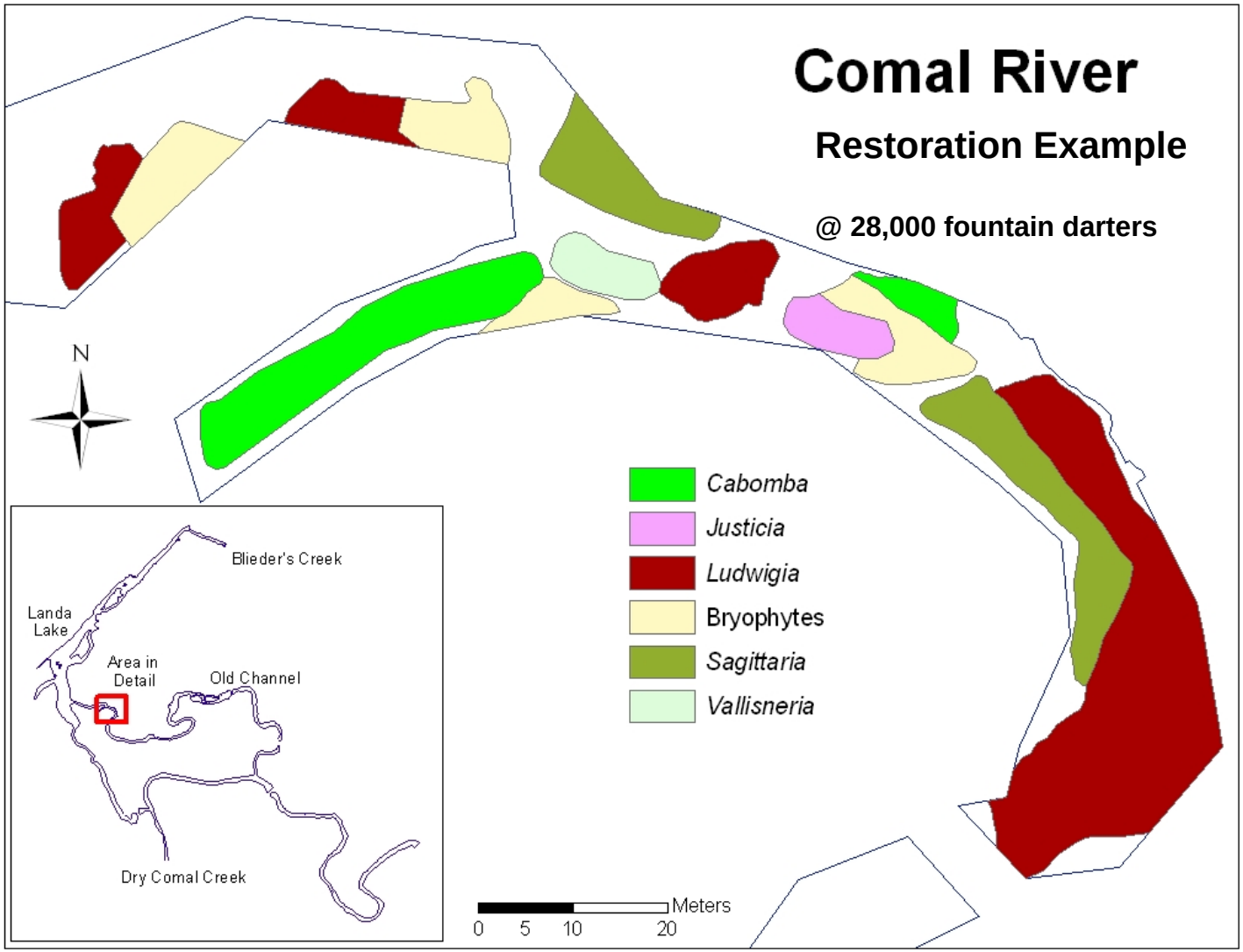


Figure 25. Potential Aquatic vegetation community following restoration in proposed Old Channel ERPA.

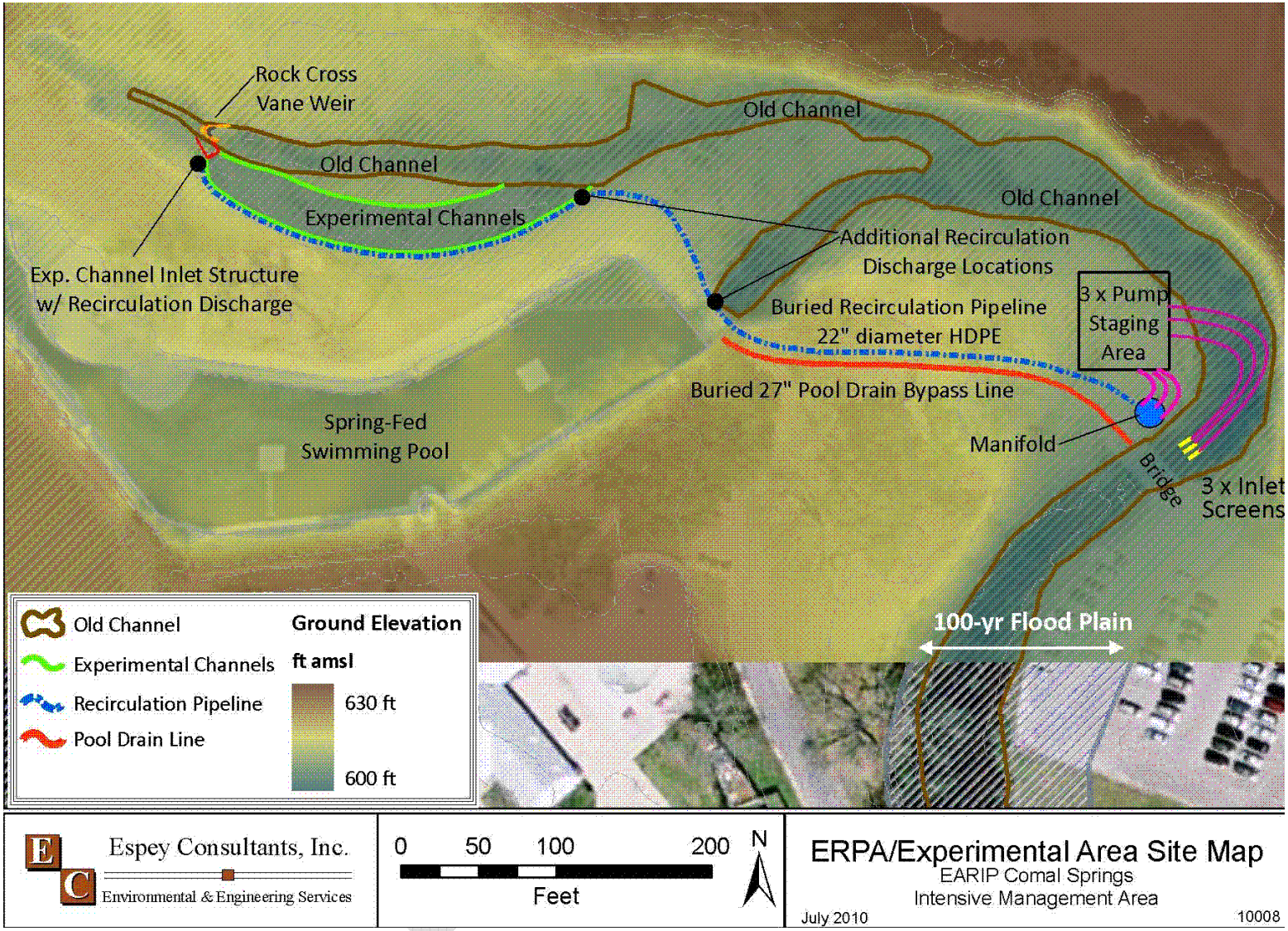


Figure 26. Conceptual Old Channel ERPA and Experimentation area

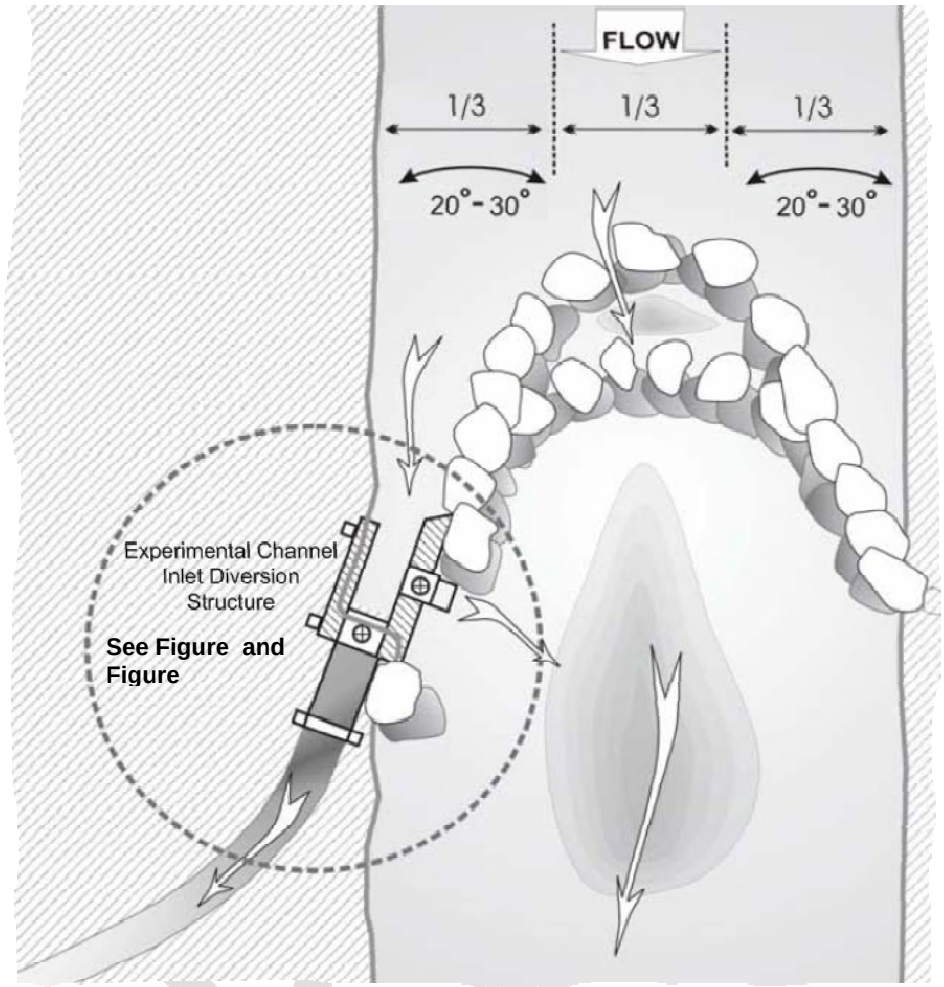


Figure 27. Rock Cross Vane Weir with Diversion Structure

Figure 28. Rock cross vane weir, South Fork Platte River, Colorado

Since the recirculation system would only be used only during severe droughts, a combination of permanently installed and temporary rental components is proposed to avoid maintenance and testing that would be necessary for critical components of a seldom-used dedicated permanent system. Underground piping to transfer water from downstream pumps to the upstream end of the recirculation area is proposed to be permanent, while the pumps themselves and the in-channel intake structures are proposed to be rented and/or temporarily placed (Figure 26).

The primary challenge with flow recirculation involves the means to divert and pump up to 50% of the flow in the channel into a pipe under low flow conditions. The option presented here is the use of wire-wrapped well screen deployed horizontally in the channel at least 6 inches or more above the channel bottom (Figure 29). Wire-wrapped well screen offers a relatively large open area to limit entrance velocities, but the aperture of the opening is very small to limit intake of sediment and other materials in the channel. Well screen is readily available, easy to deploy, durable and can easily be modified for use in the channel. Drawing water over the relatively large intake area also serves to minimize impact or disturbance to the channel, thereby preventing scour or other impacts that may be caused by a more typical single intake located near the channel bank.

The conceptual design (Figure 29) is to use an 8.5 ft segment of 12-inch diameter, 20-slot (0.020-inch) stainless steel well screen connected to a trailer-mounted 100-hp pump by a 12-inch

flexible suction hose. This configuration will be capable of diverting nearly 3,000 gpm while limiting the entrance velocity at the well screen to 1.5 fps. If required, lower entrance velocities can be achieved by using longer sections of well screen or wider screen openings. To achieve the target recirculation of 20 cfs (~9,000 gpm) at 1.5 fps entrance velocity, a total of three (3) well screen and pump units are necessary.

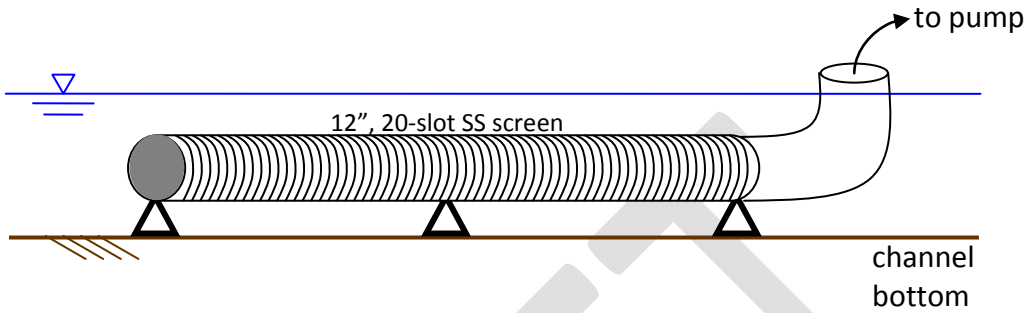


Figure 29. Recirculation Intake Screen

The discharge line from each pump will be connected to an aboveground manifold that directs the flow into an underground 22-inch (or 24-inch) SDR-17 HDPE pipe (Figure 30 and Figure 31). The pipe conveys the recirculated water upstream to the discharge location (Figure 26). The conceptual design presented here assumes the recirculation project is constructed with the diversion project so that the discharge of the recirculation pipe is integrated into the diversion structure at the upstream end of the constructed channels (Figure 26).

In addition to recirculation, the project allows for bypass of pool cleanout water around the ERPA area (red line, Figure 26). A pipeline buried in the same trench as the recirculation pipe would be used to collect pool flow-through and once-weekly pool clean out water and direct this water to discharge downstream of the existing low-water bridge. This configuration would prevent pool waters with potentially high temperatures and potentially including contaminants (e.g., suntan lotion) from entering the ERPA area and from being continuously recirculated through the system. Two pool drain configurations are considered. To drain the pool in approximately four hours using gravity, a 27" diameter pipe is estimated to be required. Another alternative is to rent a pump and discharge into a smaller diameter pipeline.

Recirculation features would be activated when total Comal spring flow is reduced below approximately 60 cfs. Recirculation to augment within ERPA flows by 20cfs (40 cfs total) would be maintained to protect the ERPA down to a condition of low flows of approximately 20 cfs entering and leaving the ERPA. The exact flow rates would be determined by additional future study; this study has identified the level of infrastructure necessary to maintain these features.

An additional concern raised with the Old Channel ERPA is the potential for "take" associated with native vegetation restoration activities and potential impingement/entrainment from recirculation strategies. At the flow levels being considered, take will be considerable throughout the Comal system and additional take will likely occur from these activities. During the permitting and environmental documentation component of this project (should it move forward), all efforts should be made to design restoration strategies and recirculation structures to

minimize take to the degree practicable. However, it needs to be reiterated that the goal of the ERPA is to promote survival in the wild. At this time, we believe that the benefits from the ERPA far outweigh concerns regarding "take" that may occur as a result of implementation and management of the ERPA.

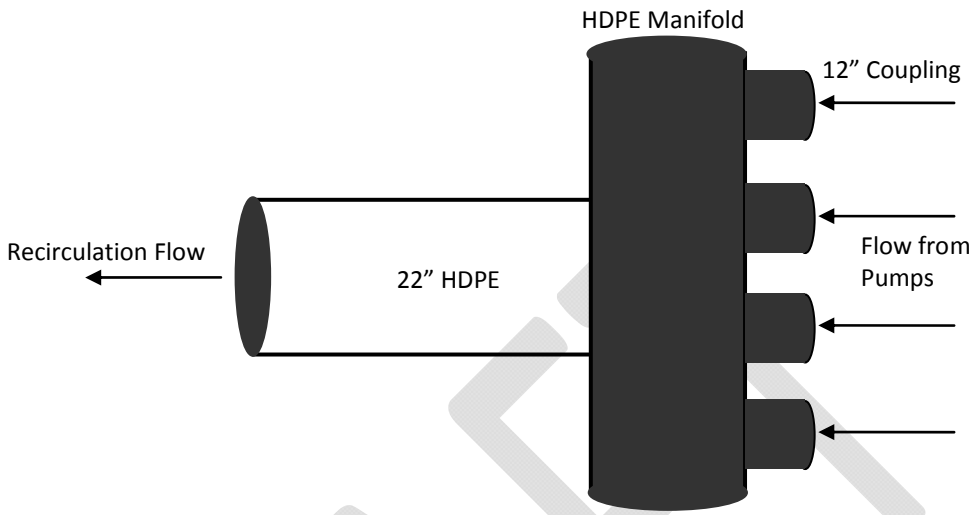


Figure 30. Recirculation Manifold-Plan

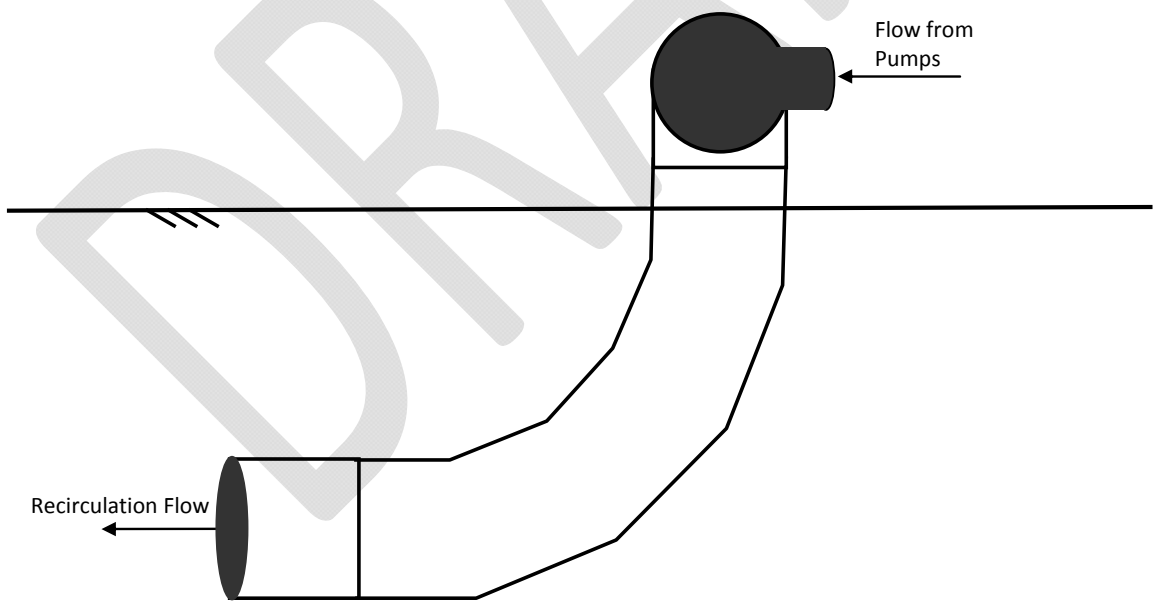


Figure 31. Recirculation Manifold-Profile

Costs were estimated for a recirculation system capable of a sustained flow of 20 cfs (Table 8). The cost estimate includes the installation cost of the HDPE pipeline. Operations costs are tabulated per month (assuming a 3-month operation period) and include equipment rental and

fuel/power costs. The total cost of construction and fabrication of permanent infrastructure and equipment is about $167,000. The rental cost of one electric-powered pump unit, required pump intake/discharge hoses, and electricity is approximately $12,400 per month; because 3 pump units are required to achieve the desired recirculation flow of 20 cfs, the total monthly cost is about $35,000. These costs assume 3-phase electrical service is available near the project site.

Use of diesel pumps are not recommended because of the potential of spills associated with the need to handle approximately 7,500 gallons of diesel fuel per month adjacent to sensitive endangered species protection areas during critical time periods. Additionally, the operation cost could be significantly higher than electric, outweighing savings offered by eliminating the need for installing an electrical service. Estimated cost totals approximately $11,000 per month for electric pumps, compared to approximately $26,500 per month for diesel-fueled pumps operating under the same conditions. Specific details related to operations procedures, security, fencing and exact placement of all structures and components of this ERPA would need to be identified in subsequent phases of this project.

5.2.5.1 *Temperature Modeling Overview – Old Channel ERPA*

Water temperature has been identified as a critical habitat component for the fountain darter in the Comal system. Under extreme low flow conditions, temperature of the lake and stream reaches are most impacted because of slow circulation and water clarity. Since extreme low flow conditions are anticipated to correspond with high summer temperatures, the worst-case condition is identified as high ambient air temperatures, coupled with clear skies and low spring flows. For this assessment, water clarity is assumed to be consistently good (clear) under all flow conditions and scenarios. As previously described, four checkpoint temperature ranges have been identified as critical to the fountain darter life cycle: at and above 77 to 79 (°F) there is reduction in fountain darter larval production; between 79 and 82 (°F) and above there is a reduction in egg production, and at approximately 91 (°F) and 94 (°F) larval and adult thermal death can be expected based on laboratory studies (Brandt et al. 1993, Bonner et al. 1998, McDonald et al. 2007). Model scenarios considering potential Old Channel/New Channel flow splits were evaluated to assess impacts to temperature (Section 5.2.2). Additionally, potential impact of the Old Channel ERPA was evaluated to determine whether the recirculation component will have a significant temperature impact (increase).

The original QUAL2E model developed by Dr. Hardy in the late 1990s was used as a basis for new modeling work. The overall spatial extents and model framework were preserved for the new model. However, revisions were made to the model geometry, parameters and boundary conditions to reflect the present status of the system. Following this extensive set of revisions, the new QUAL2E model was calibrated using real-time data collected during the low flow conditions exhibited during July 2009. Upon new model calibration, three variations of the QUAL2E model were used in this evaluation: (1) Landa Lake with New Channel model; (2) Old Channel model and (3) Landa Lake flow screens model. Additionally, a new Water quality Analysis and Simulation Program (WASP) model was developed specifically for this project to evaluate impacts to temperature caused by recirculating water within the Old Channel ERPA.

Table 8. ERPA Old Channel Recirculation measures, estimated costs

Infrastructure and Purchased Equipment

Description	Quantity	Unit	Unit Price	Total
Mobilization	1	LS	$5,000	$5,000
Clear and Grub	0.25	Ac	$5,000	$1,250
22" HDPE SDR 17 Pipe and Installation	740	LF	$80	$59,200
Pipe Manifold Structure	1	LS	$2,000	$2,000
12" Gate Valve	4	EA	$1,500	$6,000
24" Gate Valve	1	EA	$15,000	$15,000
12" 20-slot SS Well Screen, 20-ft Joint	2	EA	$2,500	$5,000
Screen Assembly	3	EA	$750	$2,250
6" PVC Pipe and Installation	300	LF	$30	$9,000
Revegetation	1200	SY	$1.50	$1,800
Electrical Service Line	500	LF	$65	$32,500
Subtotal				$139,000
Contingencies	20	%		$27,800
Total				**$167,000**

Rental Equipment

Description	Quantity	Unit	Unit Price	Total
100-hp Trailer-Mounted Pump with Noise Abatemen	9	Mo	$7,000	$63,000
12-in Flexible Suction Hose	150	LF/Mo	$6	$8,100
12-in Flexible Discharge Hose	60	LF/Mo	$2	$1,080
Total				**$72,200**
Per Month				**$24,100**

Fuel Cost (Diesel)

Description	Quantity	Unit	Unit Price	Total
Fuel (Diesel, 3.5 gph, 3 pumps, 3 months)	22680	Gal	$4	$79,380
Per Month				**$26,500**

Electric Power Cost

Description	Quantity	Unit	Unit Price	Total
Electricity	362410	kWh	$0.084	$30,400
Demand Charge (3 months)	168	kW	$3.75	$1,888
Total				**$32,300**
Per Month				**$10,800**

Total (Diesel)	**$280,000**
Total (Electricity)	**$272,000**
Operations Total Per Month (Diesel)	**$50,600**
Operations Total Per Month (Electricity)	**$34,900**

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It should be noted that Hardy (2011) presents an updated QUAL 2E water quality model, based on additional input modifications and adjustments to boundary conditions. As the results of our updated QUAL2E model and the subsequently revised Hardy (2011) QUAL2E model are nearly identical, we refer to Hardy (2011) for the detailed modeling evaluation of water temperature at low flows in Landa Lake and various Old / New Channel flow splits as opposed to repeat the methodology, calibration, and results section herein.

In summary, when total spring flow drops below approximately 100 cfs and Spring Runs 1 and 2 cease surface flow, temperature in the lake begins to increase. Temperature of receiving streams (Old Channel and New Channel), are impacted both by source water (lake water) temperature and ambient environmental conditions; however, because of the short distance from the lake to the habitat areas of interest, the lake temperature has a significant impact on stream temperatures. At 30 cfs total Comal springflow, diurnal variations in temperature are considerable, but even under the worst-case conditions modeled, night-time temperatures are often below all temperature checkpoint ranges. However, during day-time under typical sun and shade conditions, temperatures in Landa Lake, New Channel and Old Channel (lower portions of Reach 19 [Hardy 2011: Old Channel – Golf Course bridge to Elizabeth Street]) exceed checkpoint ranges for reduction in larval and egg production. Both models used indicate that diurnal temperature conditions are established as soon as flow levels become established; maximum temperatures for each scenario are typically reached after two days and do not continue to increase. A large factor in this relates to the spring source water temperature that remains constant across the entire range of conditions (74.3 °F [23.5°C] was assumed for all modeling scenarios). In the New Channel under flow management conditions where flow is completely cut off, fountain darter mortality temperatures are reached in one segment and temperature in all segments exceeds 90°F (30°C) during the day. As such, the flow-split management recommendations (discussed in Section 5.2.2) were made to maintain at least 10 cfs through the New Channel. The full set of updated temperature model runs can be found in Hardy (2011).

WASP modeling was conducted to specifically assess potential impacts in the Old Channel ERPA (Figure 32). It needs to be noted that the WASP model calibration uses our updated and calibrated QUAL2E results for boundary conditions and input into WASP. Hardy (2011) results were not available at the time of our analyses. As results for our updated QUAL2E model and the revised Hardy (2011) model are nearly identical, we are confident in using these results as input parameters to the WASP model for this feasibility report. However, because of the additional updates to the QUAL2E model (HARDY 2011), the feasibility report should be considered preliminary and additional WASP runs conducted based on the Hardy (2011) QUAL2E model during the permitting and environmental documentation phase of this project, should it move forward.

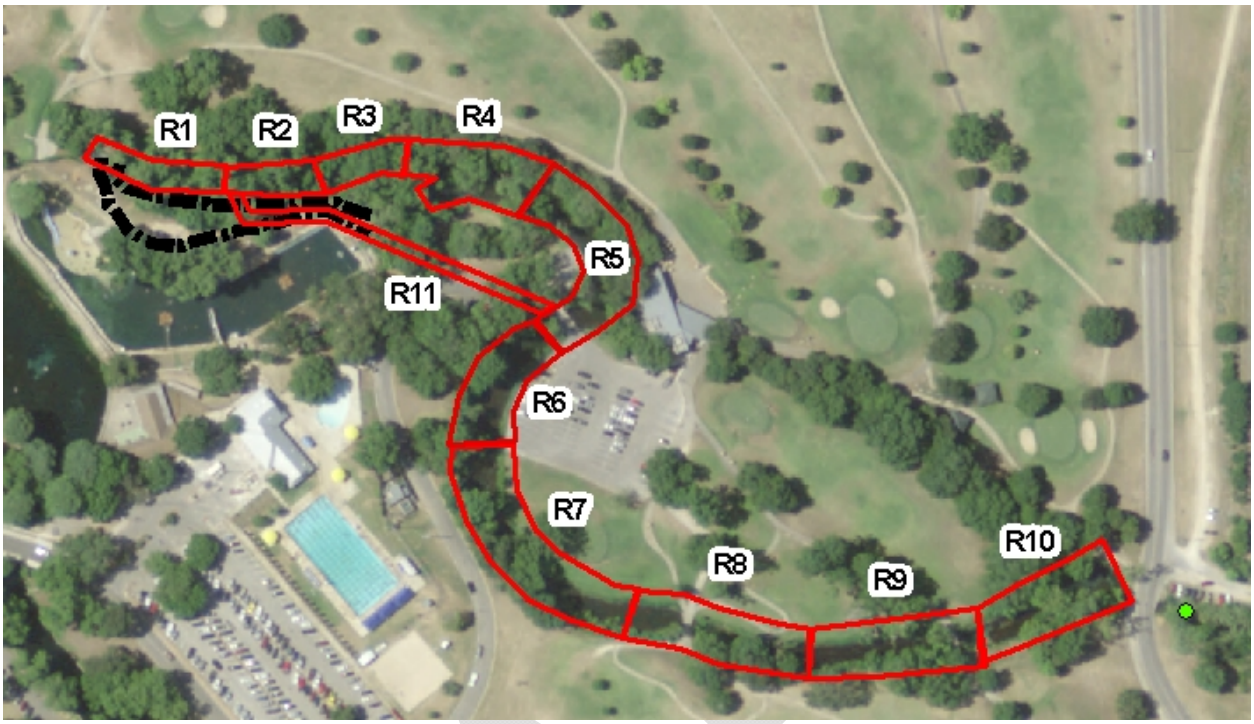

Figure 32. WASP segmentation, Old Channel ERPA recirculation

Figure 33 shows the WASP water temperature model results for July 2009 worst case ambient air temperature modeled conditions. Landa Lake maximum (80.6 °F) input temperatures were used based on QUAL2E results. As evident in Figure 33, diurnal fluctuations in water temperature are evident and range between approximately 76 and 81 °F (similar to shown in Figure 12). The purple line in Figure 33 represents when the recirculation pump was turned on (July 10) in the model with the full 20 cfs being recirculated at that time. Figure 33 indicates that because of the continuous input of 20 cfs from Landa Lake, recirculating 20 cfs for a total Old Channel flow of 40 cfs through the ERPA does not measurably increase water temperatures in this reach (Figure 33).

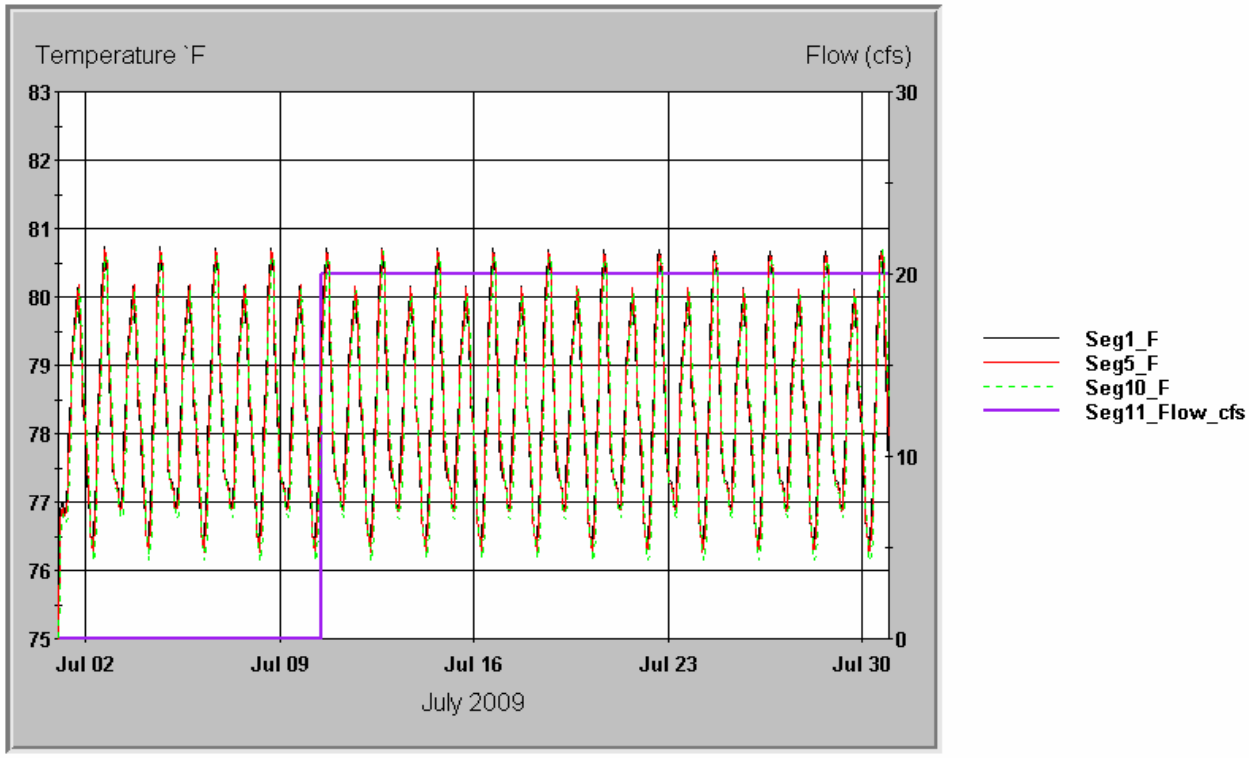

Figure 33. WASP temperature model results for the Old Channel ERPA recirculation. Purple line represents when 20 cfs recirculation was started (July 10) in model simulation.

5.2.5.2 *Old Channel proposed permanent experimentation channel*

A key component of the proposed Old Channel ERPA is the incorporation of a permanent area to use for applied research. Applied research specifically considered in the development of this conceptual design is discussed in Section 5.3. The proposed experimentation area consists of two parallel channels, constructed in an area just below Landa Lake and adjacent to the existing Old Channel (Figure 26). The purpose of the constructed research channel is to provide the ability to experiment with flow conditions to evaluate potential impacts to endangered species and their habitats.

The constructed research channel is envisioned as two permanent channels, each approximately 13-foot wide and 230 feet long, constructed parallel to the Old Channel (Figure 34). The southern (right) bank of the diversion channel runs alongside an existing low concrete wall adjacent to the swimming pool. For construction of the channel, an engineered segmental masonry unit retaining structure that varies in height from 3 to 7 feet is proposed to be constructed 5 feet north of the existing concrete wall with a shorter retaining structure proposed as the northern bank of the channel (Figure 35). The existing and proposed topography of the area with the diversion channels will necessitate some cut and fill (Figure 36).

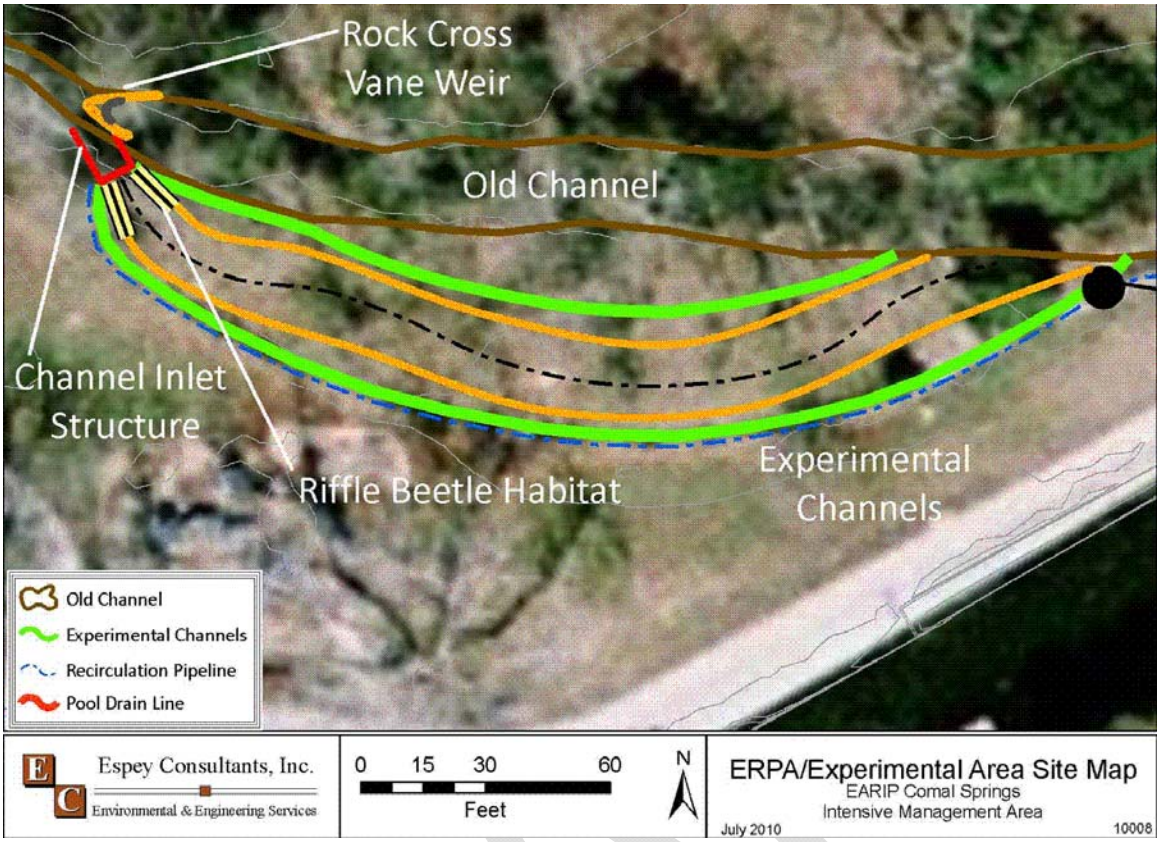

Figure 34. Old Channel ERPA and experimental channels, aerial photo

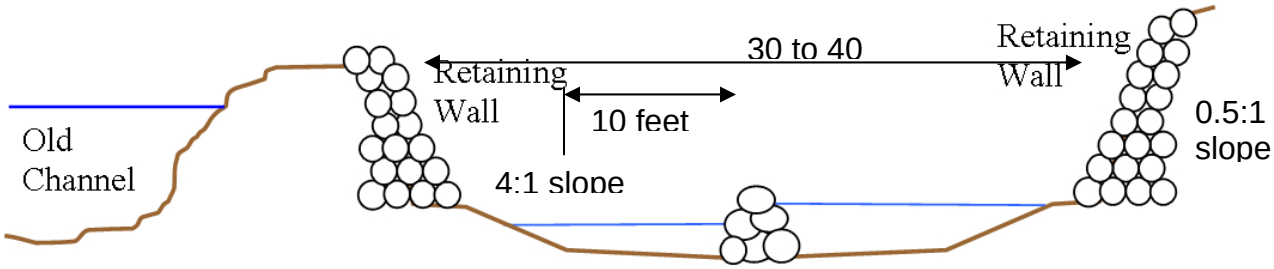

Figure 35. Typical Experimental Channel Cross-section

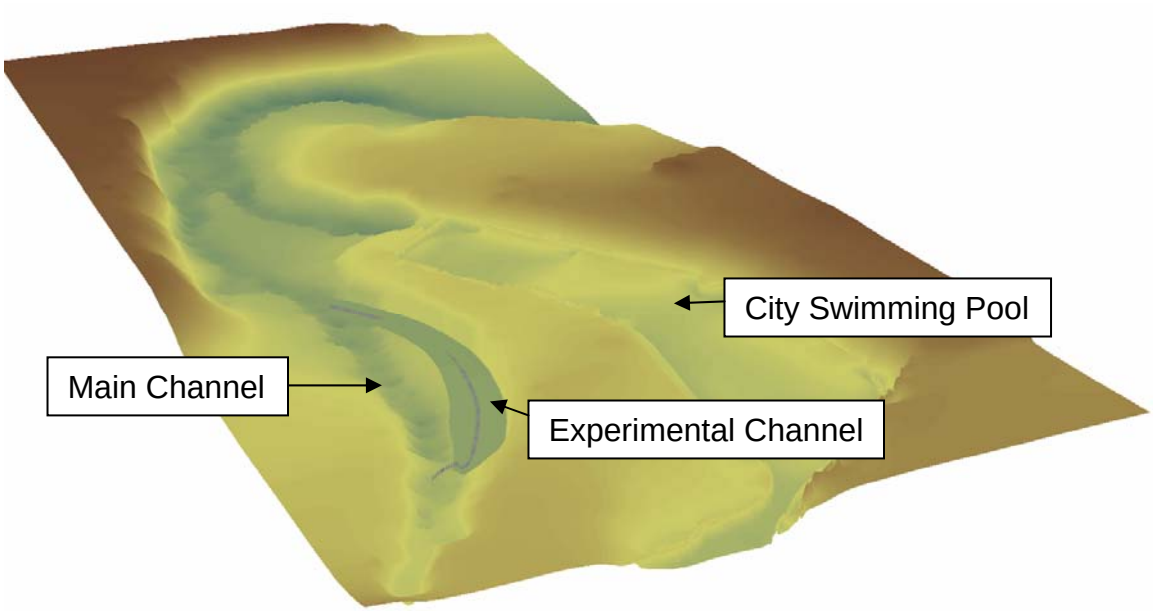

Figure 36. Old channel topographic scene, with experimental channels

Figure 37 shows the approximate location of the experimental channel on recent aerial photography. There has been considerable discussion regarding the aesthetics of the proposed channel. It needs to be clear that the proposed area is tucked between the existing retaining wall from the swimming pool that has a chain link fence on top of it and the actual river channel itself. The location is currently wooded with understory vegetation and not visible from the Golf Course road. The area would only be visible from within the swimming pool area and from the Golf Course looking across the existing Old Channel. The experimental channel would be designed considering aesthetics with boulder formed retaining structures and natural substrates. Coupled with an educational kiosk within the swimming pool area to explain the purpose of the experimental channel, endangered species protected, and applied research being conducted, we believe this would be a very positive upgrade to the current land use in this area.

The experimental channel will be unlined as the point is to use natural substrate and vegetation features to mimic the preferred habitat of the fountain darter. These features will serve to increase the channel roughness and limit flow velocities. A Manning's n value for the channels of 0.045 for a winding sand or gravel channel with vegetation is an assumed roughness value; a slope of 0.0011 is consistent with the energy slope of the water in the Old Channel just upstream of the golf course bridge. This slope is anticipated to provide sufficient flexibility to incorporate riffles and runs and pools into the experimental channel, but should be further evaluated before final design is completed. The slopes, depths of flow, and velocities for a range of discharges are given in

Table 9 assuming channel geometry similar to that shown in (Figure 35).

Figure 37. Proposed Old Channel Experimental Channel Location

Table 9. Old channel experimental channels, hydraulic design parameters

Slope	Q (cfs)	Average Velocity (fps)	Average Depth (ft)
0.0005	10	0.7	1.0
0.0005	20	0.9	1.4
0.0011	**5**	**0.7**	**0.56**
0.0011	**10**	**0.9**	**0.81**
0.0011	**20**	**1.2**	**1.17**
0.0011	**35**	**1.4**	**1.55**
0.0022	10	1.2	0.68
0.0022	20	1.5	0.98

The northern channel will be approximately 210 ft long along the channel centerline while the southern channel will be about 260 ft long. The downstream terminus of each channel will be at the same elevation as the base of the Old Channel to allow the channels to act as an extension of the Old Channel habitat. The approximate profile of the channels is shown in Figure 38. At the greatest depth, the channel bottom is approximately 7 feet below the existing ground surface elevation and typical excavation is between 2 and 5 feet below existing natural ground level. Because of the limited distance available between the Old Channel and the pool, the use of boulder formed retaining structures bordering the channels will be necessary.

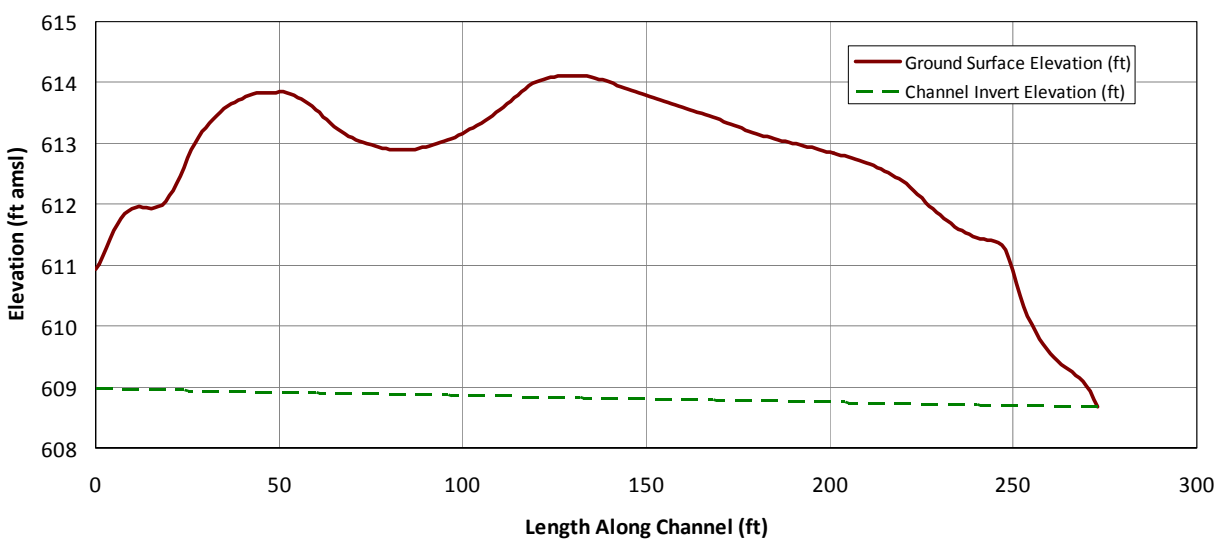

Figure 38. Proposed profile of experimental channel

The channel slope of the experimental channel is proposed to be significantly less than in the adjacent section of Old Channel; therefore, a drop inlet structure will be required at the head of the channels as previously described. A rock cross-vane weir (Figure 27) is proposed to provide head to deliver water to the head gates of the diversion channels (Figure 39 and Figure 40) and to

control impact to the existing Old Channel. Near the upstream end of the experimental channels and the control structure, constructed riffle beetle habitats are proposed. These consist of a pipe buried beneath native rock or gravel substrate similar to substrate where beetles are found; the pipe will percolate or upwell water through the rocks to mimic flow of water through natural habitats (Figure 39 and Figure 40).

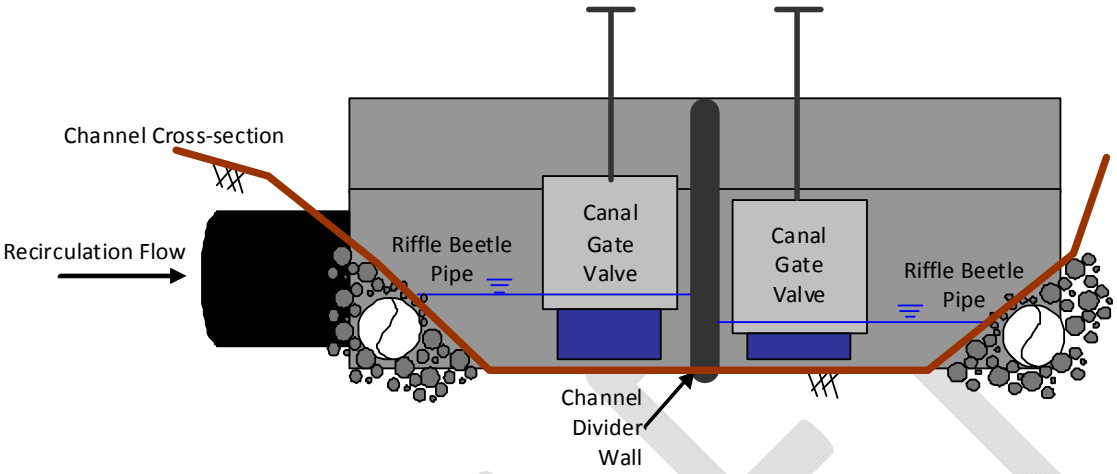

Figure 39. Headgate Structure-Section

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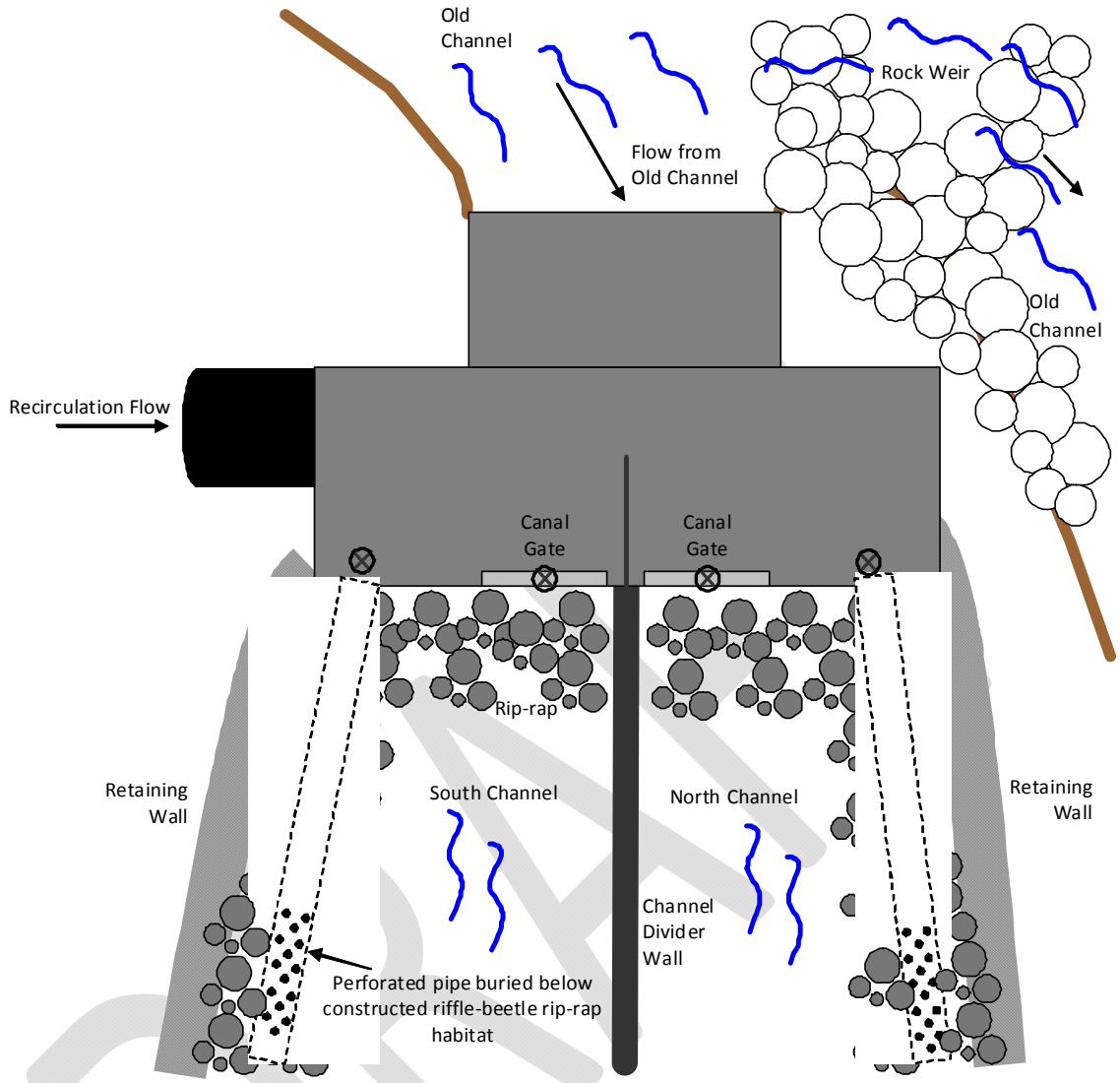

Figure 40. Headgate Structure-Plan

The cost to construct the proposed permanent experimental diversion channel, including the control structure and rough in-channel grading but excluding vegetation and habitat final in-channel grading, is estimated at approximately $265,000 (Table 10).

Table 10. Experimental channel estimated construction cost

Description	Unit	Quantity	Unit Price	Total
Mobilization	1	LS	$15,000	$15,000
Clear and Grub	0.50	Ac	$5,000	$2,500
Excavation and Grading	1300	CY	$15	$19,500
Segmental Masonry Unit Wall	3100	SF	$25	$77,500
Rock Vane Weir	50	LF	$240	$12,000
Headgate Structure	1	LS	$15,000	$15,000
Riffle beetle upwelling habitat	2	LS	$2,000	$4,000
Channel Lining Gravel/Rip Rap	170	CY	$100	$17,000
Channel divider wall	26	CY	$1,000	$25,556
Surveying	1	LS	$5,000	$5,000
Channel Construction	520	LF	$50	$26,000
Subtotal				$219,056
Contingencies	20	%		$43,811
Total				**$262,867**

Alternate configurations of the experimental channel or the recirculation system could provide similar benefits. These alternate configurations were not discussed in detail because of additional cost of constraints; however, these could be investigated as part of the environmental documentation and final design phase of the project. The proposed experimental channel configuration is constrained by existing walls that outline the perimeter of the spring-fed swimming pool. If some of the pool area could be re-purposed and dedicated to the experimental channel area, the channels could be augmented to be wider. More sinuous, wider channels would allow more flexibility in design of natural habitat. Widening the existing configuration by approximately 10 to 15 feet would improve the design presented in this report.

The proposed recirculation system is based upon temporarily installing rented pumps. Aesthetics, noise and security were among some concerns of stakeholders, particularly the City of New Braunfels. Additional options related to purchase and installation of permanent pumps in a dedicated structure could be investigated, as could installation of permanent intake structures. Another option is to construct a permanent housing for temporary rented pumps; this may address some concerns while not necessitating a long-term maintenance program for infrequently-used, expensive pumping equipment.

5.2.5.3 *Old Channel ERPA Permitting*

Permitting requirements will depend on the exact component configuration, but it is anticipated that an evaluation of any in-channel structure (e.g., the old channel ERPA) would require flood evaluation. This would require FEMA flood permitting with the need for updated flood maps through the FEMA process.

It is also anticipated that a water rights permit would be required through TCEQ. On May 21, 2010, the project team met with Chris Loft (TCEQ water rights permitting section manager). Mr. Loft indicated that a bed and banks authorization would need to be granted for diverting water

from the old channel, as proposed for the ERPA recirculation option. Mr. Loft recommended a pre-application meeting with TCEQ staff in the permitting, environmental and water quality sections. Additional staff could be assembled from the 401 certification group at the same time. We recommend that such a meeting be scheduled if this project moves past the feasibility stage and as details are further developed. Additionally, should the project move forward, a permittee would need to be identified and evaporation losses would need to be identified as well as operational aspects and reliability. An existing water right holder would need to contract water to cover the evaporation losses since the Comal River system is currently fully appropriated.

The amount of water to be impounded by this project within the recirculation system is anticipated to be less than 1 acre-foot. That volume could be achieved during higher flow (e.g., 60 cfs total Comal spring flow) conditions by diverting and recirculating an increasing amount of water over an extended period of time; for example, the diversion rate could be increased from 0 to 4 cfs over the course of 24 hours, thus achieving a full 20 cfs over the course of 5 days. Since the recirculation system will be operating, impact on flow at downstream user diversion points could be minimized to less than 1 cfs on any given day.

5.2.5.4 *Old Channel Reach 2 ERPA*

There is also the potential for high quality fountain darter habitat present in Reach 2 (Old Channel within Schlitterbahn loop, Figure 10) of the Old Channel which makes it favorable for ERPA consideration should the Reach 1 site not be acceptable to stakeholders. However, this area is not favorable for providing riffle beetle habitat because of the distance from typical beetle habitats near Landa Lake. Additionally, this area exhibits low hydraulic gradient (0.0001 ft/ft) which makes it less flexible for experimentation compared to Reach 1 near Landa Lake. To control flow and experiment within this reach, pumps would be required and this would considerably increase the cost associated with this option. The proposed Old Channel experimental channel (Reach 1) is proposed to have a slope of 0.0011. Although, the Reach 1 location is remotely located and not visible from the Golf Course road, the Reach 2 location is even more remote being tucked in behind the railroad tressle in an area used primarily as a parking lot for Schlitterbahn employees when the park is in operation. One idea for future consideration might be discussions with the City of New Braunfels and Schlitterbahn regarding an educational facility to be constructed in cooperation with a research channel within this reach.

5.2.6 Landa Lake – Temporary flow screens

A primary concern expressed by the EARIP SSC has been the potential for increased temperature conditions in Landa Lake and subsequently to downstream locations. Hardy (2011) describes the temperature modeling conducted to assess this concern. Because of the original concern, we evaluated whether alterations of flow patterns within Landa Lake would be successful in reducing water temperatures during extreme drought conditions. One option is to cut off shallow areas entirely, restricting water only to deeper areas within the lake. Another option investigated in this project is to install temporary baffles or screens to direct flow to deeper areas (Figure 41). This was proposed to reduce retention time and keep lake temperatures low, particularly in areas where water is diverted into the Old Channel. Temporary, quickly-deployable structures are proposed in lieu of permanent structures. A survey was completed to identify potential products/technologies that would be suitable and cost-effective. From this survey, cost estimates are developed for two candidate technologies, water-inflatable cofferdams Figure 42) and floating baffles (Figure 43).

The concept of temporary structures allows for some limited water exchange from one side of the screen to the other to prevent complete dead zones on the non-flow side of the baffles. Exchange may be either through holes in the screen, by the material itself or by gaps between the buoys on top or weights at bottom. Exchange across the screen would need to be minimized to the avoid short-circuiting that would make ineffective their main purpose to direct flow.

Water-inflatable cofferdams appear to be the well-suited for deployment in Landa Lake, are simple and quick to install, and are low-cost. Aqua Dam, Inc. (www.waterstructures.com) inflatable dams are shown on a water-inflatable dam deployed in an Idaho stream to limit the channel width to increase the depth of flow and allow salmon passage over a riffle (Figure 42). Water-inflatable cofferdams offer the following benefits: durability (can be reused multiple times), ease of installation and removal, no permanent structures required and safe. Depending on the depth of water for the installation, a crew of 4 to 6 can install a 100-foot dam in less than one hour. The cost of the inflatable dams is estimated assuming a water surface elevation of 620 ft in Landa Lake. The total cost of the inflatable dams is approximately $126,000 (Table 11). The estimated cost to install the dams is $11,200, and the cost of removal is $13,200 (Table 11).

An alternative to the water-inflatable dams is the use of custom-manufactured floating baffles (Figure 43). The use of floating baffles would require installation of permanent anchor structures at the endpoints of each baffle along the shoreline and in the lake. However, once the anchor points are installed, deployment and removal of the floating baffles would be very fast and straight forward. Unit cost for 3 ft to 6 ft baffle curtains constructed of 45 mil reinforced polypropylene is $36 per linear foot (provided by Layfield Environmental Systems Corporation). The estimated cost for a floating baffle system for Landa Lake, including installation of permanent anchor points along the shore and in the lake, is approximately $67,000 (Table 12). The cost to deploy the baffles (included in the total above) is about $4,600 (Table 12).

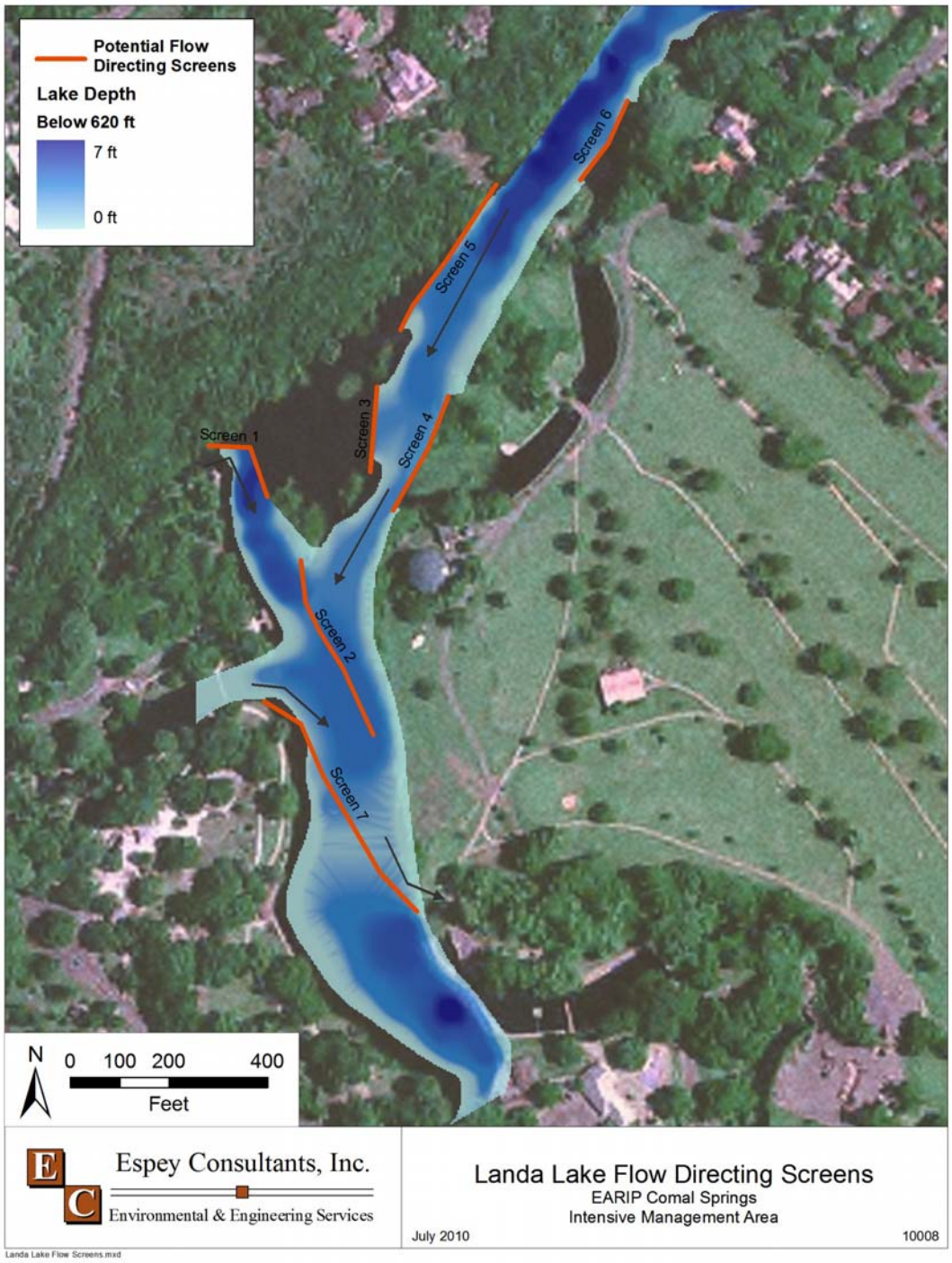

Figure 41. Landa Lake flow screens

Figure 42. Aqua Dam inflatable cofferdams

Table 11. Inflatable cofferdam estimated costs

Description	Unit	Quantity	Unit Price	Total	
Inflatable Dams	1	LS	$75,750	$75,750	
Miscellaneous Equipment	1	LS	$2,500	$2,500	ropes, waders, knives, winches
Portable Pumps (One Week Rental)	2	Ea	$1,000	$2,000	
Installation Labor	112	Hr	$100	$11,200	assume 1-hour per 100-ft
Removal Labor	132	Hr	$100	$13,200	includes 20 additional hours for re-rolling dams
Subtotal				$104,650	
Contingencies	20	%		$20,930	
Total				**$126,000**	

Inflatable Dams and Labor Quantity Estimates

Line	Depth Range	Design Depth (in)	Length (ft)	Dam (ft)	Unit Cost ($/ft)	Cost	Crew Number	Time (hr)	Total Time (hr)
1	0-6	72	50	8	125	$6,250	6	4	24
2	0.9-4.25	51	120	6	250	$37,500	5	5	25
3	0-3	36	45	4	50	$2,500	4	3	12
4	1-3	36	80	4	50	$5,000	4	3	12
5	0-3.25	39	90	5	70	$7,000	5	3	15
6	0-3	36	60	4	50	$5,000	4	3	12
7	0-3	36	135	4	50	$7,500	4	3	12
Subtotal						$70,750			112
Shipping						$5,000			
Dams Total						**$75,750**			

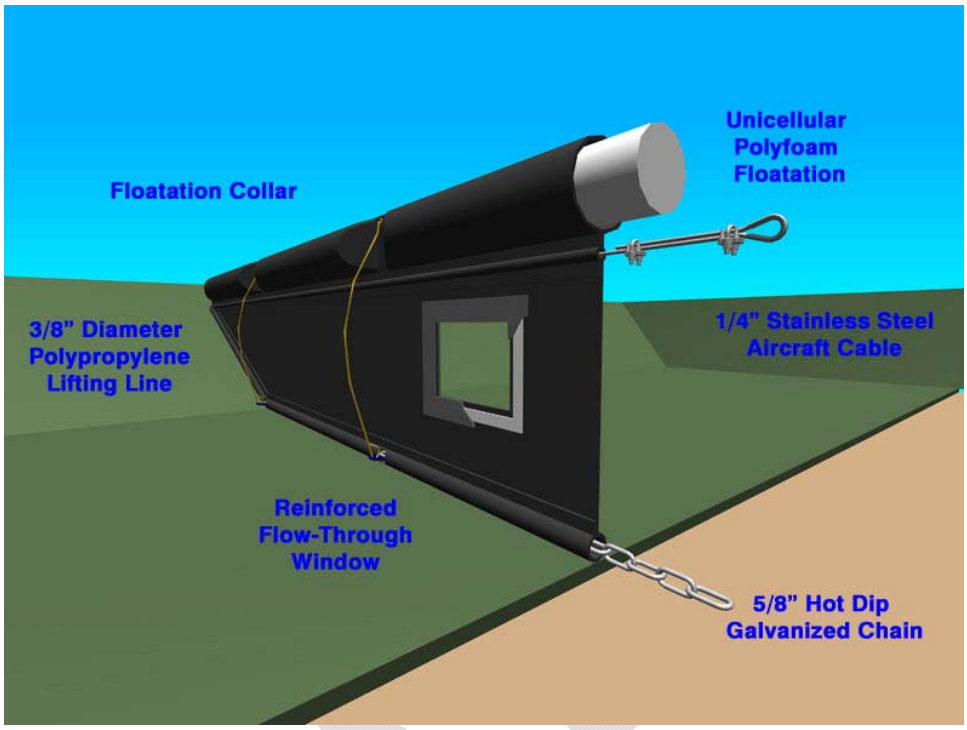

Figure 43. Environetics floating baffles (flow screens)

Table 12. Flow screen (baffle) estimated costs

Description	Unit	Quantity	Unit Price	Total	
Floating Baffles	1	LS	$26,600	$26,600	
Miscellaneous Equipment	1	LS	$1,500	$1,500	waders, winches, etc.
Shore Anchorage Points	3	Ea	$2,500	$7,500	assume 6" steel bollard buried at least 48", set in concre
Lake Anchorage Points	11	Ea	$1,000	$11,000	
Baffle Installation Labor	46	Hr	$100	$4,600	assume 2-hours per baffle
Baffle Removal Labor	46	Hr	$100	$4,600	same as installation
Subtotal				$55,800	
Contingencies	20	%		$11,160	
Total				**$67,000**	

Floating Baffles and Labor Quantity Estimates

Line	Depth Range (ft)	Design Depth (in)	Length (ft)	Unit Cost ($/ft)	Cost	Crew Number	Time (hr)	Total Time (hr)
1	0-6	72	50	36	$1,800	3	2	6
2	0.9-4.25	51	120	36	$5,400	4	2	8
3	0-3	36	45	36	$1,800	3	2	6
4	1-3	36	80	36	$3,600	3	2	6
5	0-3.25	39	90	36	$3,600	3	2	6
6	0-3	36	60	36	$3,600	3	2	6
7	0-3	36	135	36	$5,400	4	2	8
Subtotal					$25,200			46
Shipping					$1,400			
Baffles Total					$26,600			

The flow screens were then evaluated for potential benefits from the partitioning of Landa Lake (Figure 44). The original QUAL2E model with modifications noted in Section 5.2.5.1 was calibrated to July 2009 conditions. Air temperature during this period

was very hot (100 to 104 degrees), conditions were sunny, and spring flow conditions are somewhat low (160 cfs).

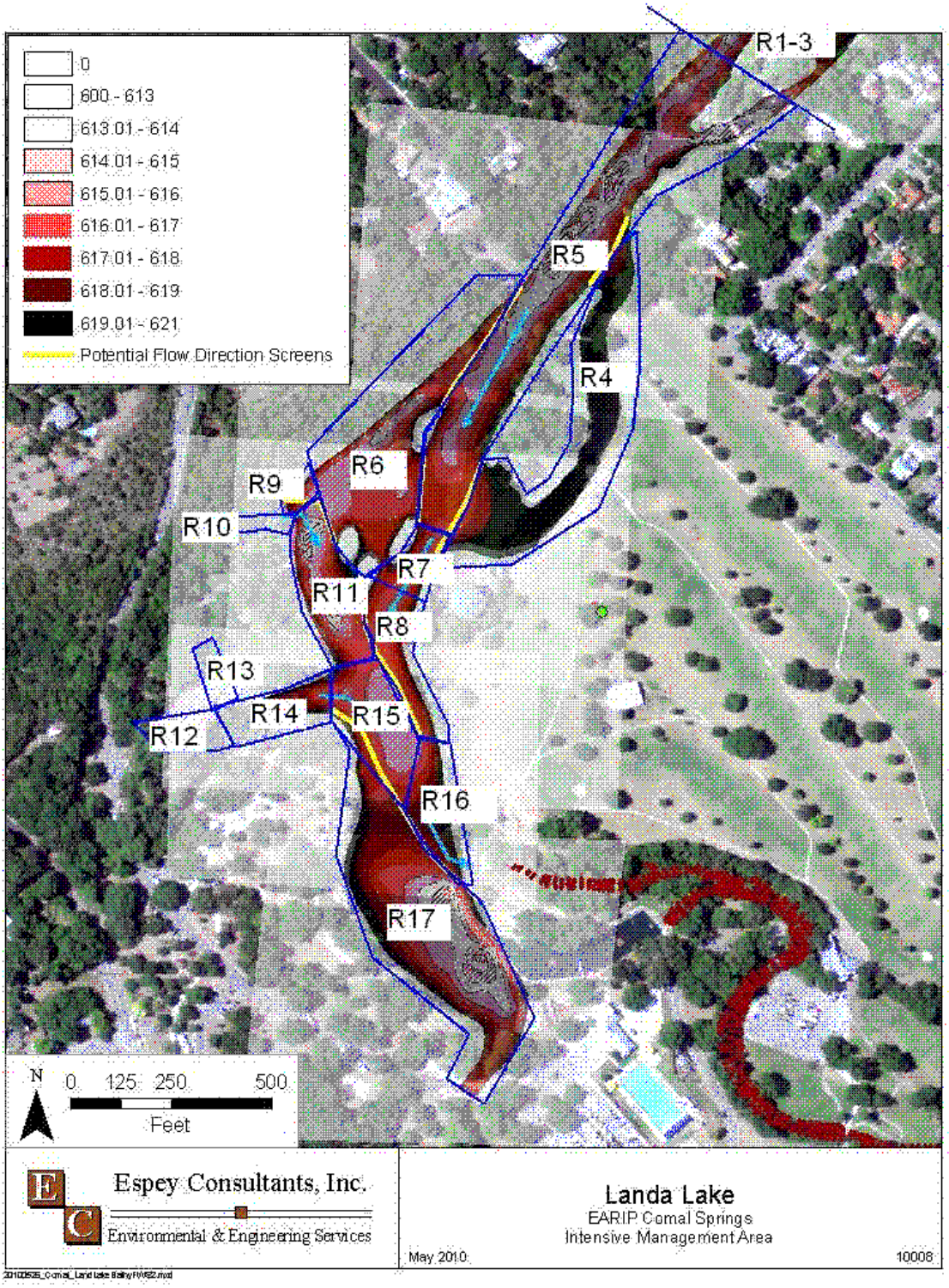

Figure 44. QUAL2E segmentation, Landa Lake with flow screens

Temperature modeling shows that implementing the flow direction screen strategy within the lake does have a considerable impact on lake temperature with limited effect downstream. The reduction in residence time resulting from partitioning of the lake reduces maximum day-time lake temperatures in some areas by 6° to 7°F; however, the partitioning also creates lake areas with limited circulation and results in temperatures increases of up to 10°F (91°F in some areas). Lake temperature reductions resulting from installation of flow screens do not significantly impact temperature within the Old Channel.

Deployment of temporary flow baffles or screens within Landa Lake to direct flow away from shallow areas was hypothesized to reduce temperature within the lake and flowing into the Old Channel. It appears that positive effects occur in protected portions of the Lake, but are not extended downstream to the Old Channel. No significant improvements to temperature in the Old Channel coupled with the potential negative impacts within portions of the lake makes this strategy unfeasible in our opinion. As such, we do not recommend this alternative for further consideration.

5.3 APPLIED RESEARCH

Perhaps the most valuable component of the ERPA concept over the lifespan of the HCP (and definitely during the first phase) will be the applied research that can be conducted to better understand the ecological dynamics of the Comal system, particularly under low flow conditions.

5.3.1 Old Channel ERPA experimental channel

The experimental channel proposed in the Old Channel ERPA was specifically designed to address the key unknowns repeatedly discussed by the EARIP SSC and also reiterated by Hardy (2011). Based on the comments received to date, and several misunderstandings about the experimental channel, we think it prudent to first describe what it IS and what it is NOT (Table 13).

Table 13. Old Channel ERPA Experimental Channel Description

Old Channel ERPA Experimental Channel Description	
IS	**Is NOT**
for Applied Research to guide HCP phase 2 development and the adaptive management plan.	*to recirculate water through to keep endangered species alive during the drought.* Note: Maintaining a viable population of fountain darters during drought is the purpose of optimizing habitat conditions in the ERPA reach of the MAIN channel of the existing river at all times.
a small, constructed channel split in two to provide an experimental control and is proposed to be constructed in a remote area	*some giant structure located along a visible roadway*
constructed with boulder designed walls and earthen bottom	*a concrete lined ditch*
designed to tie back into the main channel in a non-intrusive manner limiting the potential for any downstream erosional impacts or channel modification.	*in a highly erodible area or frequently disturbed area from flooding, as it is located immediately below the dam.* Note: in the 10 year Variable Flow study, only the June 2010 flood was significant enough to cause major damage in this stretch of river.

Several comments have also been received questioning the need to conduct field experiments, with the argument that all necessary studies could be conducted in a laboratory (i.e. the San Marcos National Fish Hatchery and Technology Center [NFH&TC]). Other comments agree that on-site is the appropriate place to conduct the studies but would prefer to conduct any research in the Upper Spring Run reach, Landa Lake or main channel of the river as opposed to an experimental channel. Table 14 provides the key studies envisioned for the Old Channel ERPA based on unknowns identified by researchers over the years and repeatedly discussed by the EARIP SSC and EARIP steering committee during HCP development. The table compares which studies could be conducted in the laboratory and which ones could be conducted in the main lake or river portions of the Comal system.

Upon review of Table 14, it is evident that the key unknowns simply can't be addressed in a laboratory setting. It would require a living stream to be created that essentially simulates the conditions of the natural environment. This would require an enormous effort to create, and amount of water and electricity to maintain and still would likely fall short relative to simulating conditions field conditions. For instance, stakeholders have commented that the NFH&TC has wells in the Edwards so the water would be identical. The wells statement is correct, but the water in the natural environment (other than at the immediate spring openings) is different both chemically and biologically than direct aquifer water. The chemical and biological processes that are undergone in Landa Lake clearly change the make-up of the water before entering the Old Channel.

Table 14. Applied Research Components and Facility/Area Comparison

Applied Research Components - Comal Springs	Facility or Area				
	Laboratory	Upper Spring Run Reach	Landa Lake	Within Old Channel	ERPA Experimental Channel
RESTORATION / HABITAT CREATION					
Evaluate transplant methodologies for various types of native aquatic vegetation	No	Not Recommended - frequent disturbance	Yes	Yes	Yes
Evaluate success of transplants over extended time period	No	Not Recommended - frequent disturbance	Yes	Yes	Yes
Track maintenance required to keep exotic species from re-establishing	No	Not Recommended - frequent disturbance	Yes	Yes	Yes
Channel manipulation - depth, width, slope, substrate, cutbanks, woody debris, etc.	No	Not Recommended - frequent disturbance	No	Yes	Yes
LOW-FLOW DURATIONAL RESEARCH					
Evaluate potential aquatic vegetation decay (both surface [stem and leaves] and subsurface [roots] plant biomass.	Possibly in a living stream, but very difficult to simulate Landa Lake inflow	Yes - but only possible when total flow is near or below 150 cfs.	Yes - but only possible when total flow is near or below 60 cfs	Yes at all flows - but a flow by-pass would be necessary and you would need to allow take of fountain darter habitat.[1]	Yes at all flows - "take"[2] only in research channel - not in main channel
Evaluate potential changes in physicochemical parameters (i.e., water temperature, dissolved oxygen, carbon dioxide, etc.)	see above	same as above	same as above	Again, you would need to allow parameters to exceed conditions suitable for fountain darters in the main channel to test effects.[1]	same as above
Low-flow effects on fountain darter reproduction	No	same as above	same as above	same as above	Yes
Low-flow effects on fountain darter movement	No	same as above	same as above	same as above	Yes
Low-flow effects on fountain darter clumping and potential predation or competition	No	same as above	same as above	same as above	Yes
Low-flow effects on fountain darter population size	No	same as above	same as above	same as above	Yes
Low-flow effects of gill parasites on fountain darters	No	same as above	same as above	same as above	Yes

[1] - this option is also possible with only manipulation of existing culverts. However, under this option, take of fountain darter habitat would extend to a larger portion of the Old Channel. If you do not allow take of habitat, you would not reach the point of learning about decaying and dying aquatic vegetation.

[2] - Take is put in " " in the ERPA column because this is created habitat and may not be considered actual take of fountain darter habitat.

Table 14. continued Applied Research Components and Facility/Area Comparison

Applied Research Components - Comal Springs	Facility or Area				
	Laboratory	Upper Spring Run Reach	Landa Lake	Within Old Channel	ERPA Experimental Channel
GENERAL					
Effect of Snail Removal on parasite control	No	Yes	Yes	Yes	Yes
COMAL SPRINGS RIFFLE BEETLE					
Establish sustainable riffle beetle population in upwelling and spring run habitats in the upper portion of the old channel	No	No	No	Potentially with channel manipulation, unproven	Potentially, but unproven
IF CSRB successfully established in Old Channel					
Effect of CSRB movement with flow	No	No	No	Potentially with channel manipulation and flow by-pass	Yes, the CSRB area would be designed specifically to test these components.
Low-flow effect on CSRB movement	No	No	No	same as above	same as above
Low-flow effect on CSRB population size	No	No	No	same as above	same as above
FLOW-RELATED COMPONENTS DESCRIBED ABOVE					
Track condition of the system entering into and recovery following the low-flow condition	No	Yes	Yes	Yes	Yes
Evaluate repeated durations within a relatively short time-period (a few years).	No	No	No	Yes, with take in the main channel	Yes with "take"[2] only in the research channel
Evaluate cumulative impacts from repeat low-flow conditions.	No	No	No	Yes, with take in the main channel	Yes with "take"[2] only in the research channel

[2] - Take is put in " " in the ERPA column because this is created habitat and may not be considered actual take of fountain darter habitat.

Secondly, the Upper Spring Run reach and Landa Lake would make good research areas for most components were there not a few fatal flaws. The first is there is no flow control for either area and, thus the researcher would need to wait for the conditions to happen naturally. This would require flows near or below 150 cfs in the Upper Spring Run reach and near or below 60 cfs to be meaningful in Landa Lake. For example, 150 cfs has only been seen twice in the past decade for a short period of time and 60 cfs has not been observed since the early 1980's. Thus, experiments designed for evaluation of durational low-flow conditions are not feasible in these locations. Additionally, the Upper Spring Run reach can be drastically affected by even modest flooding in Blieders Creek which has happened numerous times over the past decade.

The main portion of the Old Channel has also been mentioned as a "better" research area and was considered for inclusion early on in the ERPA design. As discussed previously, flows within the Old Channel have the ability to be controlled via the culverts at Landa Lake at this time. However, without some type of flow-bypass around the Old Channel ERPA (in this example – simply restored and maintained habitat in the ERPA) optimal habitat would not be maintainable during higher than average or lower than average conditions as discussed in Section 5.2.5. Additionally, without the bypass, any flow manipulations to the Old Channel for experimental purposes would affect the entire Old Channel and not just the ERPA making this alternative undesirable. Should a flow-bypass be constructed, experiments could be conducted within the main channel ERPA. However, this also poses several practical issues for consideration. For instance, in order to test the effects/impacts of low flow (extended and repeated durations), experiments in the main channel would need to allow habitat to degrade to beyond the condition that would be considered "take" for the fountain darter. If you only experimented to the point of initial impact and not beyond, there is no way to quantify the full effect these types of events would have. This issue is highlighted here because the same entities recommending research in the main channel have also publicly stated that no "take" of fountain darters or habitat should be allowed in existing habitats. This severely limits the utility of applied research in the main system and essentially turns this option into a monitoring effort that can go slightly beyond the bounds of what would have occurred anyway.

Should a flow-bypass be installed and take be allowed in the main channel, meaningful experiments could be conducted. However, this again is not without some drawbacks. The first drawback is that experimenting in the area that is supposed to be protected at all times, contradicts the point of maintaining optimal fountain darter habitat in the ERPA at all times. As such, experiments would likely only be feasible when flow conditions are average or above, and as soon as drought is predicted (likely some established flow trigger), this area would need to be restored to optimal conditions regardless of what stage the experiment was in. In our opinion, recreating optimal habitat prior to each drought is not considered equivalent in protection of the species as maintaining optimal habitat at all times. Additionally, another drawback is that the main channel is just one channel. So, unless one was to go in and physically create separate channels (either temporarily or permanently), or deem an area downstream in the Old Channel a suitable

reference point, you would only have one data point. It is very difficult to tease out potential impacts when you have no reference or control.

In summary, we recommend an experimental channel with a built-in reference over attempting to conduct applied research within the main channel or attempting to develop some elaborate, more expensive scheme in an off-site laboratory. We also recommend that monitoring be conducted in the main ERPA channel, as well as in the Upper Spring Run reach and Landa Lake so that when lower flow conditions do occur, there is background data to compare against. Additionally, we recommend specifically targeted research within the latter two areas, should total Comal springflow fall to near 150 cfs (Upper Spring Run reach) or 60 cfs (Landa Lake).

5.3.2 Spring Run 3 Riffle Beetle Permanent Observation Area

A second consideration for applied research would be a permanent observation well constructed near the edge of Spring Run 3 to enable sub-surface observation of riffle beetle habitat and movements. One current hypothesis is that as surface springs cease emitting, riffle beetles move to habitat areas deeper underground. This concept is supported by a laboratory study (BIO-WEST 2002c) but has yet to be documented in the wild. The proposed well would be approximately 15 feet deep from ground level, to allow for observation below elevation 615 feet and for screening (if necessary) down to 612 feet. A mobile camera would be inserted or permanently installed to monitor riffle beetle activity. The monitoring activity would be used to assess how riffle beetles utilize karst habitat and whether drought management measures near the surface (e.g., recirculation and diffusers) are effective or necessary.

The well could be 8-inch diameter uncased to allow observation and migration of beetles along the rock face. A 6 inch well head with lock and water-tight seal should be installed with annular grout to promote security and minimize contamination. An alternate but less preferable method could be to make the casing of this observation well plexiglass to enable viewing of the beetles. Native gravel similar to that found in adjacent Spring Run 3 riffle beetle habitats would be used as necessary in the annular area between the casing and existing rock. Perforated casing or screen should be installed at a level deeper than anticipated habitat viewing; the screen may be useful for cycling water through the annular gravel for cleaning following installation or for flushing sediment accumulations in viewing area.

Investigation of suitable camera types and lights would be necessary to ensure viewing of beetles is possible across a range of conditions. Additionally, permitting requirements of this observation well with TCEQ, EAA, and USFWS would need further discussion.

A preliminary cost estimate is $7,000 to drill a 25 foot deep 8” well in rock using a rotary drill, including mobilization, site access with a truck-mounted rig (e.g., F550 dually truck with derrick) and completion as described above. There would be an additional $5,000 to $10,000 upfront cost for cameras evaluation, selection, and placement.

6.0 ALTERNATIVES FORMULATION AND EVALUATION

The project team evaluated the ERPA components discussed above to formulate alternatives for comparison in order to provide the EARIP with information for consideration in the HCP. The following alternatives are identified for further consideration and three of them contain a package of ERPA components that were deemed "feasible" for the Comal system based on analysis conducted for this study. Four alternatives (A, B, C, D) are presented for comparison, costing, and evaluation purposes fully understanding that there are a lot of additional combinations of ERPA components that could be packaged together or taken individually and considered by the EARIP. All four alternatives are first described and then evaluated for biological risk relative to the described EARIP flow regime. Again, this regime allows for a minimum daily total Comal springflow of 30 cfs (20 cfs Old Channel, 10 cfs New Channel) for a maximum of 6 months followed by 2-3 months of 80 cfs (50 cfs Old Channel, 30 cfs New Channel). Additionally, these low-flow events are assumed to be rare events with the main occurrence taking place during a repeat of conditions similar to the drought of record.

6.1 ALTERNATIVES

6.1.1 Alternative A - No action

The No Action alternative (A) considers moving forward according to Senate Bill 3 (SB3) with only existing management and monitoring activities currently in place. This alternative does not include any of the ERPA components discussed above or EARIP Comal restoration subcommittee proposed restoration/mitigation actions.

6.1.2 Alternative B - No ERPA structure

Alternative B includes all existing management and monitoring activities that are not superseded by the following ERPA components:

- re-establishment of native vegetation in Landa Lake and Old Channel,
- active flow-split management,
- expanded monitoring program for water quality conditions in Landa Lake relative to low-flow impacts to water temperature and dissolved oxygen, and
- a decaying vegetation removal program.

In addition to the ERPA components, the following EARIP Comal restoration subcommittee recommendations are also included.

- Control of harmful exotics
- Optimization of fountain darter habitat in the Old Channel of the Comal River. *Note: Although proposed by the subcommittee, we do not recommend habitat enhancement in the New Channel.*
- Evaluation and control of the gill parasite. *Note: This did not make the final list for the subcommittee but we recommend its inclusion.*

These above stated Comal restoration subcommittee recommendations are included in all of the following alternatives and thus, will serve as a background which is equal for all but the No Action alternative.

6.1.3 Alternative C - Old Channel ERPA (Temporary)

Alternative C includes all components of Alternative B, with the addition of the Old Channel ERPA. The Old Channel ERPA for this comparison includes the main channel ERPA with recirculation along with the proposed experimental channel described in Section 5.2.5. Configurations of this package that could be considered are as follows:

- Old Channel ERPA (with recirculation) – temporary infrastructure, including experimental channel. (*ALTERNATIVE C1*)
- Old Channel ERPA (with recirculation) – permanent infrastructure, including experimental channel. (*ALTERNATIVE C2*)
- The flow-by pass only option, with the rock vane weir moved downstream closer to the main channel ERPA.
- The flow-by pass and recirculation option, with the rock vane weir moved downstream closer to the main channel ERPA.
- The flow-by pass option, with the experimental channel; or
- Just the experimental channel alone.

For costing and comparison purposes, we selected C1 - Old Channel ERPA (with recirculation), temporary infrastructure and experimental channel as we feel this option package provides the components necessary to achieve the purpose of guiding phase 2 of the HCP development and adaptive management.

6.1.4 Alternative D - Old Channel ERPA (Permanent) Plus

Alternative D includes both Alternative C options (C1 and C2) and adds the Spring Run 3 connectivity component along with the Spring Run 3 observation well.

6.2 ANALYSIS

The initial step in the alternatives analysis was to conduct an evaluation of biological risk. This exercise examined what risk would be associated with the No Action alternative (A) relative to SB3 modeled flow regime with the other three alternatives (B, C, and D) evaluated against the EARIP flow regime as discussed throughout this report. Based on continuing feedback, we also looked at biological risk associated at 60 cfs and 80 cfs as minimums. Table 15 shows the biological risk assigned to each alternative resulting from this exercise.

Table 15. Biological Risk Evaluation

Alternative	Springflow Protection	BIOLOGICAL RISK[1,2]					
		30 CFS		60 CFS		80 CFS	
		Fountain Darter	CS Riffle Beetle	Fountain Darter	CS Riffle Beetle	Fountain Darter	CS Riffle Beetle
A - No Action	SB 3	No springflow guarantee - BIOLOGICAL RISK - DETRIMENTAL					
B - No ERPA Structure	EARIP Flow Regime[3]	SEVERE[4]	High	High	High	Moderate	Moderate
C - Old Channel ERPA (temporary)	EARIP Flow Regime[3]	High / Moderate[5] / Low	High / Moderate[6]	Moderate[5] / Low	High / Moderate[6]	Full Alternative not necessary but experimental channel still recommended	
D - Old Channel ERPA (permanent), SR3 connectivity and observation well	EARIP Flow Regime[3]	High / Moderate[5] / Low	High / Moderate[6] / Low[7]	Moderate[5] / Low	High / Moderate[6] / Low[7]	Full Alternative not necessary but experimental channel still recommended	

[1] Biological Risk categories - Detrimental, Severe, High, Moderate, Low

[2] Assessment conducted as if the EARIP flow regime would support the minimum 6 month daily flow levels specified in the table.

[3] EARIP Flow Regime defined as the minimum total Comal springflow not occuring for greater than 6 months with flows of 80 cfs for 2-3 months following those events.

[4] Severe based on no mechanism to protect a designated area in the Comal system. Should model projections be wrong, off-site refugia is the only option.

[5] Moderate based on having the ability to maintain optimal habitat under most conditions; potential for Low pending testing and proven success of the ERPA.

[6] High based on unproven concepts. Potential for Moderate following testing and proven success of CS Riffle Beetle establishment in of the ERPA.

[7] High based on unproven concepts. Potential for Low following testing and proven success of spring run connectivity.

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The biological risk categories used in Table 15 include the following with associated definitions for this evaluation:

- Detrimental (Jeopardy)
  - likely to cause extirpation of the species
- Severe
  - major impact to habitat and populations throughout the system
  - Low potential for full recovery of habitat and populations throughout the entire range
- High
  - major impact to habitat in extents of available habitat
  - moderate impact to habitat in optimal habitat areas
  - population reduction but not to the jeopardy level
  - Full recovery of habitat and populations throughout system to pre-drought condition possible with human intervention.
- Moderate
  - major impact to habitat in extents of available habitat
  - minor impact to habitat in optimal habitat areas
  - population reduction but to a lesser degree than High
  - Full recovery of habitat and populations throughout system to pre-drought condition possible with less human intervention than High.
- Low
  - major impact to habitat in extents of available habitat
  - limited to no impact to habitat in optimal habitat areas
  - population reduction but to a lesser degree than Moderate
  - Full recovery of habitat and populations throughout system to pre-drought condition possible with less human intervention than Moderate.

The first point to understand regarding the biological risk definitions is that they are created for the extreme event. Even under the highest flow (80 cfs) scenario presented in Table 15, there will be major habitat impacts in portions of the Comal system. At 80 cfs, a good portion of Spring Runs 1 and 2 will be subsurface, the Upper Spring Run reach will have been stagnant for a considerable amount of time with water quality and habitat degradation implications, and the New Channel and lower portion of the Old Channel will experience water temperatures high enough to cause reduced fountain darter larval and egg production. All these conditions will increase in impact as total Comal springflows decrease. As such, both the fountain darter and Comal Springs riffle beetle populations will likely decline under all scenarios. However, the key is the amount of habitat decline in high quality habitat areas, the degree of overall population decline, and the potential for full recovery following the drought event. An additional key is the ability to protect and maintain high quality habitat in some portion of the system under all circumstances, even if the bulk of assumptions underpinning the hydraulic, habitat, and water quality modeling conducted to date are proven false when a severe drought happens. It also needs to be clear that we are not talking about the ability of the EARIP bottom up flow regime to meet the flows required as that is a separate issue. We are assuming that the daily minimum flows and durations targeted in Table 15 will be met.

The assumptions in the biological modeling and the biological unknowns are what have driven this whole ERPA feasibility evaluation. The ability to protect and maintain high quality habitat in some portion of the system under all circumstances and the ability to learn from applied research throughout the adaptive management program are the true benefits of the proposed ERPA alternatives.

6.2.1 Alternative A

Returning to the biological risk assigned to each Alternative in Table 15, the No-Action alternative (A) does not ensure spring flow and, thus is given a Detrimental ranking.

6.2.2 Alternative B

Alternative B is focused on the fountain darter, has some very positive features and is the least expensive of the alternatives. However, biological risk for the fountain darter is ranked Severe at 30 cfs because there is no protection of a designated area of high quality habitat under all circumstances. Through restoration and maintenance of aquatic vegetation one can get optimal conditions for fountain darter habitat going into the drought, but if the drought continues and you have 6 months of 20 cfs going down the old channel, it is very unlikely that you will maintain high quality conditions throughout this time period. This is especially true if our assumptions about aquatic vegetation are inaccurate and we start experiencing die-offs in Landa Lake with decaying organic matter being transported to and settling out in the Old Channel. Another downside to Alternative B is there is no applied research proposed with this Alternative which is the foundation for understanding a lot of the unknowns (especially aquatic vegetation response to low flow) that continue to dominate discussions on this topic.

Alternative B receives a High ranking for the Comal Springs riffle beetle based on the fact that Spring Run 3 will be subsurface for 6 continuous months. Populations will likely decline but we do not anticipate past the point at which the population could recover. These conditions have been experienced on more than one occasion in the historical record and over 6,500 Comal Springs riffle beetles have been collected from 2004-2010 via the cotton lure methodology and twice a year sampling at the three locations described in Section 5.2.4.

At 60 cfs, the Alternative B fountain darter ranking switches to High because 40 cfs would be transferred through the Old Channel at the lowest flow condition which would likely facilitate the maintenance of high quality fountain darter habitat. The Comal Springs riffle beetle ranking remains the same at 60 cfs as Spring Run 3 would still not be experiencing complete surface flow. At 80 cfs, both species receive a Moderate ranking under Alternative B as conditions for the darter are improved in both the Old and New Channels and Spring Run 3 would now support surface flow for the majority of the run.

6.2.3 Alternative C

Alternative C focuses on both the fountain darter and Comal Springs riffle beetle. The biological risk for the fountain darter at 30 cfs is assigned a High/Moderate/Low ranking. The High ranking is because the ERPA has yet to be proven successful at any level. Moderate, because our analysis shows that the ERPA would likely provide a protected

area of the system under most all conditions. It is also possible that the ranking could be shifted to a Low if the ERPA proves to be effective for longer periods than originally projected. An additional benefit of Alternative C is it allows for applied research to be conducted to address biological unknowns. Similar to Alternative B, Alternative C receives a High ranking for Comal Springs riffle beetle because the ERPA components for the beetle are unproven. It has the potential for Moderate if populations of riffle beetles could be established and protected in the headwaters of the experimental channel. However, even if reproducing populations of the riffle beetle cannot be successfully established, applied research targeted at movement and habitat preferences might still be practical in the experimental channel. Comal Springs riffle beetles can survive in an aquarium at the NFH&TC, so it is anticipated that researchers might still be able to conduct experiments on riffles beetles translocated to this area. If it turns out the water quality is not amenable and needs to be direct Edwards Aquifer water (as is present in spring orifices and used at the NFH&TC) then consideration should be given to drilling a well near the research channel and providing direct Edwards Aquifer water to the research area for experimentation during average and above total Comal springflow conditions.

At 60 cfs, the Alternative C fountain darter ranking switches to Moderate because 40 cfs would be transferred through the Old Channel at the lowest flow condition which would likely facilitate the maintenance of high quality fountain darter habitat. What would happen is that the infrequently used recirculation portion of the ERPA at 30 cfs would now rarely if ever be required, but would be available as a safety measure should unknowns be encountered. With the ERPA in place, the potential for shift to a Low ranking for the fountain darter exists. The Comal Springs riffle beetle ranking for Alternative C at 60 cfs does not change as habitat conditions do not significantly improve. At 80 cfs guaranteed daily minimum flow, the full Alternative C would not be necessary as flows in the Old Channel would support themselves and Spring Run 3 would be inundated. However, we recommend that the experimental channel still be implemented even at these flow minimums.

6.2.4 Alternative D

Alternative D maintains the same rankings as Alternative C for the fountain darter as the only difference is the permanent vs. temporary infrastructure associated with the ERPA. The one addition for the Comal Springs riffle beetle is the potential to go to a Low ranking should the spring run connectivity concept be tested and proven effective. Another potential advantage of Alternative D would be knowledge gained via the observation well. As with Alternative C, Alternative D maintains the same rankings at 60 cfs, and the full alternative is not necessary at 80 cfs guaranteed minimum daily spring flow.

Table 16 shows the ERPA associated cost ranges for each of the alternatives. No costs were calculated for the No Action as it contains no ERPA activities. Although, several recommendations of the EARIP Comal ecosystem restoration subcommittee were discussed above, no costs were assigned to those activities as that cost would remain the same across Alternatives B, C, and D. As expected, cost for Alternative B (with few

components and no structural components) is the least expensive, followed by Alternative C with temporary structures in the Old Channel ERPA, followed by Alternative D with the permanent Old Channel ERPA structures and the addition of Spring Run 3 connectivity structures and the observation well.

The infrastructure, environmental documentation, permitting, routine maintenance, and applied research costs can all be summed up to get a total cost for each alternative minus the actual operational costs during drought. The operational costs (Monthly when used column, Table 16) would need to have some constant assumption behind it to calculate how often it would be in operation. This could be done by examining the final EARIP bottom-up approach hydrology and determining how many months each option would be in operation. This exercise was not conducted for this study as the final EARIP bottom-up approach has not been determined.

Table 16. Estimated Cost Ranges for Alternatives evaluated

ALTERNATIVE	COST RANGE[1]				
	Upfront	Operation	Maintenance	Applied Research	
	Infrastructure / Env. Doc. / Permitting	Monthly when in use	Routine Annual	Upfront	Annual
A - No Action	N/A	N/A	N/A	N/A	N/A
B - No ERPA Structure	$150,000 - $175,000	N/A	$15,000 - $25,000	N/A	N/A
C - Old Channel ERPA (temporary)	$500,000 - $950,000	$50,000 - $65,000	$15,000 - $25,000	$150,000	$100,000 - $250,000[2]
D - Old Channel ERPA (permanent), SR3 connectivity and observation well	$1,750,000 - $2,750,000	$30,000 - $40,000	$50,000 - $75,000	$200,000	$125,000 - $300,000[3]

[1] EARIP Comal Restoration subcommittee recommendations were not costed as they would be the same for all alternatives

[2] Assumed $250,000 per year for Phase 1 (7 years), then $100,000 per year for Phase 2 (8 years if a 15 year HCP term)

[3] Assumed $300,000 per year for Phase 1 (7 years), then $125,000 per year for Phase 2 (8 years if a 15 year HCP term)

Table 17 shows a biological risk and feasibility level comparison between alternatives. The biological risk comparison was described above. The costs were ranked as Low (Alternative B), moderate (Alternative C), and High (Alternative D). Permitting and environmental documentation was also ranked in order of difficultly. As Alternative B

has no structural components to be installed and does not affect downstream water distribution, there would be no USACE, TCEQ, or EAA permits required. Federal and state scientific collection permits would likely require modification or special approvals granted by USFWS and/or TPWD for the applicant to remove non-native vegetation and re-establish native vegetation. Alternative C would require considerably more complex environmental documentation and permitting. A TCEQ water rights permit, and 401 certification would likely be required. A USACE 404 permit would likely be required for the placement of the rock vane weir, and construction of the experimental channel. Again, federal and state scientific collection permits would need to modified or granted by USFWS and/or TPWD in order to conduct applied research on federally listed species. Alternative D would require the greatest level of environmental documentation as well as permitting complexity. Again a USACE 404 permit, and associated TCEQ 401 water quality certification would be required for the Old Channel ERPA and potentially the Spring Run 3 connectivity project. A TCEQ water rights permit would likely be required for both the Old Channel ERPA and Spring Run 3 connectivity project. Additional City permits and possibly a State Historical Preservation Office permit would be required for both Alternatives C and D.

Table 17. Feasibility Evaluation

ALTERNATIVE	ERPA ALTERNATIVES FEASIBILITY[1]								
	BIOLOGICAL RISK[2]						COST	PERMITTING / ENV. DOC.	INTANGIBLES[3]
	30 cfs		60 cfs		80 cfs				
	FD	RB	FD	RB	FD	RB			
A - No Action							N/A	N/A	N/A
B - No ERPA Structure									
C - Old Channel ERPA (temporary)					N/A	N/A			
D - Old Channel ERPA (permanent), SR3 connectivity and observation well					N/A	N/A			

[1] Biological Rank / Feasibility Level /
- Detrimental / Fatal Flaw
- Severe / Extremely Difficult
- High / Difficult
- Moderate / Moderate
- Low / Easy

[2] FD = Fountain Darter, RB = Comal Springs Riffle Beetle

[3] Main intangibles include City of New Braunfels concern regarding aesthetics and TPWD's reluctancy to support the Old Channel ERPA concept

The final column in Table 17 relates to intangibles that may impede the ability to move forward with a given alternative. It is unlikely that there would be much opposition to Alternative B based on stakeholder meetings and feedback received to date on this study. There has been considerable feedback from the City of New Braunfels regarding the aesthetic value of Landa Park and noise, etc. that might be caused by the implementation and operation of ERPA components. This issue would need to be discussed in greater

detail with the City of New Braunfels should the EARIP choose to move forward with an ERPA alternative or component. With today's technology and naturally friendly designs, we do not feel this intangible is detrimental to the project; it just needs to be diligently addressed so that all parties are comfortable with the end result.

A second intangible is the reluctance being put forth by TPWD staff regarding conducting research in an experimental channel adjacent to the Old Channel as proposed. Based on recent TPWD feedback, it does appear TPWD supports many of the activities presented in Table 14 and addressing these questions in an experimental research channel rather than a laboratory environment. However, TPWD opposes the proposed Old Channel research channel on the Comal System, and recommends investigating potential research facilities at other locations in the Comal and/or San Marcos systems. To protect the endangered species going into the future with the EARIP described flow regime, we strongly feel that applied research needs to be conducted on-site. We are not opposed to evaluating other options within the Comal or San Marcos systems in greater detail, as where the research is done is less critical than that it is done. However, in contrast to TPWD, we do feel the proposed Old Channel research facility is feasible.

The third and likely most difficult intangible is TPWD's opposition to the Old Channel ERPA for the protection of endangered species habitat. We respectfully disagree with TPWD on this issue as we believe ensuring a protected reach of high quality habitat under all conditions is vital to the fountain darters continued existence in the wild at Comal Springs. It is our hope that further discussions with TPWD or the formation of an EARIP ERPA subcommittee or special review team may alleviate some or all of TPWD's staff concerns. However, should concerns not be alleviated, this may prove to be a difficult intangible for the project.

7.0 RECOMMENDATIONS

Considering all aspects, our current recommendation to the EARIP is Alternative C. The value gained by minimizing biological risk and the potential further reduction of biological risk should conceptual ideas be tested and proven, coupled with the ability to learn via applied research throughout the HCP adaptive management process outweighs the slightly higher costs and potential difficulties with permitting and intangibles. We rank Alternative D a very close second. It is second only based on costs and increased time that may be necessary to address all permitting requirements. Alternative D is the most complete package with the greatest potential to minimize biological risk for both the fountain darter and the Comal Springs riffle beetle. However, costs are high primarily because of permanent structures that would be required to house or support equipment that may not ever be used. Permanent structures for this alternative are driven by aesthetics and possibly through discussions with the City of New Braunfels cost saving options might be available that would reduce these costs. The additional components in Spring Run 3 would be valuable as an additional safety measure and research tool should Alternative D or the Spring Run 3 components of it be selected. One solution to the potential for the increased time this alternative might require because of permitting complexities is to phase the implementation of Alternative D components. Finally, we are uncomfortable with Alternative B relative to the described EARIP flow regime as it

puts a lot of pressure on the hydrological modeling and predictions of maintaining flows at the recommended levels, in addition to allowing very little flexibility should some of the assumptions used in the biological and water quality modeling prove to be incorrect.

In summary, Alternative B, C, and D all appear feasible and capable of providing benefits at varying levels to the EARIP. It is our professional judgment that Alternative C or D would meet or exceed the goals of the HCP for consideration with the described EARIP flow regime (assuming flows met the regime described in this report). We are supportive of Alternative B as an alternative should the minimum flow levels be raised from 30 cfs daily average flow to 60 cfs daily average flow, but would still highly recommend the addition of an experimental channel to be included with that alternative.

Finally, should the EARIP decide to move forward with an ERPA or components thereof, we recommend that the formation of an EARIP ERPA subcommittee or some form of third-party independent review team be assembled to oversee the ERPA implementation and studies conducted during the adaptive management phase of the HCP.

DRAFT

8.0 SAN MARCOS EVALUATION

8.1 INTRODUCTION AND ENVIRONMENTAL BACKGROUND

During the course of the Comal feasibility study the EARIP requested that a preliminary evaluation of the San Marcos system also be conducted. As such, this section addresses the San Marcos system but with less detail than provided for the Comal system above. The foundational concept of evaluating an ERPA remains the same as for the Comal system. Designated areas within the San Marcos Springs/River ecosystem were evaluated considering the potential to restore and protect habitat for the threatened and endangered species that inhabit those areas. Differences in the evaluation stem from the threatened and endangered species present, the existing habitat conditions, system-specific anthropogenic factors such as recreation, and the proposed EARIP flow regime for the San Marcos system.

The proposed EARIP flow regime evaluated is the same one identified in Hardy (2011) for the protection of the threatened and endangered species during a repeat of conditions similar to the drought of record. The evaluated flow regime includes a minimum daily average springflow of 45 cfs for a period not to exceed 6 months, followed by 2 to 3 months of springflow at 80 cfs minimum daily average. It is also assumed that conditions similar to the drought of record are infrequent events.

The focus of the preliminary ERPA evaluation of the San Marcos system is on the fountain darter, San Marcos salamander (*Eurycea nana*), and Texas wild-rice (*Zizania texana*). The Comal Springs riffle beetle is also present in Spring Lake as is the Texas Blind salamander (*Eurycea rathbuni*). However, the Comal Springs riffle beetle was not examined as it appears that the evaluated EARIP flow regime provides enough spring flow through Spring Lake to maintain Comal Springs riffle beetle Spring Lake habitat. The Texas Blind salamander is an aquifer dwelling species and similar to the Peck's Cave amphipod and Comal Springs dryopid beetle in the Comal system, is a subterranean species. As such, it was assumed that maintaining a minimum of 45 cfs daily average would be protective of this aquifer dwelling species. A thorough description of each of the San Marcos threatened and endangered species, their existing habitat and known life history requirements is presented in SSC (2008, 2009).

8.1.1 Spring Lake

The existing habitat in the San Marcos system differs from the Comal system in several ways. Spring Lake is located at the headwaters of the San Marcos River similar to Landa Lake, but is considerably deeper than Landa Lake. Spring Lake provides high quality habitat for both the fountain darter and San Marcos salamander. At the evaluated flow regime (Hardy 2011) of 45 cfs minimum daily average spring flow for a period of 6 months, followed by 2 to 3 months of 80 cfs daily average springflow, it is not anticipated that the fountain darter or salamander habitat within Spring Lake would be affected to the degree necessary for active management through some type of ERPA. However, it would be a valuable exercise to evaluate the aquatic gardening practices in Spring Lake conducted by Texas State University (TSU) to see if adjustments to any of those practices during low-flow events might be beneficial to existing high quality

habitat. Although not evaluated in this investigation, should the temperature model (Hardy 2011) be proven to be inaccurate or the evaluated flow regime not be met, another option that has been discussed has been to coffer off the slough arm of Spring Lake in order to facilitate the turnover of lake water more rapidly potentially allowing cooler temperatures to move downstream.

8.1.2 San Marcos River

The Upper San Marcos river channel starts below Spring Lake Dam where water spills through the western and eastern spillways (Figure 45) moving downstream until it is joined by Blanco River flows near the eastern part of town. A high level evaluation of the Upper San Marcos River was conducted with the best potential ERPA location being identified just below Spring Lake Dam. Best potential refers to the ability of a proposed ERPA to protect high quality habitat in the wild during periods of extreme drought, but also considers overall costs, species present, permitting and environmental documentation feasibility, and intangibles. At Spring Lake Dam, the Salt Grass restaurant is adjacent to the western spillway with the Riverside apartments adjacent to the eastern spillway. The eastern spillway is the only location in the San Marcos River that supports quality habitat for all three species (fountain darter, San Marcos salamander, and Texas wild-rice) focused on in this assessment. The area below Spring Lake Dam is highly recreated during the summer months, with increased recreation in the eastern spillway during lower flows. There are several old pilings in the eastern spillway channel that are broke off and sharp and extremely difficult to see during average to higher flow conditions. Swimming and wading in this area during average to higher flows is difficult and dangerous because of these obstacles and thus, this area is typically not used to the same degree as during lower flows when the obstacles can easily be seen and avoided.

The eastern spillway has a lot of potential for an ERPA because all three aforementioned threatened and endangered species reside in this reach. The main difference, from an ERPA perspective, between the eastern spillway and the Old Channel ERPA proposed for the Comal system is the amount of recreation that takes place in the eastern spillway. This area would not be a good choice for an ERPA if recreation was not controlled. If recreation was controlled, then restoration and protection of fountain darter and San Marcos salamander habitat, as well as protection and enhancement of Texas wild-rice plants would be beneficial in this area. As mentioned for the Comal system, restoration or enhancement is only one component as protection of the restored or enhanced areas would need to follow. Fortunately, flow over Spring Lake dam can be manipulated to travel down the western spillway or eastern spillway. Additional structures may be necessary to achieve the purposes of an ERPA but with the correct setup, a flow-split management scheme could be implemented for the protection of restored habitat. Currently, under higher than average conditions, flows through the eastern spillway scour out Texas wild-rice plants, and limit the suitability of fountain darter and San Marcos salamander habitat because of extreme velocities. Additionally, with the proper structure(s), flow could potentially be controlled and provided for experimentation within the eastern spillway.

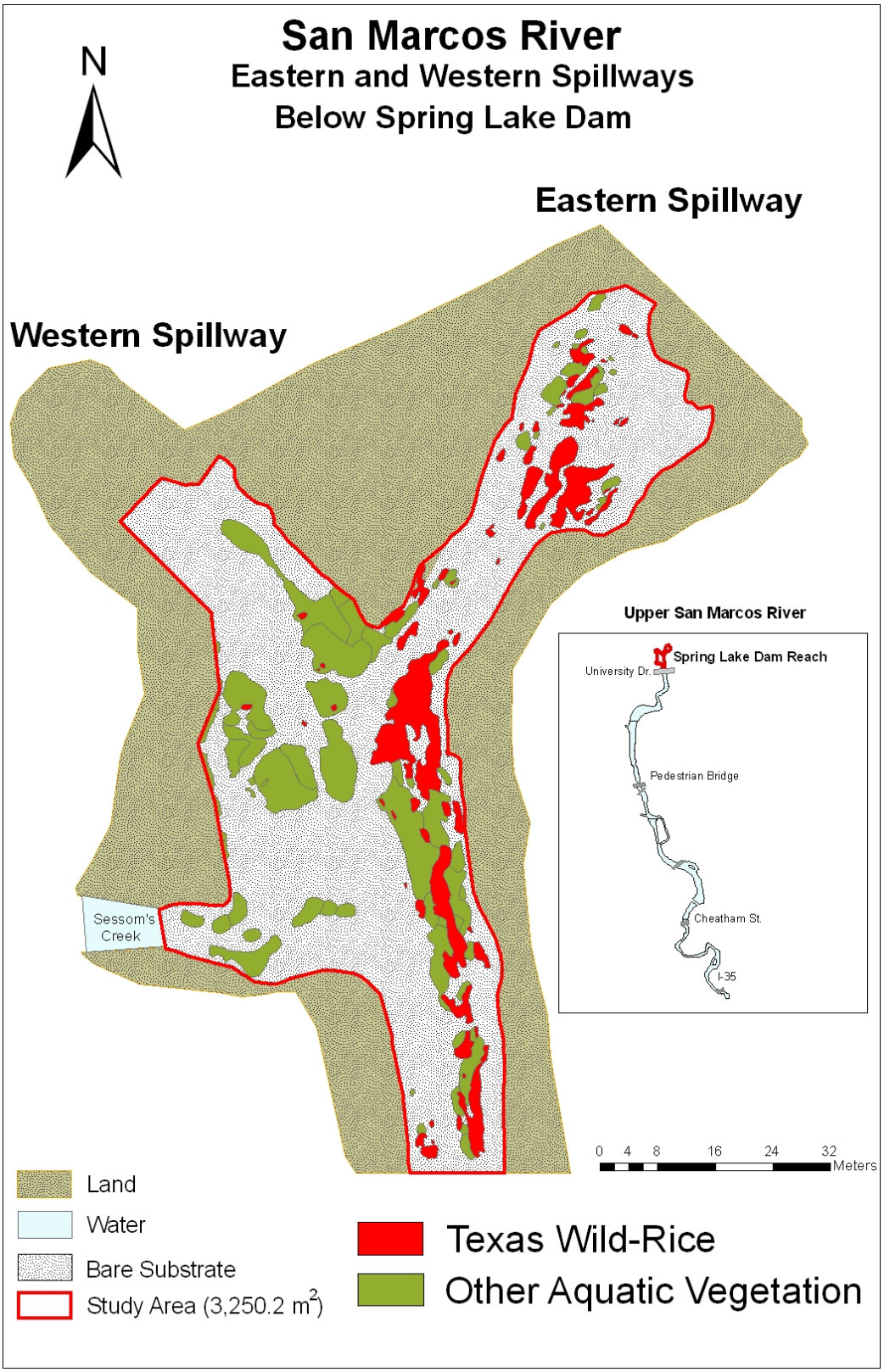

Figure 45. San Marcos River from Spring Lake Dam to University Avenue.

When considering the evaluated flow regime described above for the San Marcos system, it does not appear that an ERPA in the eastern spillway below Spring Lake dam would be mandatory for the survival of these three species during conditions similar to a repeat of the drought of record. However, restoration and protection (both from flow and recreation) would provide an additional level of protection for future unknown hydrological conditions. Additionally, the potential for applied research in the reach is also very intriguing and we recommend further evaluation of this important aspect.

Although not an ERPA in the sense of the projects described for the Comal system and above for the eastern spillway, a restoration/enhancement component that we feel does warrant further evaluation and ultimate implementation for the adaptive management component of the HCP is the restoration and enhancement of Texas wild-rice stands within high quality habitat. Texas wild-rice within the San Marcos River has been steadily increasing over the past two decades, with minor setbacks following floods and impacts associated with low flow conditions (Figure 46).

Since the original ERPA analysis (later in this section), the concept of enhancement of Texas wild-rice plants during low flow conditions has received a lot of positive feedback from the EARIP and City of San Marcos. To be fair, it has also received some skepticism and as such Hardy (2011) conducted some additional analysis as presented in his report. We will not repeat the Hardy (2011) evaluation in this report, nor do we present the later analysis in contradiction to any of the additional work that Dr. Hardy has provided. Both sets of analyses relay the same message which is encouraging relative to the potential ability to maintain Texas wild-rice stands in high quality habitat during low-flow conditions, with the potential for expansion of these stands.

Regarding Texas wild-rice, Hardy (2011) concludes,

> "Physical habitat simulations within the San Marcos River for TWR based on occupied optimal habitat areas indicate that the proposed flow regime within the San Marcos River being considered by the EARIP will provide adequate quantity and quality habitat to sustain this species during a repeat of the drought of record provided effective recreation control can be implemented. Analyses examining the potential benefit from removal of non-native vegetation within mixed stands of TWR in optimal areas and removal of non-natives within a 2 meter buffer of occupied optimal TWR stands can substantially increase aerial coverage of TWR."

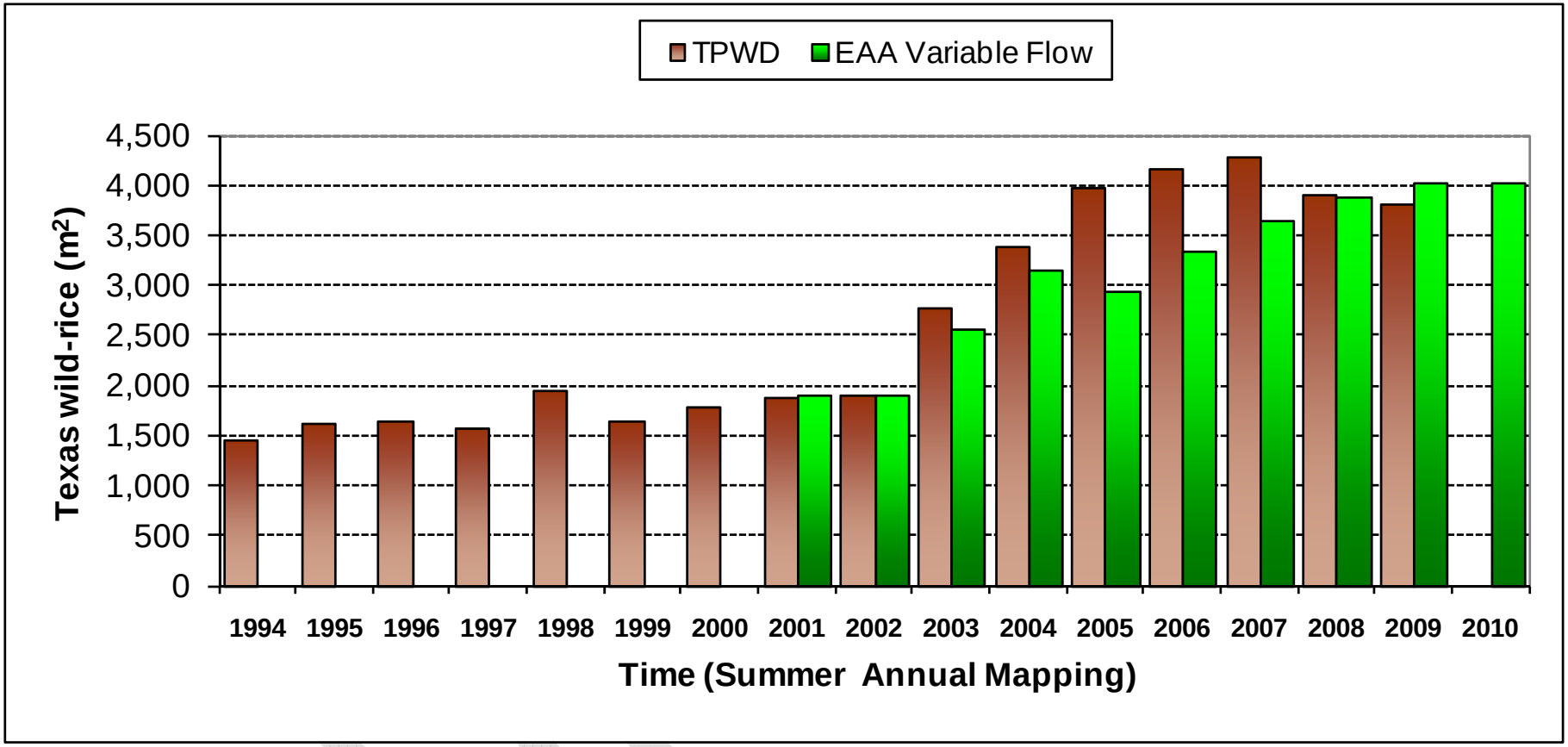

Figure 46. Total coverage (m^2) of Texas wild-rice measured in the San Marcos River during annual summer monitoring.

Table 18 is taken directly from Hardy (2011) and shows the rationale behind that conclusion. Based on existing Texas wild-rice data collected by TSU in 2009, coupled with modeling data at 45 cfs, approximately 1,500 m^2 of Texas wild-rice is projected to remain in optimal habitat areas, with approximately 1,200 m^2 in suboptimal areas. So, even if all the Texas wild-rice in suboptimal areas would be eliminated (which is highly unlikely), and only 75% (which is again likely an overestimate of loss, since it is optimal habitat) of the Texas wild-rice in optimal areas be sustained, over 1,100 m^2 of Texas wild-rice would remain in the San Marcos River. This amount is still greater than the total river population in 1989.

Table 18. Hardy (2011) Texas wild-rice modeled Weighted Usable Area available and occupied based on 2009 vegetation mapping.

Table 15. Predicted optimum TWR areas (m^2) [not necessarily occupied], 2009 mapped TWR predicted within optimum/suboptimum areas, additional areas with removal of H. verticillata and H. polysperma within TWR patches and a 2 meter buffer around TWR patches in the San Marcos River. Note that the sum of columns 3 and 4 is the total of occupied 2009 TWR habitat mapped by Texas State.

Discharge (cfs)	Optimum area (>75% suitable)	Optimum area (>75% suitable)	Suboptimum area (<75% suitable)	*H. verticillata* *H. polysperma* Removal in TWR patches	2 m buffer TWR patches
30	21,709	1,246	1,486	594	779
45	26,785	1,518	1,224	1,134	1,292
50	29,087	1,596	1,146	1,269	1,452
55	29,182	1,603	1,134	1,345	1,527
60	31,049	1,630	1,113	1,423	1,585
70	33,667	1,675	1,068	1,499	1,673
80	34,730	1,678	1,057	1,548	1,748
90	36,274	1,667	1,087	1,564	1,793
100	37,142	1,635	1,100	1,572	1,827
120	37,407	1,542	1,199	1,219	1,795
140	36,957	1,428	1,308	1,345	1,722
160	36,077	1,288	1,451	1,278	1,663
180	35,366	1,144	1,592	1,212	1,614
200	33,294	980	1,760	1,074	1,515
220	31,875	781	1,954	958	1,371
240	30,226	615	2,121	840	1,201
260	28,043	482	2,250	741	1,083

With the control of recreation in the river as proposed by Hardy (2011) and supported by this report, it is very likely that some Texas wild-rice in suboptimal areas will survive as well as more than 75% of the Texas wild-rice in optimal areas. So, based on the evaluated EARIP flow regime, with only recreation control, it is possible that over 2,000 m^2 of Texas wild-rice might survive following a repeat of conditions similar to those experienced during the drought of record. Hardy (2011) goes on to show (Table 18) that an additional 2,200 m^2 could potentially be established in optimal habitat areas should the exotic *Hygrophila* and *Hydrilla* be removed from a 2-meter buffer surrounding existing Texas wild-rice plants.

We concur with Hardy (2011) that the proposed EARIP flow regime will be sufficient for the survival of Texas wild-rice assuming the effective implementation of recreational control during low flow periods. We also agree that non-native vegetation removal adjacent to and downstream of Texas wild-rice plants should be conducted in order to let the Texas wild-rice stands expand into these areas.

To be consistent with our biological risk analysis conducted for the Comal system (extreme conditions evaluation), we assigned the 45 cfs minimum daily average flow condition within the context of the EARIP flow regime as Moderate risk. Texas wild-rice in suboptimal areas will be impacted through drying of wetted area, increased recreational activity and herbivory during these times. However, with the amounts preserved in optimal habitat areas and the potential for additional Texas wild-rice in these areas via non-native vegetation removal, recovery to pre-drought conditions is expected.

The analysis presented below was originally conducted in summer 2010 to evaluate minimum flows that may be acceptable for the survival of Texas wild-rice during a repeat of hydrological conditions similar to the drought of record. The analysis was completed with the updated Hardy (2011) model. However, to be clear about its use in this report, this analysis is not provided to refute minimum flows (as we are supportive of the EARIP flow regime as described in Hardy 2011 and this report). The analysis is presented herein to assess increases in biological risk as springflow decreases below 45 cfs and to support Texas wild-rice enhancement activities. For this exercise, fall 2009 Texas wild-rice mapping conducted for the EAA Variable Flow study was used. The total extent of Texas wild-rice in the San Marcos River was mapped in November 2009 using real-time Trimble® GPS equipment (BIO-WEST 2010b). A total of 3,350 m^2 of Texas wild-rice stand area was mapped, with most of the stands located upstream of the I-35 bridge. Although not evident in the annual mapping data presented in 2009 (Figure 46), recreational impacts during the low flow conditions experienced in 2009 did impact the amount of Texas wild-rice in the river in the summer and fall 2009, and this total represented the lowest areal coverage of Texas wild-rice observed since 2006. Therefore, we chose this period as an added level of conservatism. As a follow-up, annual mapping in summer 2010 shows that Texas wild-rice has expanded to back over 4,000 m^2.

Additionally for the analysis, data from the TSU aquatic vegetation mapping effort of the entire San Marcos River in 2009 was used. Due to potential errors associated with satellite coverage, tree cover along the river banks, and GPS accuracy during the field mapping efforts, there may be some errors in evaluating the overlapping areas of the habitat model and the location of mapped vegetation areas. To determine potential quality habitat for Texas wild-rice at low-flow conditions, the habitat model results from the Hardy (2011) 30 cfs model run were overlaid on the current mapped vegetation in the San Marcos River. Model nodes with habitat suitability results higher than 0.75 were analyzed first to identify areas that 1) currently have Texas wild-rice growing in them, and 2) do not have Texas wild-rice growing in them, but have another type of vegetation or bare substrate. To add an additional level of conservatism, we classified optimal habitat as needing a suitability of 1.0 and only carried forward that analysis at 30 cfs.

Results of the 30 cfs model run predict there are 1,679 m^2 of optimal quality (all 1.0 suitability) Texas wild-rice habitat, of which 233 m^2 currently (based on 2009 mapping) have Texas wild-rice growing in them (Figures 47 through 50). Under a hypothetical situation in which all Texas wild-rice stands except those located in optimal (1.0 suitability) quality habitat (233 m^2 predicted at 30 cfs) were lost under low-flow conditions, we attempted to look at potential scenarios for the conservation and re-establishment of Texas wild-rice in other areas of predicted high quality habitat. We then

evaluated the remaining areas of predicted optimal quality (1.0 suitability) habitat to determine if it would be feasible to plant all or part of the remaining predicted 1,446 m^2 of high quality habitat with Texas wild-rice. Four main areas for planting are apparent from the map analysis – a portion of the river in Sewell Park where Texas wild-rice is currently abundant (Figure 47), two areas that are downstream of City Park and are downstream of current wild-rice stands, and an area upstream of Rio Vista Park that does not currently support wild-rice (Figure 49). The area of these optimal quality Texas wild-rice habitats and their associated mapped vegetation types is presented in Table 19.

Table 19. Predicted high quality (1.0 suitability) Texas wild-rice habitats in the upper San Marcos River at 30 cfs modeled flow conditions that do not currently have Texas wild-rice.

Vegetation	**Area**
Cabomba caroliniana	18.13 m^2
Colocasia esculenta	45.75 m^2
Hydrilla verticillata	984.11 m^2
Hygrophila polysperma	143.92 m^2
Potamogeton illinoensis	18.45 m^2
Sagittaria platyphylla	6.79 m^2
Substrate (unvegetated)	228.85 m^2
Total	**1,446 m^2**

If additional Texas wild-rice were planted and successful in the bare areas (half of which are close to existing stands), it would add approximately 229 m^2 of Texas wild-rice area. If Texas wild-rice were transplanted into areas currently supporting *Hydrilla* and *Hygrophila* plants, it could add approximately 1,100 m^2. *Hydrilla* and *Hygrophila* are invasive non-native plants and removing them would likely have additional ecosystem benefits. The analysis would be incomplete if one did not go back and evaluate what would be the suitability of these newly established areas during average flow conditions. Therefore, we examined the 1,679 m^2 of optimal quality (all 1.0 suitability) Texas wild-rice habitat predicted under 30 cfs flow conditions at 170 cfs (slightly higher than historical average springflows). This follow-up analysis showed that this area has a predicted average habitat suitability of 0.64 at 170 cfs. As such, non-native vegetation removal and Texas wild-rice establishment or enhancement appears feasible for when flow conditions return to average. The existing modeling tools should be used to maximize the potential for success by first attempting these activities in optimal (1.0) suitability areas at both the low flow target and the average flow condition.

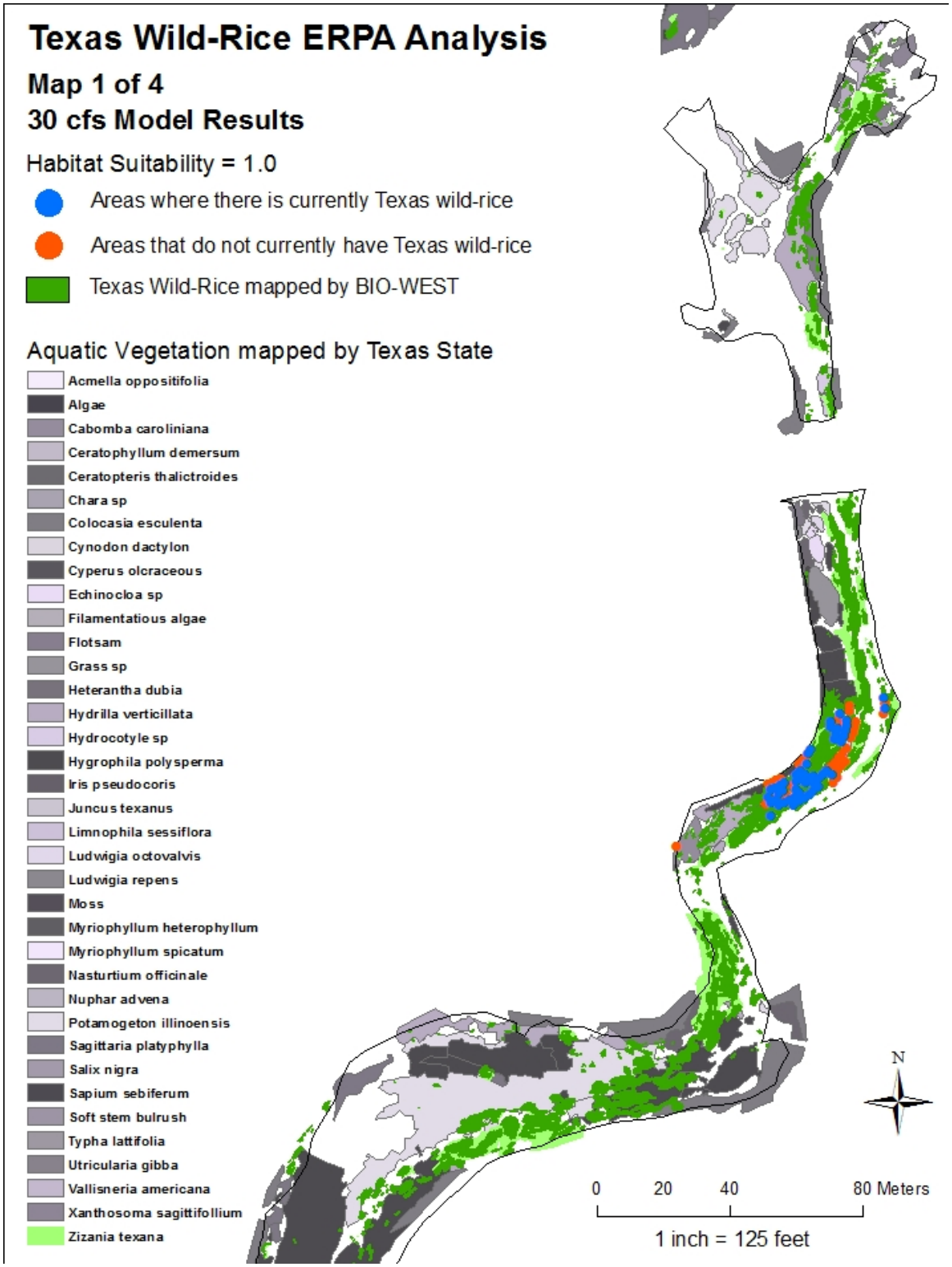

Figure 47. Texas wild-rice ERPA Analysis – 30 cfs model results (1.0 suitability) - Map 1

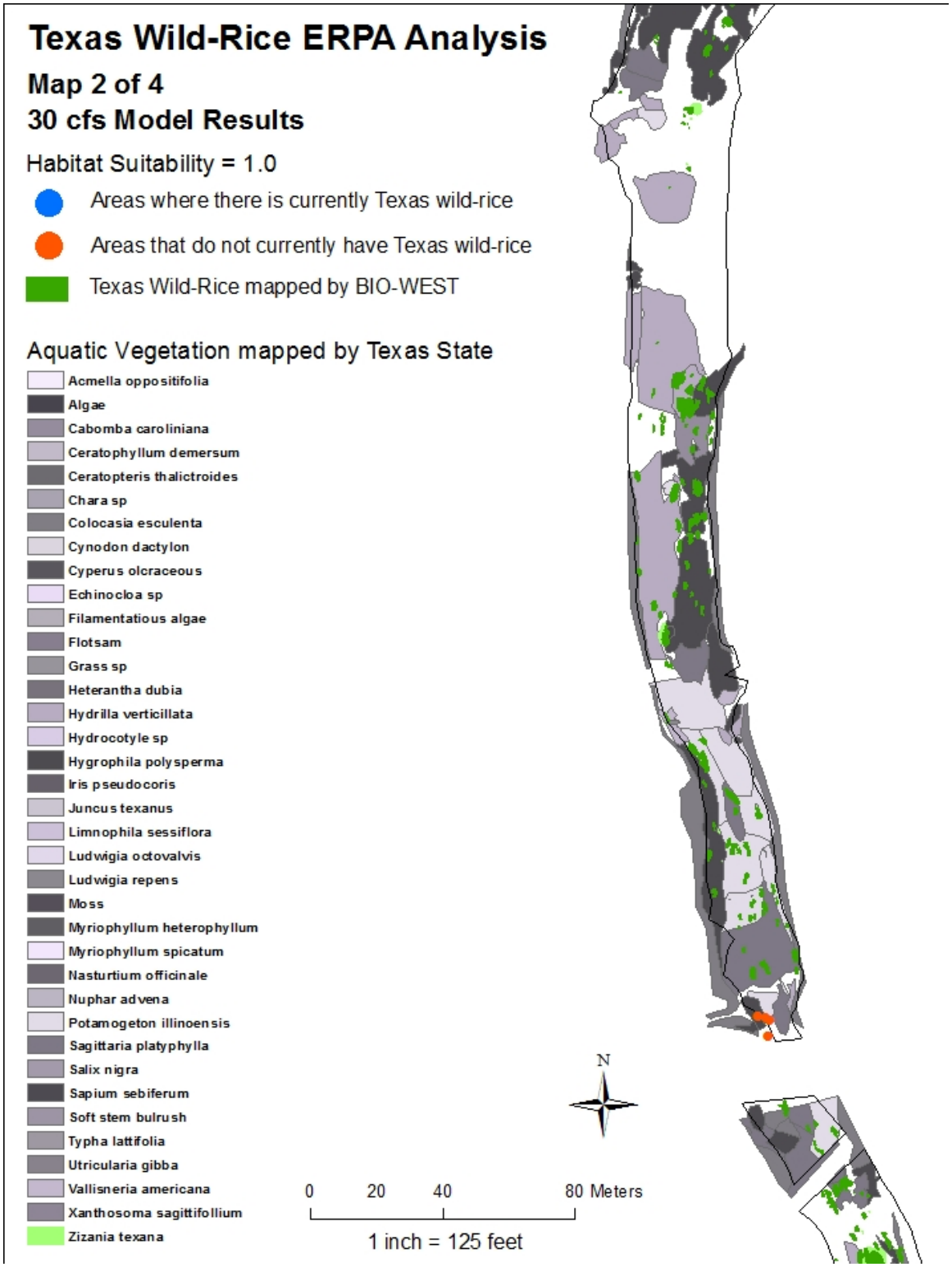

Figure 48. Texas wild-rice ERPA Analysis – 30 cfs model results (1.0 suitability) - Map 2

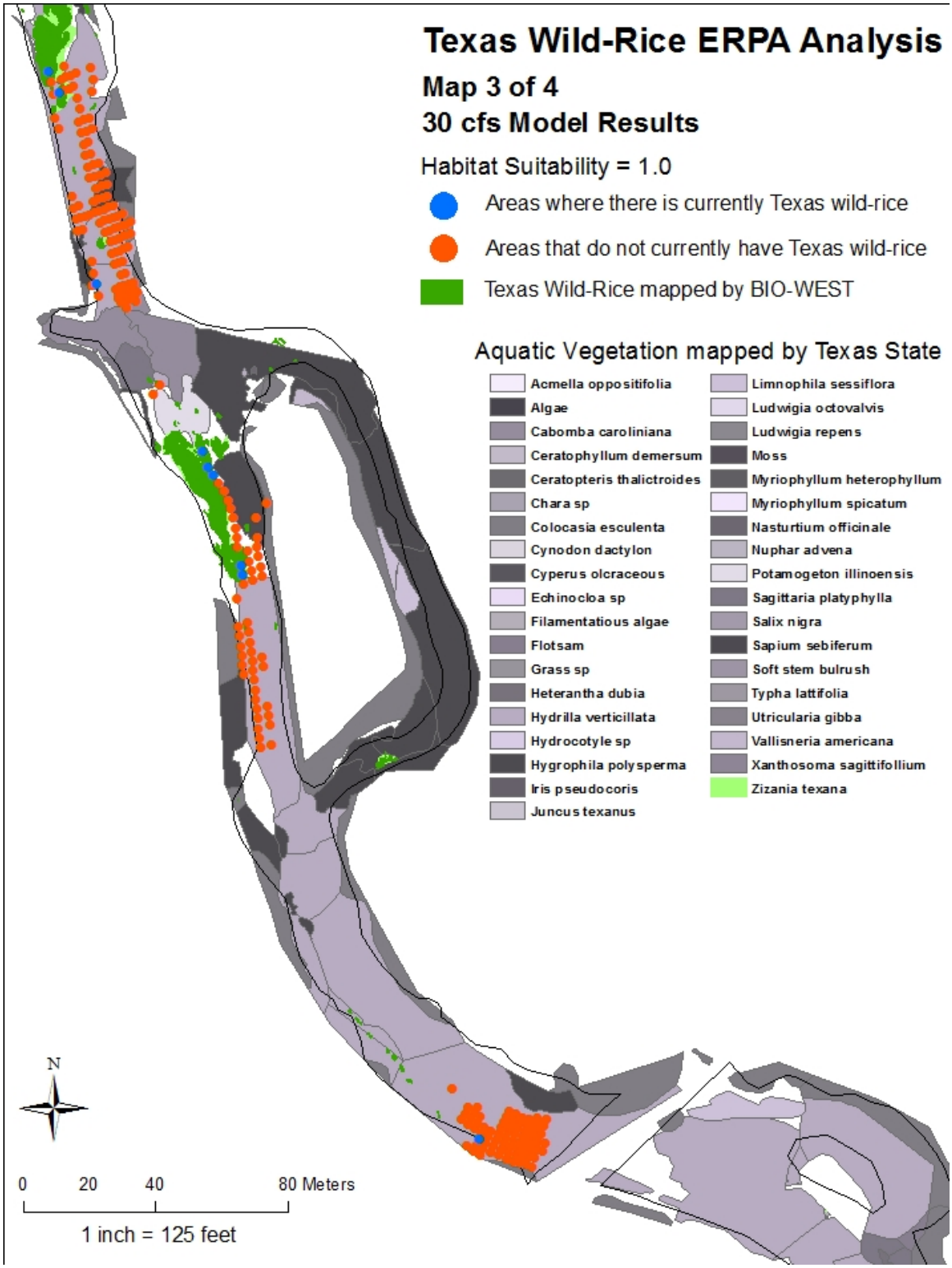

Figure 49. Texas wild-rice ERPA Analysis – 30 cfs model results (1.0 suitability) - Map 3

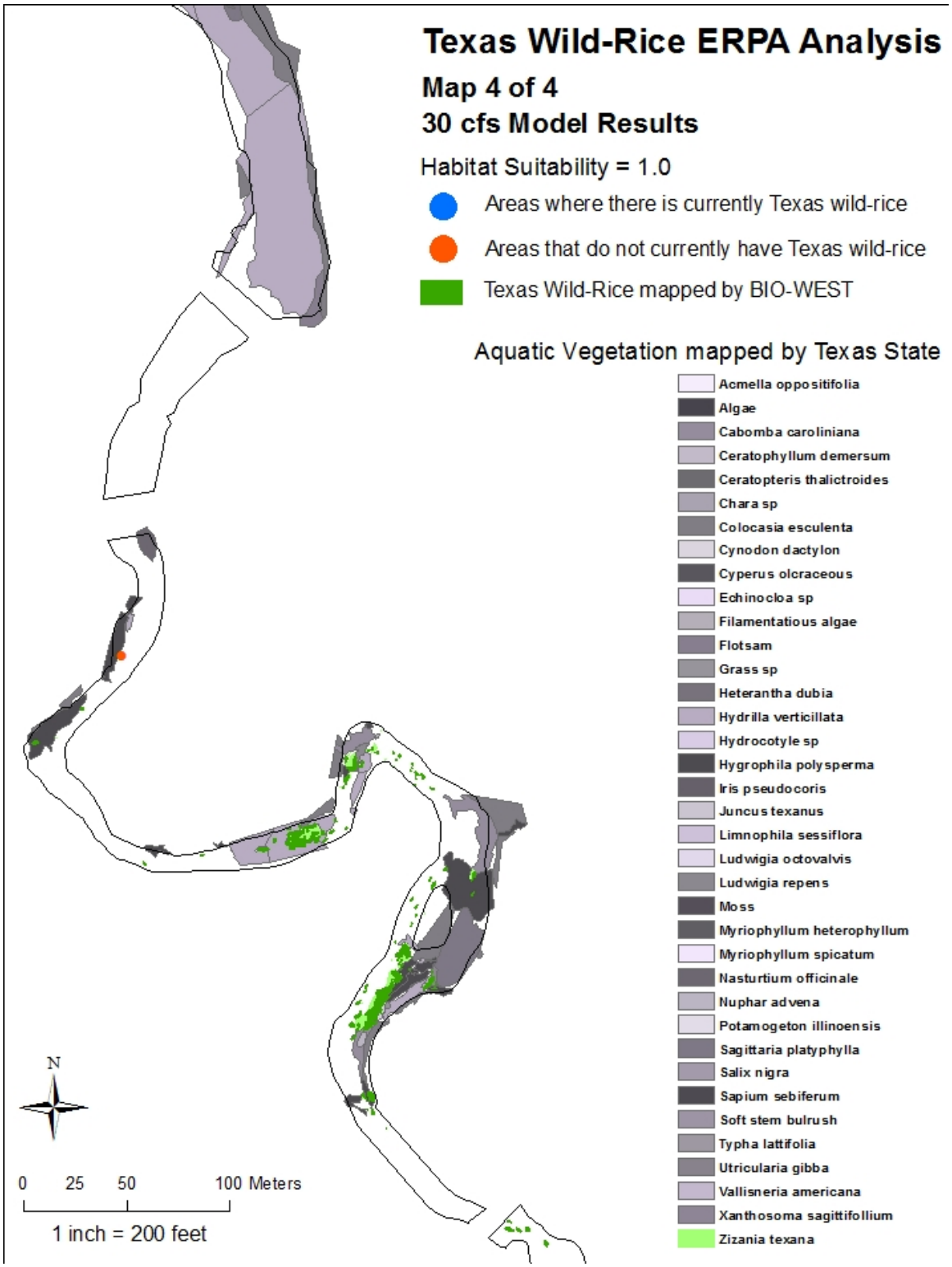

Figure 50. Texas wild-rice ERPA Analysis – 30 cfs model results (1.0 suitability) - Map 4

A comparison of 30 cfs from Hardy (2011) shows that using a suitability value of 0.75 as optimal predicts approximately 1,200 m^2 of occupied Texas wild-rice area in optimal areas; approximately 1,500 m^2 of occupied Texas wild-rice in suboptimal areas; and the potential for approximately 1,300 m^2 to be gained if *Hydrilla* and *Hygrophila* were removed (Table 18). Based on both these analyses, we conclude that biological risk at 30 cfs inserted into the evaluated EARIP flow regime would shift to High (extreme biological risk assessment categories as discussed in Comal) as more areas would be impacted. The potential for recovery still appears possible. However, at 30 cfs versus the recommended 45 cfs minimum, there would be much greater pressure on successful recreation control over broader areas as well as successful removal of non-native vegetation in optimal Texas wild-rice habitat areas, followed by successful expansion or re-introduction of Texas wild-rice.

Finally, we evaluated the results of the 15 cfs model run to assess increased biological risk to Texas wild-rice. It quickly became evident that only small amounts of optimal (1.0 suitability) Texas wild-rice habitat remains at this flow level with less than 100 m^2 predicted to be occupied. Therefore, we expanded our analysis to include what we term quality (>0.75) habitat. Results of the 15 cfs model run predict 2,564 m^2 of quality (>0.75 suitability) Texas wild-rice habitat, of which 238 m^2 currently (2009 mapping) have wild-rice growing in it (Figure 51 – only the uppermost segment is shown because it quickly became evident that this flow level would be Detrimental to Texas wild-rice).

There are two main differences in the predicted habitat for Texas wild-rice between the 30 cfs and 15 cfs model results. First, the 15 cfs habitat results in this comparison include somewhat lower habitat quality values (0.79-1.0 values). Second, is the location of the areas that are predicted as quality habitat. Results of the habitat model under 15 cfs flow conditions show the predicted quality habitat is in areas that are currently unvegetated, too deep and typically have too high velocities to support Texas wild-rice stands at average flows. The total area of good quality habitats and their associated mapped vegetation types are presented in Table 20. Even if one could be successful in going in under low flow conditions and transplanting Texas wild-rice in these bare areas (which we don't recommend because of stress on the plants and slim chance of success), when the river returned to average conditions all that restoration would be blown out.

Table 20. Predicted good quality (>0.75 suitability) habitats in the upper San Marcos River at 15 cfs modeled flow conditions that do not currently have Texas wild-rice.

Vegetation	Area
Colocasia esculenta	16.97 m^2
Grass	9.08 m^2
Hydrilla verticillata	211.19 m^2
Hygrophila polysperma	40.25 m^2
Nasturtium officinale	27.87 m^2
Potamogeton illinoensis	13.40 m^2
Sagittaria platyphylla	28.05m^2
Substrate (unvegetated)	1,979.19 m^2
Total	**2,326 m^2**

Based on the 15 cfs evaluation it is clear that these flow levels would be Detrimental and likely cause jeopardy to Texas wild-rice populations in the San Marcos River, even with extensive recreation control.

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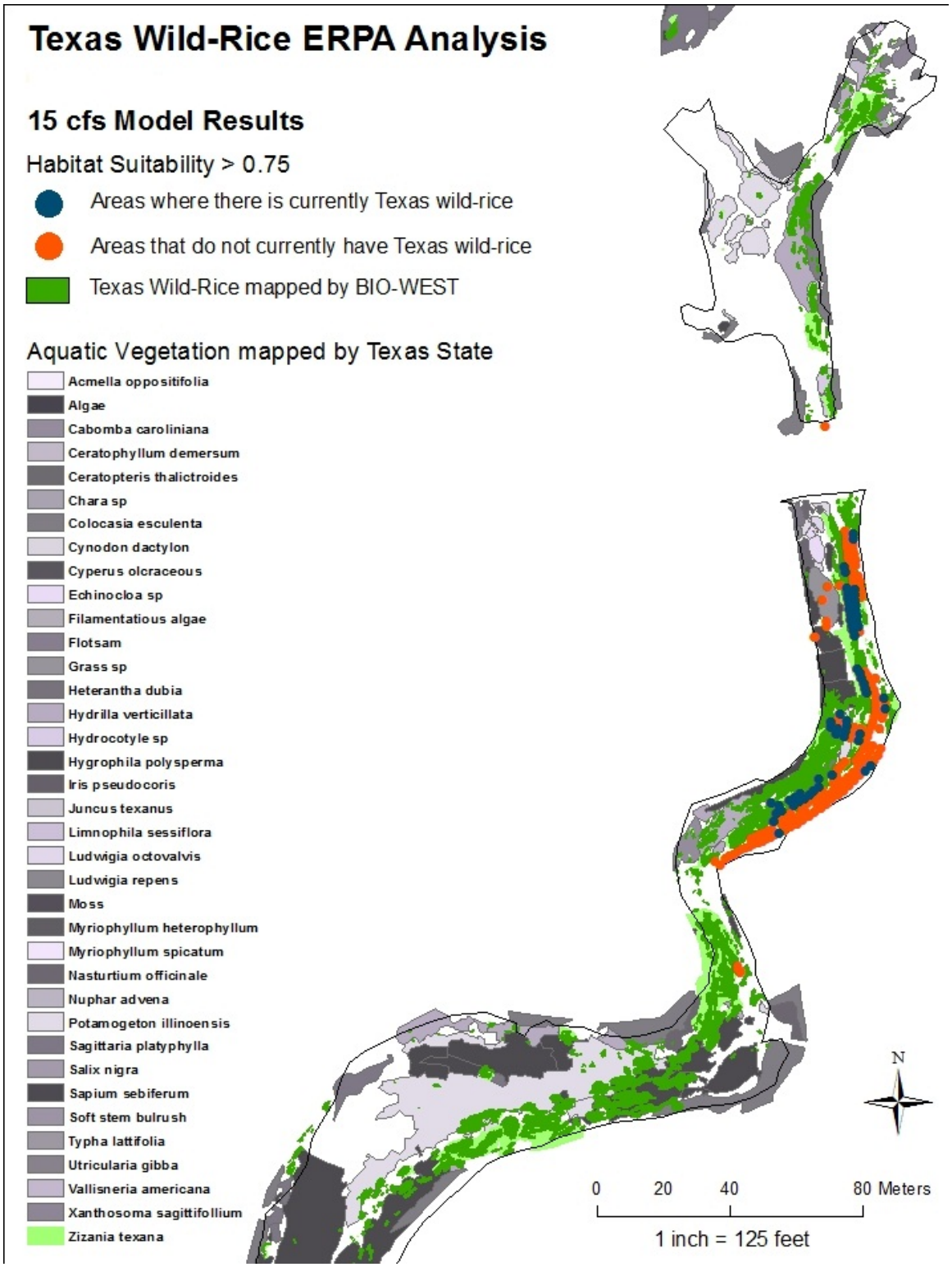

Figure 51. Texas wild-rice ERPA Analysis – 15 cfs model results (> 0.75 suitability)

8.2 SAN MARCOS RECOMMENDATIONS

Based on our preliminary assessment of ERPA's in the San Marcos system, we conclude that the evaluated EARIP flow regime as described in this document is sufficient to sustain the threatened and endangered species in this system without the necessity of a specific ERPA. However, we reiterate that the eastern spillway has a lot of potential for an ERPA. Should model assumptions be proven wrong, flows required to meet the evaluated EARIP flow regime not be deemed feasible, or if an added measure of safety is determined necessary by the EARIP or the USFWS during HCP review, further evaluation of this area would be warranted. Additionally, the eastern spillway has the potential to be converted into an applied research area that might greatly increase the understanding of the threatened and endangered species and their habitat during low flows. Regardless if the eastern spillway is turned into an ERPA or an applied research location, we recommend that this area be restricted from all recreational activities. This alone will greatly enhance the protection of these three species and their habitat in this reach.

TPWD has recently recommended an evaluation of some additional San Marcos locations to conduct endangered species research with on-site experimental channels. These include designing and building experimental channels at Aquarena Springs in the location of existing buildings to be torn down; the existing TSU raceways; and/or the slough arm of the San Marcos River in relation to a proposed fish bypass (or ladder) at Rio Vista Dam. Although none of these locations meet the criteria for an ERPA as defined, they are potential applied research locales and we are supportive of further evaluation of research activities at any or all of these locations.

We concur with the Hardy (2011) analysis regarding 45 cfs and the protection of Texas wild-rice in the San Marcos River. We also concur with the first recommendation in Hardy (2011) which promotes Texas wild-rice enhancement activities. Expansion or enhancement could first be observed through the reduction of non-native aquatic vegetation surrounding Texas wild-rice stands (adjacent to or downstream). We recommend caution regarding removing any aquatic vegetation from just upstream of established Texas wild-rice plants as this could drastically increase the effects of scour on the Texas wild-rice root wads. Additionally, establishment of Texas wild-rice stands in areas modeled to be high quality habitat during low-flow conditions is also recommended. In either case, protection (in this case, recreation control) of these areas would also need to occur to improve the chances for success. We echo Hardy (2011) by stressing that activities associated with Texas wild-rice enhancement need to be initiated early on in the first phase of the EARIP adaptive management program. If one waits to attempt this work during low flow conditions, the stress on the plants associated during those conditions will significantly decrease the success of any such activity.

As recommended for the Comal system, should the EARIP decide to move forward with an ERPA or components thereof for the San Marcos system, we recommend that the formation of an EARIP ERPA subcommittee or some form of third-party independent review team be assembled to oversee the ERPA implementation and studies conducted during the adaptive management phase of the HCP. Should the EARIP decide to only

pursue Texas wild-rice enhancement, these activities could likely be overseen by the San Marcos River ecosystem restoration subcommittee.

DRAFT

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APPENDIX K:

HDR ENGINEERING, INC. AND TODD ENGINEERS, "EVALUATION OF WATER MANAGEMENT PROGRAMS AND ALTERNATIVES FOR SPRINGFLOW PROTECTION OF ENDANGERED SPECIES AT COMAL AND SAN MARCOS SPRINGS," OCTOBER 2011

Evaluation of Water Management Programs and Alternatives for Springflow Protection of Endangered Species at Comal and San Marcos Springs

Prepared for:

Edwards Aquifer
Recovery Implementation Program
(EARIP)

Prepared by:

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Executive Summary

ES-1 Introduction

The Edwards Aquifer Recovery Implementation Program (EARIP) is a collaborative, consensus-based, regional stakeholder process that is tasked with the development of a plan to protect federally-listed endangered species, while managing Texas' Edwards Aquifer for the benefit of all. The primary threat to these species is the intermittent loss of habitat from reduced spring flows that is caused by naturally fluctuating rainfall patterns and regional pumping. The Edwards Aquifer is a unique karst aquifer, is the primary source of drinking water for more than 2 million people, and serves the domestic, agricultural, industrial, and recreational needs of the area. It also is the source of the two largest springs in Texas: Comal and San Marcos.

This report has been prepared under the direction of the EARIP Steering Committee and Program Manager and focuses on the technical evaluations of alternatives to provide springflow protection during droughts. HDR Engineering, Inc. (HDR), along with Todd Engineers and Westward Environmental, Inc., prepared this report on the bases of our participation in discussions with Stakeholders and the Program Manager and the performance of technical evaluations under the direction of the Program Manager. As preliminary results were developed and presented, often in the form of slide presentations, the Stakeholders revised or added new alternatives and programs and requested follow-up technical evaluations. This process continued until the Stakeholders informally agreed on a phased approach in implementing a Habitat Conservation Plan (HCP). Stakeholders informally adopted the Bottom-Up Program for springflow protection.

Improvements in groundwater and surface water conditions that are attributed to management programs need to be compared against a standard set of conditions in order to quantify the relative benefits of each program. This standard, or baseline, represents groundwater and springflow conditions that would occur absent the management programs being considered. This type of analysis isolates the impacts of a program from the normal variability in natural hydrologic conditions.

For this study, a baseline scenario was developed using the U.S. Geological Survey's MODFLOW groundwater model (MODFLOW) and incorporating the current allowable permitted pumping and Critical Period Management (CPM) rules for the model period of record (1947-2000).

ES-2 Bottom-Up Program

The Bottom-Up Program consists of four water management alternatives, including: (1) Voluntary Irrigation Suspension Program Option (VISPO), (2) Municipal Water Conservation, (3) SAWS ASR with Trade-Off Option, and (4) Stage V CPM Reductions. These alternatives individually cannot provide the required springflow protection, but together in an incremental and cumulative manner can provide significant springflow protection during the Initial Adaptive Management Phase. The activities are arranged in the selective cumulative (Stacked) manner as shown in Figure ES-1.

Figure ES-1. Schematic Showing Stacking of Alternatives in Bottom-Up Program

ES-2.1 Voluntary Irrigation Suspension Program Option

The operational concept of VISPO is to establish an agreement between holders of Edwards pumping permits (mostly irrigation) and the EARIP so that owners of the permits are willing to curtail or eliminate authorized pumping when drought conditions seem to threaten springflow protection. The agreement would pay the permit holders a "standby fee" each year for participating in VISPO plus an "implementation fee" for actual curtailment when a drought condition is triggered. At this time, five and ten year agreements are under consideration.

ES-2.2 Municipal Water Conservation

Municipal water conservation (Conservation) is based on a draft *Voluntary Dedicated Water Supply Program* that was developed by a Conservation Work Group, that explored water conservation potential for small water communities and water systems and the agricultural

sector. Most opportunities for conservation are believed to include: residential uses of "exempt" wells, "lost water" through municipal infrastructure deficiencies, industrial and commercial processes, rural and small community residential plumbing technologies, excessive landscape watering, use of gray water, and use of condensate and rain water harvesting for landscape.

ES-2.3 SAWS ASR with Trade-Off Option

The San Antonio Water System (SAWS) Aquifer Storage & Recovery (ASR) facilities in south Bexar County are used for storage, recovery, and transport of Edwards water. The water is obtained by leasing Edwards irrigation permits and stored in SAWS ASR. When needed for springflow protection, the water is recovered and delivered into SAWS water distribution system, thereby serving as an off-set or trade-off for SAWS not to pump their authorized Edwards permits by an equal amount.

ES-2.4 Stage V

In the event that implementation of the first three alternatives (layers) of the Bottom-Up Program is not sufficient for springflow protection, an additional CPM stage (Stage V) is added as an "emergency" measure.

ES-2.5 Springflow Protection from the Bottom-Up Program

The calculated springflow protection at Comal and San Marcos Springs from the Bottom-Up Program is measured by results from the MODFLOW simulations. The scenarios included baseline conditions and the successive stacking of four layers of alternatives. As implied, the baseline scenario represents conditions with full Initial Regular Permit (IRP) pumping constrained only by CPM rules. Successively, follow-up scenarios added one layer at a time in the Bottom-Up Program. Incrementally, one could determine the level of improvement in springflow protection for a given alternative by comparing results from a given layer with the results of the previous layer. It's important to note that performance of an alternative in the stacked layer approach would be different if simulations had been done as a stand-alone alternative or, possibly, in a different sequence.

The selected measures or indicators of springflow protection for Comal and San Marcos Springs are MODFLOW simulated hydrographs, number of months below preselected springflow thresholds, and selected springflow statistics. The periods of particular interest are the drought of record (1947-1957) and the full MODFLOW simulation period (1947-2000).

Representative measures of springflow protection are minimum monthly springflow, minimum 6-month moving average springflow, and long-term average springflow. These statistics are presented for the 1947-2000 period in Table ES-1 for Comal and San Marcos Springs. As shown in this summary, the minimum monthly average springflows for Comal and San Marcos Springs are 27 cfs and 51 cfs, respectively, for the full Bottom-Up Program. The minimum 6-month moving average springflows for Comal and San Marcos Springs are 39 cfs and 53 cfs, respectively. The long-term average springflows are 196 cfs at Comal and 155 cfs at San Marcos.

Table ES-1.
Selected Springflow Statistics in Cubic Feet per Second (1947-2000)

Spring	Statistic	Baseline (348K+)	VISPO	VISPO + Conservation	VISPO + Conservation + SAWS ASR	VISPO + Conservation + SAWS ASR + Stage V
Comal	Minimum Month	0	0	0	15	27
	Minimum 6-Month Moving Average	0	0	0	31	39
	Long-Term Average	178	182	186	195	196
San Marcos	Minimum Month	2	16	19	49	51
	Minimum 6-Month Moving Average	12	25	29	53	53
	Long-Term Average	153	153	154	154	155

ES-2.6 Estimated Cost

A summary of estimated costs for the Bottom-Up Program, not including administrative and management costs, is provided in Table ES-2 for layers 1-3 and Table ES-3 for layer 4. The greatest annual cost is for Edwards water leases, which average $12,395,000 per year over 1947-2000 conditions. The total annual cost is estimated to be $15,475,000. The most costly layers are VISPO and SAWS ASR. It's important to note that these program components also have the greatest impact on springflow protection.

Table ES-2.
Estimated Costs for Layers 1-3 of Bottom-Up Program

Program Component	Investment	Annual (54-Year Average)			
		Edwards Water Leases	Depreciation	O&M	Total
Layer 1: VISPO (10-Year Option)	N/A	$4,172,000	N/A	N/A	$4,172,000
Layer 2: Municipal Conservation (10-Year Program)	$19,730,000	$1,973,000	N/A	N/A	$1,973,000
Layer 3: SAWS ASR	N/A	$6,250,000	Waived	$3,080,000	$9,330,000
Total (Layers 1-3)	**$19,730,000**	**$12,395,000**	**$0**	**$3,080,000**	**$15,475,000**

Table ES-3.
Range of Estimated Costs for Layer 4 of Bottom-Up Program

Alternative (from 2011 Region L Water Plan)	Unit Cost (acft/yr)	Annual Cost
Irrigation Water Conservation	$140	$3,836,000
Municipal Water Conservation	$600	$16,440,000
Near-Term Water Management Strategies for SAWS	$1,300	$35,620,000
Long-Term Water Management Strategies for SAWS	$2,300	$63,020,000
Drought Management	$150 to $15,000+	$4,110,000 to $411,000,000+
Note: Annual cost is based on acquiring 27,400 acft/yr.		

1 Introduction

The Edwards Aquifer Recovery Implementation Program (EARIP) is a collaborative, consensus-based, regional stakeholder process that is tasked with the development of a plan to protect federally-listed endangered species, while managing Texas' Edwards Aquifer for the benefit of all. The Edwards Aquifer is a unique karst aquifer, is the primary source of drinking water for more than 2 million people, and serves the domestic, agricultural, industrial, and recreational needs of the area. It also is the source of the two largest springs in Texas: Comal and San Marcos (Figure 1-1). These springs, which are vital to eight endangered species, feed tributaries to the Guadalupe River that, in turn, provide freshwater inflows to bays and estuaries on the Gulf Coast.

There are eight federally-listed species listed as either threatened or endangered that depend directly on water in, or discharged from, the Edwards Aquifer system. They are the fountain darter, San Marcos salamander, San Marcos gambusia, Texas blind salamander, Peck's cave amphipod, Comal Springs dryopid beetle, Comal Springs riffle beetle, and Texas wild rice. The San Marcos gambusia has not been seen since 1982 and may be extinct.

The primary threat to these species is the intermittent loss of habitat due to reduced spring flows caused by naturally fluctuating rainfall patterns and regional pumping. Other threats include invasive non-native species, recreational activities, predation, direct or indirect habitat destruction or modification by humans, and other factors that decrease water quality.

This report has been prepared under the direction of the EARIP Steering Committee and Program Manager and focuses on technical evaluations of alternatives for providing springflow protection during droughts. Key technical analyses include:

- Incremental comparisons of baseline and springflow protection alternatives;
- Identification and assessment of surface water for recharge enhancement;
- Technical evaluations and costs of projects and programs to measure their effectiveness for springflow protection purposes; and
- Preparation of reports and presentations.

HDR Engineering, Inc. (HDR), Todd Engineers, and Westward Environmental, Inc. have participated in ongoing discussions and meetings with Stakeholders and provided technical analyses on topics identified by the Stakeholders. As preliminary results were developed and presented, often in the form of presentations at meetings, the Stakeholders revised or added new

alternatives and programs and requested follow-up technical evaluations. This process continued until the Stakeholders informally agreed on a phased approach in implementing a Habitat Conservation Plan (HCP). The approach begins with an Initial Adaptive Management Phase, which includes actions that are sufficient to avoid jeopardizing the continued existence of the species in the short-term while long-term actions and programs are being developed and, possibly, implemented. For this initial phase, the Stakeholders adopted the Bottom-Up Program for springflow protection. Since the initial concept of the Bottom-Up Program was formulated, it has been refined on the basis of performance in meeting the goals of springflow protection at acceptable costs.

The technical evaluation of the Bottom-Up Program is described in detail in Section 3 of this report. This description is preceded by discussion of the baseline against which all springflow protection alternatives were compared (Section 2); and followed by summaries of the technical evaluations of springflow protection alternatives (Section 4) that were considered prior to ultimate selection of the Bottom-Up Program. Special technical analysis requested by the EARIP Program Manager or were necessary to support technical evaluations of one or more alternatives springflow protection program are summarized in appendices.

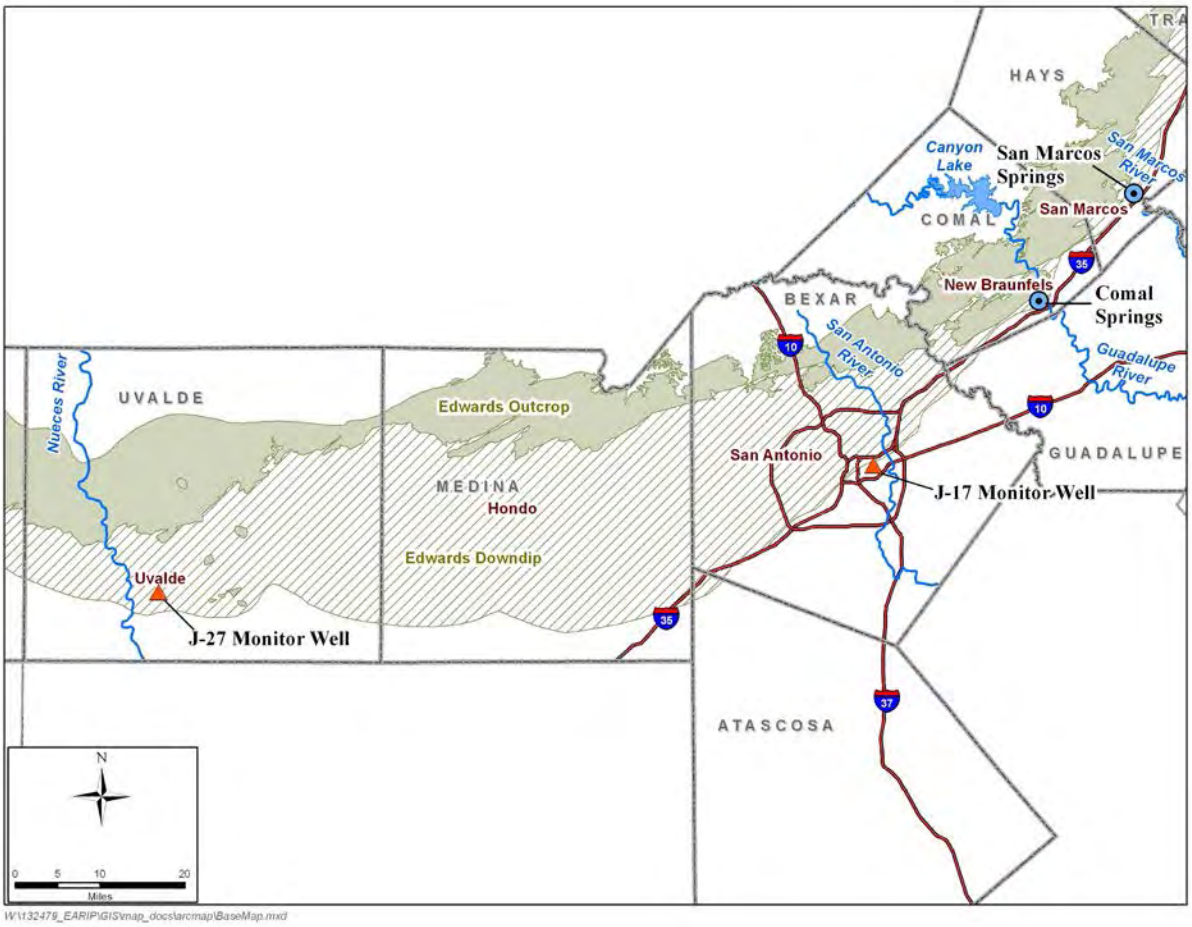


Figure 1-1. Location of Edwards Aquifer, Major Springs, and Key Monitoring Wells

2 Baseline Conditions

Groundwater and surface water conditions resulting from management programs need to be compared against a standard set of conditions in order to quantify the relative benefits of each program. This standard, or baseline, is defined by groundwater and springflow conditions that would occur absent implementation of the EARIP management programs being evaluated. This type of analysis isolates the impacts of a program from the normal variability in natural hydrologic conditions.

For this study, a baseline scenario was developed using the U.S. Geological Survey's MODFLOW groundwater model (MODFLOW)[1] and incorporating allowable permitted pumping and Critical Period Management (CPM) rules pursuant to Senate Bill 3 (SB3) of the 80th Texas Legislature for the model period of record (1947-2000). Development of the baseline pumping scenario and resulting springflows are summarized in this section.

2.1 Modifications to MODFLOW

The baseline scenario reflects recent conditions (including permitted withdrawals) without new springflow protection programs. Baseline development required revision of model input files to reflect total permitted pumping, application of CPM rules, and "firm yield" as defined by 2011 South Central Texas Regional Water Planning Group (Region L), re-affirmed by SB3, and documented in Edwards Aquifer Authority (EAA) rules[2].

Specific model changes included: (1) redefining the pumping in the model to equal the permitted withdrawal amounts, known as Initial Regular Permits (IRPs), of approximately 572,000 acre-feet per year (acft/yr); (2) adjusting geographic distribution and use type based on 2008 pumping within each county; and (3) revising trigger levels at springs and index wells for staged withdrawal reductions. These changes were accomplished with the MODFLOW well file and management modules as described in more detail below.

The structural set up of the model (hydrologic conductivity, faults, drains, etc.) and the original recharge package were not modified to develop baseline conditions. The original

[1] Lindgren, R.J., Dutton, A.R, Hovorka, S.D., Worthington, S.R.H. and Painter, S., 2004, Conceptualization and simulation of the Edwards Aquifer, San Antonio Region, Texas: U.S. Geological Survey Scientific Investigations Report 2004-5277, 143p.
[2] Edwards Aquifer Authority, 2010, http://www.edwardsaquifer.org/display_policies_rules_m.php?pg=rules .

recharge package simulates hydrologic conditions that occurred during the model period (1947-2000), which includes the drought of record (DOR).

2.1.1 Well File Modification

The geographic distribution and amounts of pumping in the original MODFLOW model were based on estimates of actual pumping from 1947 through 2000, the transient period of record for the model. These data from the model show pumping increased from about 170,000 acft/yr in the late 1940s to about 542,400 acft/yr in the late 1980s as illustrated in Figure 2-1.

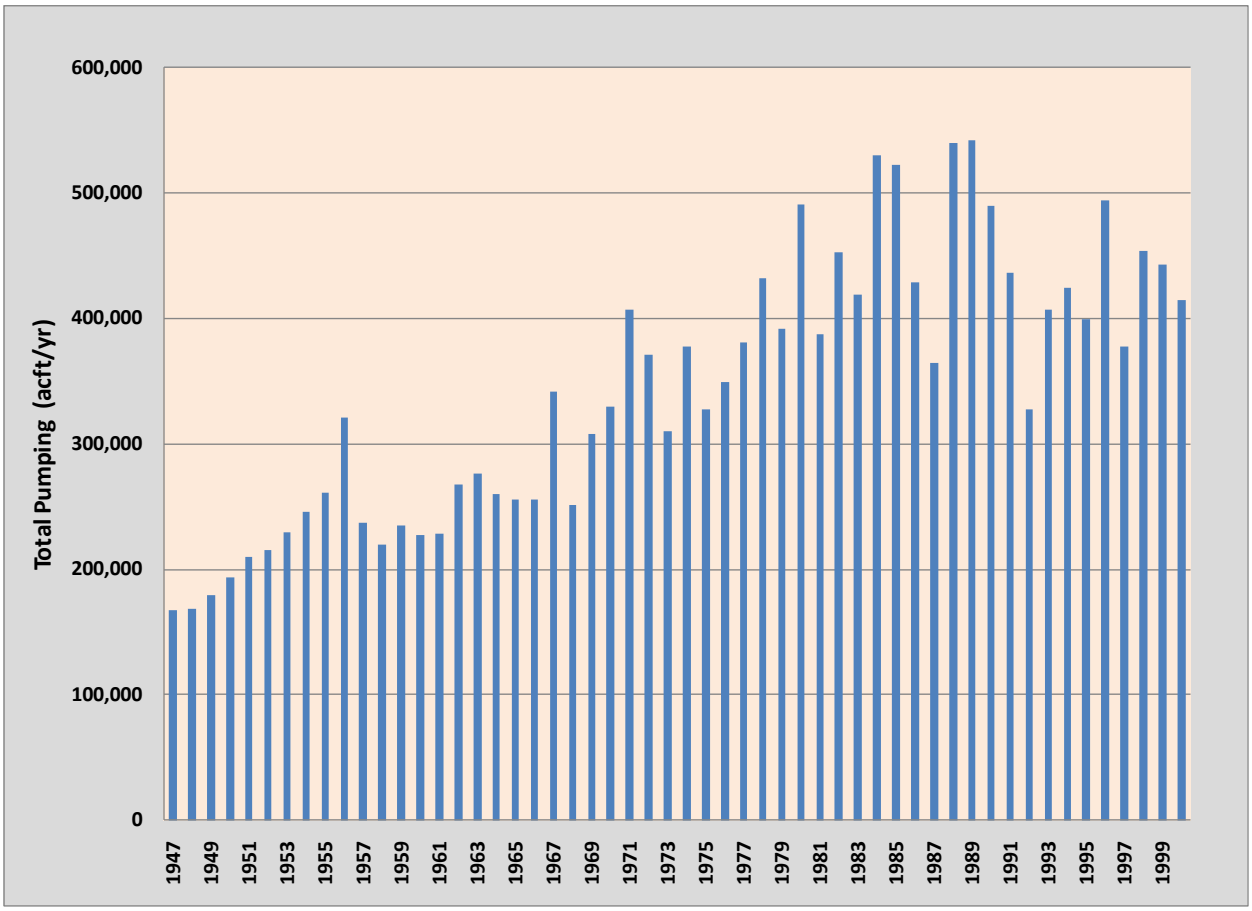


Figure 2-1. Historical Edwards Aquifer Withdrawals

The MODFLOW well file was modified for the baseline scenario to account for significant transfers (by purchase or lease) of initial regular permits from western to eastern counties and/or to change types of use (e.g., from irrigation to municipal). Furthermore, an additional 13,296 acft/yr of domestic pumping was added throughout the model area and 6,907 acft/yr of exempt Federal pumping was added to municipal totals in Bexar and Hays counties,

which results in total annual baseline withdrawals of 593,240 acft/yr from the aquifer within the EAA area. For the baseline scenario, this amount of pumping (after transient adjustments for CPM) was repeated each year. Authorized Edwards withdrawals are summarized in Table 2-1.

Section §711.329 of the EAA rules (adopted in June 2010) describes transferring pumping rights from west of Cibolo Creek to east of Cibolo Creek. These rules regarding transfers include assigning a portion of the lease or purchase to a groundwater trust, durations of the lease, and constraints on dates of sale, lease, and well registration. For purposes of this study, purchases and leases of initial regular permits (IRPs) originally west of Cibolo and presently used by entities east of Cibolo were returned to original locations in accordance with these new EAA rules. The net effect of these transfers or returns was no change in total pumping as the permitted pumping was reduced in one county and added to another. A summary of these transfer amounts is included in Table 2-1.

The spatial distribution of the permitted and exempt domestic and livestock pumping within each county is based on a 2005 annual permit distribution by county and use type provided by EAA. For example, the 2008 pumping totals for Bexar County municipal use were distributed among existing Bexar Municipal well locations on the basis of total 2005 permitted pumping at each well. Well locations and color-coded ranges of adjusted annual permitted pumping used in the baseline are shown in Figure 2-2.

Table 2-1.
Authorized Edwards Aquifer Withdrawals in Acre-Feet per Year

County	Purpose of Use	Current Authorized Amount	Cibolo Transfers - Leases	Federal Exemption	Revised Authorized Amount
Atascosa	Irrigation	2,127			2,127
Bexar	Industrial	31,054	0		31,054
Bexar	Irrigation	23,592	23		23,615
Bexar	Municipal	313,522		6,714	320,236
Comal	Industrial	9,381	0		9,381
Comal	Irrigation	808			808
Comal	Municipal	13,722	-750		12,972
Guadalupe	Industrial	546	0		546
Guadalupe	Irrigation	0			0
Guadalupe	Municipal	0	0		0
Hays	Industrial	2,766			2,766
Hays	Irrigation	704	0		704
Hays	Municipal	7,544	0	193	7,737
Medina	Industrial	1,916			1,916
Medina	Irrigation	63,415	422		63,837
Medina	Municipal	9,473			9,473
Uvalde	Industrial	529			529
Uvalde	Irrigation	86,016	306		86,322
Uvalde	Municipal	5,922			5,922
Total Permitted		**573,037**	**0**	**6,907**	**579,944**
Exempt (Domestic and Livestock		13,296			13,296
Total Pumping		**586,333**	**0**	**6,907**	**593,240**

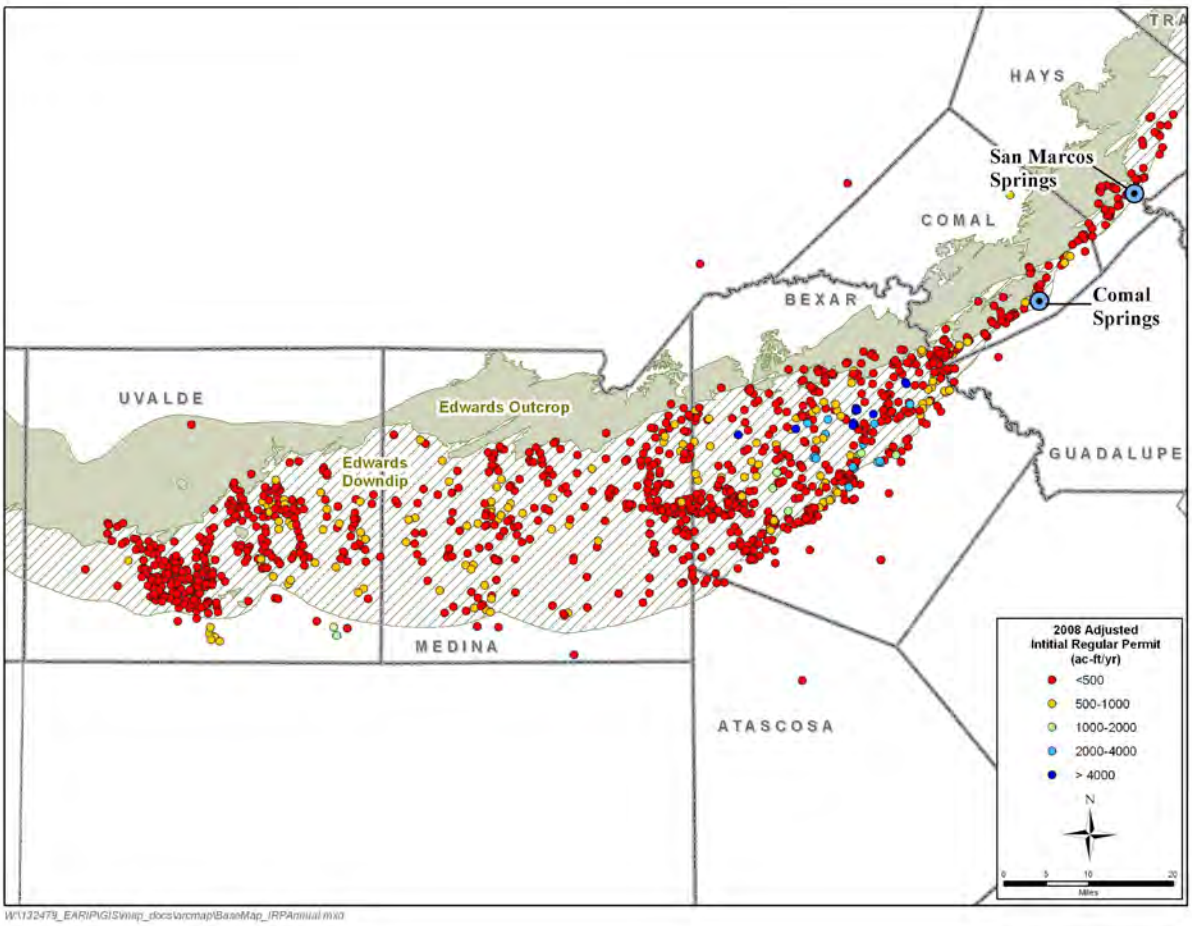


Figure 2-2. Locations of EAA Initial Regular Permits

Because well permits provide for pumping on an annual basis and the model evaluates hydrologic conditions monthly, the annual pumping total for each well was allocated to a monthly use pattern. This monthly allocation is based on an analysis by LBG-Guyton Associates on behalf of EAA that correlated the distribution of monthly pumping to well type. The percentages of annual pumping that are allocated to each month for municipal, industrial, and agricultural wells are listed in Table 2-2. As shown, agricultural use is highest in the late spring/early summer and lower during the winter months. Industrial use is assumed constant from month to month and municipal use typically increases in summer, but not to the degree associated with agricultural use. These patterns were applied to annual pumping totals for wells in the well file. To format the modified well file for use in MODFLOW, a FORTRAN program created for EAA by LBG-Guyton Associates was used.

Table 2-2
Monthly Distribution of Pumping

Pumping by Water Use (Percent of Annual)			
Month	**Municipal**	**Industrial**	**Agricultural**
January	6.9	8.3	1.1
February	6.4	8.3	1.5
March	7.5	8.3	2.6
April	8.0	8.3	5.7
May	8.4	8.3	19.0
June	9.1	8.3	29.0
July	11.0	8.3	16.1
August	11.1	8.3	9.9
September	9.0	8.3	4.7
October	8.4	8.3	5.2
November	7.1	8.3	3.8
December	7.1	8.3	1.4
Total	**100.0**	**100.0**	**100.0**

2.1.2 Amended Critical Period Management Rules

The management modules developed by HydroGeoLogic for EAA[3,4] were used to incorporate the CPM rules (Table 2-3). The management modules allow designation of well uses (municipal, industrial, or agricultural), well pools, triggers (associated with springs and/or observation wells), and various management rules, and automatically reduce pumping when triggers are reached in the simulations. Software tools developed by LBG-Guyton Associates and Todd Engineers were used to create the management module files, assign pumping wells to the correct pools and uses, and designate the triggers and management rules in the modules. CPM rules and associated annual withdrawals are summarized in Table 2-4. Although federal pumping is exempt from EAA CPM rules, each facility has their own drought management plan. For purposes of this assessment, federal water use is assumed to be reduced during drought conditions by reduction factors equivalent to EAA CPM.

[3] HydroGeoLogic, Inc., November 2004, Reference Manual for the Groundwater Management Package for MODFLOW-2000: Prepared for Edwards Aquifer Authority.
[4] HydroGeoLogic, Inc., December 2005, User's Manual for the Groundwater Management Package for MODFLOW-2000: Prepared for Edwards Aquifer Authority.

Table 2-3
Critical Period Management Rules

Critical Period Stage	San Antonio Pool				Uvalde Pool	
	Comal Springs (cfs)	San Marcos Springs (cfs)	Index Well J-17 (ft-msl)	Withdrawal Reduction (%)	Index Well J-27 (ft-msl)	Withdrawal Reduction (%)
I	<225	<96	<660	20	NA	NA
II	<200	<80	<650	30	<850	5
III	<150	NA	<640	35	<845	20
IV	<100	NA	<630	40	<842	35

Table 2-4
Withdrawal Reductions under CPM Rules As Amended by SB3

Critical Period Stage	San Antonio Pool		Uvalde Pool		Total Allowable Permitted Pumping (acft/yr)
	Allowable Permitted Pumping (acft/yr)	Withdrawal Reduction (%)	Allowable Permitted Pumping (acft/yr)	Withdrawal Reduction (%)	
Unrestricted	480,570	N/A	92,467	N/A	573,037
I	384,456	20	92,467	N/A	476,923
II	336,399	30	87,844	5	424,243
III	312,370	35	73,974	20	386,344
IV	288,342	40	60,104	35	348,446

2.1.3 Initial Water Levels

In order to apply the new well file and CPM rules, initial water level conditions within the Edwards Aquifer for the baseline had to be developed. In the original MODFLOW model, a steady state run was used to develop initial conditions for the transient model. The steady state run ensures that the hydrologic components of the model are internally in equilibrium. For the baseline scenario, the water level output from the original MODFLOW steady state run was used as input to the transient portion of the model (1947-2000) for the baseline scenario. The steady state run resulted in an initial water level for Index Well J-17 of 668 feet above mean sea level (ft-msl), which is close to the long-term average of 663 ft-msl.

2.1.4 Resolution of Dry Cells in the Model

The additional stress of increased pumping in the baseline scenario results in some dry cells in the model. A dry cell occurs when simulated water levels fall below the bottom of a model cell. Dry cells can cause numerical instability in the model and prevent the inactive cell from accepting additional recharge or continuing to simulate flow.

While there are numerical methods to re-wet dry cells, the original model did not incorporate re-wetting options and allowed the cells to remain dry through the remainder of the transient simulation. Consequently, the original model simulated a total of 56 dry cells at the end of the first half of the model (including the drought of record), thereby reducing recharge somewhat during that time period. Although the cause for those dry cells is not entirely clear, the lack of recharge was accounted for in the calibration of the model for water levels and springflow at key targets (J-17, Comal Springs, etc.). The location of these dry cells indicates potential model inaccuracies in the recharge zone including aquifer parameters such as storativity values. The number and locations of the dry cells are considered acceptable given the overall objectives of the original model. These inaccuracies are discussed in more detail in the model documentation (Lindgren et al., 2004).

Increased pumping for baseline conditions exacerbates the dry cell problem, especially during the drought of record, to a point where a reasonable numerical solution is not possible. Possible causes of the problem could be numerical error and/or over-stressing the northern constant flux boundary from increased pumping. Because the management programs in this project involve enhanced recharge or lower pumping (both resulting in higher water levels), subsequent model runs did not encounter dry cell problems as significant as under baseline conditions.

To resolve the dry cell issue, a MODFLOW module was applied to the simulation to allow dry cells to be “re-wet.” The module provides a numerical solution that does not prevent a cell from going dry, but simply allows the cell subsequently to be re-wet with additional recharge. The module is included in MODFLOW 2000[5] as a re-wetting option that allows dry cells to become “wet” if water levels in surrounding cells reach a certain level, but remain dry if surrounding cells do not meet the re-wetting criteria. Because different model inputs result in

[5] Harbaugh. A.W., Banta, E.R., Hill, M.C., and McDonald, M.C., 2000, MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model – User guide to modularization concepts and the ground-water flow process: U.S. Geological Survey Open-File Report 00-92.

different cells remaining dry, changes to recharge could vary with each model run. In addition, this package sometimes causes numerical instability due to the iterative and non-linear nature of the solution.

Notwithstanding these issues, the MODFLOW re-wetting package appears to produce valid results for the analyses of management programs presented herein. Significant numerical instability was not observed, and dry cells were re-wet according to program criteria. A check of the model mass balance indicated similar, but slightly higher, recharge amounts in the baseline scenario when compared to the original model. Differences were small and judged to be insignificant. For all model runs, recharge input and output were compared to ensure mass balance.

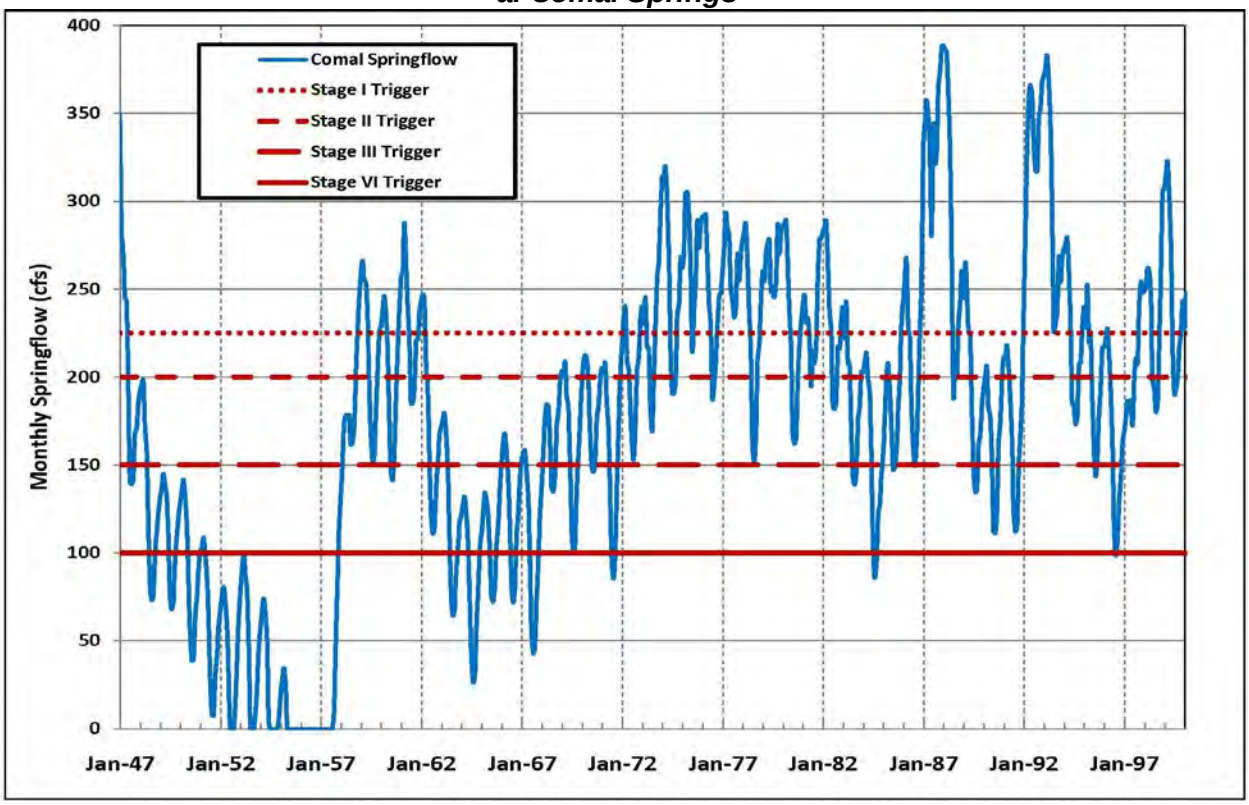
2.2 Results of Baseline Scenario

The results of the baseline scenario are documented from model output of springflow at Comal and San Marcos Springs and water levels at index wells J-17 (San Antonio Pool) and J-27 (Uvalde Pool) (Figure 1-1). For the San Antonio Pool, critical period stages are triggered by any one of three triggers (Comal Springs, San Marcos Springs, and/or J-17). For the Uvalde Pool, critical period stages are triggered only by J-27.

As shown in Figure 2-3a, Comal Springs flow is below 225 cfs (the trigger for Stage I CPM), for most of the simulation period. More restrictive CPM stages are triggered at flow rates of 200 cfs (Stage II), 150 cfs (Stage III), and 100 cfs (Stage IV), as shown in Table 2-3. A comparison of Comal Springs with San Marcos Springs (Figure 2-3b) illustrates the importance of Comal Springs as the primary springflow trigger for critical periods. Under baseline conditions, Comal Springs flow reaches critical period stages well before San Marcos springflow.

Figures 2-4a and 2-4b show simulated water levels for the baseline scenario at index wells J-17 and J-27, respectively. Similar to Comal Springs, J-17 levels indicate CPM withdrawal reductions during most of the baseline scenario. Baseline results for the Uvalde Pool show Stage IV conditions for the 1950s and 1960s. However, after about 1975, the Uvalde Pool is out of critical period.

a. Comal Springs



b. San Marcos Springs

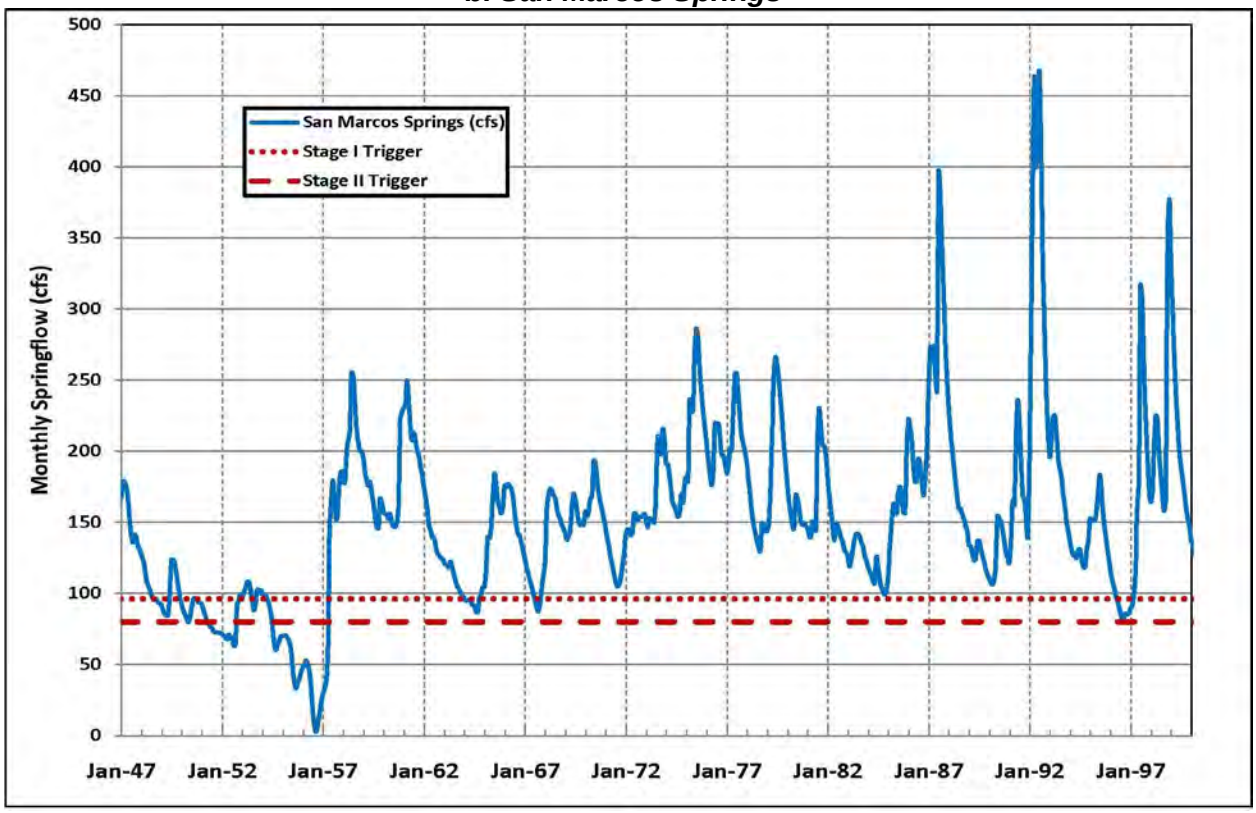
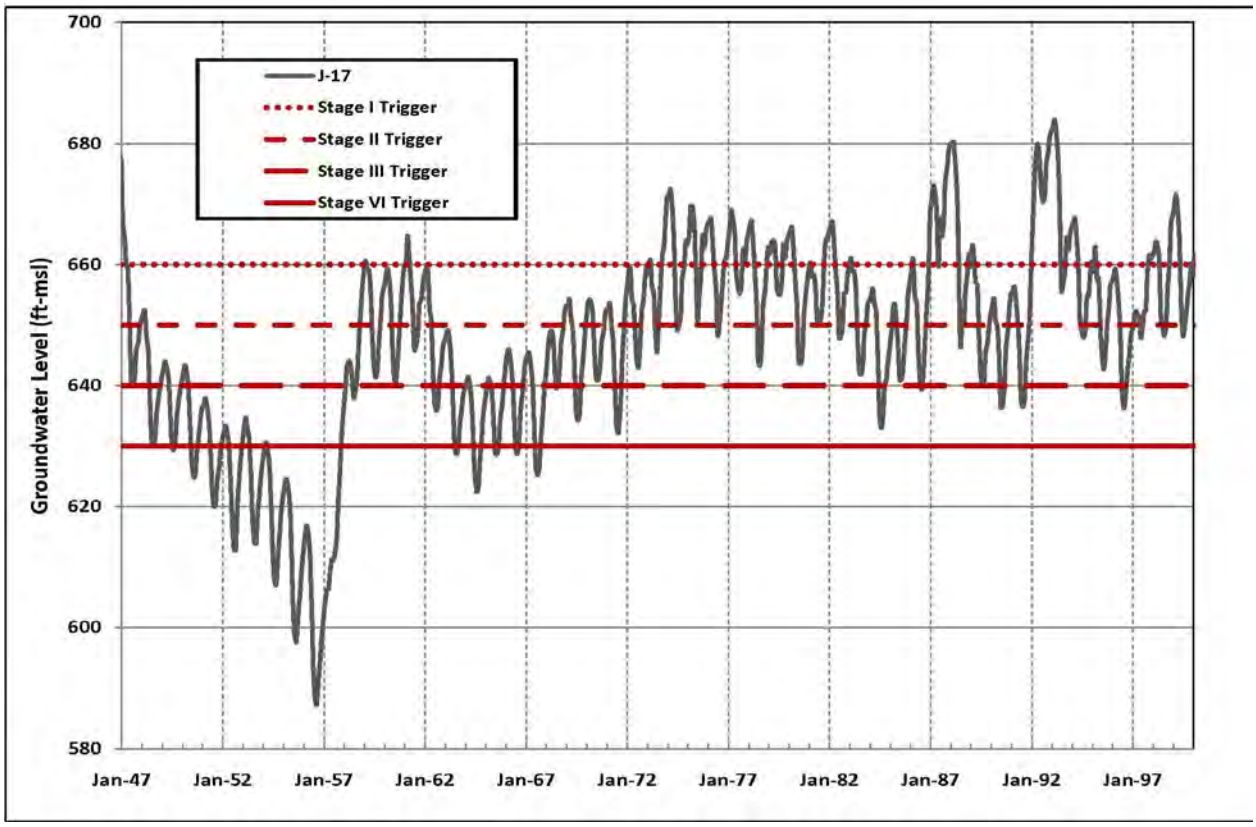


Figure 2-3. Baseline Springflow

a. J-17



b. J-27

Figure 2-4. Baseline Water Levels at Index Wells

As shown in Table 2-5, CPM Stage IV is in effect for a total of about 10 years for the San Antonio Pool and about 22 years for the Uvalde Pool in the first half of the model simulation period (1947-1973). Stage IV is only triggered for 3 months in the San Antonio Pool and not triggered at all in the Uvalde Pool during the second half of the model simulation period (1974-2000).

Table 2-5
Number of Months in Critical Period Under Baseline Conditions

Critical Period Stage	Number of Months					
	1947-1973		1974-2000		1947-2000	
	San Antonio Pool	Uvalde Pool	San Antonio Pool	Uvalde Pool	San Antonio Pool	Uvalde Pool
Unrestricted	14	33	116	324	130	357
I	48	N/A	97	N/A	145	N/A
II	67	14	79	0	146	14
III	76	19	29	0	105	19
IV	119	258	3	0	122	258
TOTAL	324	324	324	324	648	648

3 Bottom-Up Program

The Bottom-Up Program consists of four water management alternatives that individually cannot provide the required springflow protection, but collectively in an incremental and cumulative manner can provide significant springflow protection during the Initial Adaptive Management Phase. The activities are arranged in the selective cumulative (stacked) manner as shown in Figure 3-1.

Figure 3-1. Schematic of Stacking of Alternatives in Bottom-Up Program

3.1 Water Management Alternatives

The Bottom-Up Program consists of four water management alternatives, including: (1) Voluntary Irrigation Suspension Program Option; (2) Municipal Water Conservation; (3) SAWS ASR with Trade-Off Option; and (4) Stage V CPM Emergency Reductions.

3.1.1 Voluntary Irrigation Suspension Program Option (VISPO)

The operational concept of VISPO is to establish agreements between permit holders (mostly irrigators) and the EARIP so that they are willing to suspend authorized pumping when drought conditions threaten springflow protection. The agreement would pay the permit holders a “standby fee” each year for participating in VISPO plus an “implementation fee” for actual curtailment when a drought condition is triggered. Currently (2011), five and ten year agreements are under consideration.

Evaluation of the VISPO alternative for springflow protection involved the following technical assumptions:

- VISPO will apply to about 40,000 acft/yr (IRP value) of Edwards withdrawal rights. Geographic distribution among counties is based on expressions of interest as of May 2011, which total 17,227 acft/yr[6]. Participation from any single county, however, is assumed to be limited to 15,000 acft/yr. Hence, the simulated county distribution of IRP participation in VISPO is as follows: 15,000 acft/yr in Uvalde, 15,000 acft/yr in Medina, 8,520 acft/yr in Bexar, 1,045 acft/yr in Atascosa, and 435 acft/yr in Comal.
- The suspensions will be triggered on January 1 of any given year if the water level in J-17 is below 635 ft-msl level on October 1 of the previous year.
- These suspensions for a given county are assumed to be equally distributed across all irrigation wells within that county.
- Simulated pumping reductions associated with VISPO will be consistent with CPM.
- It is assumed that most, if not all, of the Edwards water committed to the VISPO program element will be from the base (or restricted) portions of irrigation IRPs.
- The cost estimate will be based on information from the VISPO Work Group. More specifically, the cost estimate will be based on a combination of 5-year and 10-year lease options. The average annual cost is assumed to equal the average annual cost for five years of the 5-year option and for ten years of the 10-year option. It's assumed that 70 percent of the options would be in 5-year agreements and 30 percent would be in 10-year agreements. The standby fee will be applied each year and the implementation fee will be applied only in years when VISPO is triggered. The long-term annual average cost will be based on the 1947-2000 model simulation period.

3.1.2 Municipal Water Conservation

Municipal water conservation (Conservation) is based on a draft Voluntary Dedicated Water Supply Program that was developed by a Conservation Work Group of the EARIP, which explored water conservation potential for small communities and water systems and the agricultural sector. Most opportunities for conservation were assumed to include: residential uses of "exempt" wells, "lost water" through municipal infrastructure deficiencies, industrial and commercial processes, rural and small community residential plumbing technologies, excessive landscape watering, use of gray water, and use of condensate and rain water harvesting for landscape.

The testing of the Conservation alternative for springflow protection consisted of the following technical assumptions:

- Total pumping reductions will amount to 10,067 acft/yr when the Edwards Aquifer is not in CPM. These reductions are to be accomplished through: toilet retrofit (1,531 acft/yr); replacement of inefficient fixtures (1,286 acft/yr); leak detection and repair (3,750 acft/yr); large-scale retrofit (2,500 acft/yr); and landscape watering savings (1,000 acft/yr).

[6] EAA, May 2, 2011 spreadsheet

- Pumping reductions will be geographically distributed in proportion to municipal IRPs. This is considered a reasonable approximation given that EARIP model assumptions do not accommodate a potential shift from initial urban savings to rural communities over time.
- Pumping will be reduced according to CPM rules.
- Cost estimates for the conservation layer will be calculated using unit rates that were initially provided by the Work Group and updated though discussions.
- In the event that there is insufficient participation by small communities and water systems and the agricultural sector in the implementation phase, the San Antonio Water System (SAWS) has committed to provide an equivalent reduction in their demand on the Edwards.

3.1.3 SAWS ASR with Trade-Off Option

The SAWS Aquifer Storage & Recovery (ASR) facilities are used for storage, recovery, and transport of Edwards water. The water for this alternative is obtained by leasing Edwards irrigation permits and storing this water in the SAWS ASR facilities in south Bexar County. When needed for springflow protection, the water is recovered and delivered into SAWS water distribution system to reduce or off-set (trade-off) SAWS permitted pumping of the Edwards Aquifer by an equal amount.

Technical assumptions for evaluation are based on extensive discussions with SAWS officials and the working documents provided by SAWS and the EARIP ASR Work Group with the following file names:

05-17-11 Attachment 5a SAWS ASR EARIP Exec Summary 051211.pdf

05-17-11 Attachment 5b EARIP SAWS ASR Concept 051211 Final.pdf

05-27-11 SAWS ASR modeling52711.docx

There are some minor inconsistencies and broad generalizations among the three documents and within the Final Concept paper. These inconsistencies can be attributed mainly to illustrative examples and are not to be treated as constraining this layer of the Bottom-Up Program. It is understood that final details may be adjusted as the Habitat Conservation Plan (HCP) and other program documents are developed. As a result, the following Technical Assumptions are not fully consistent with all three documents, but do honor SAWS' concepts as discussed with the SAWS ASR Work Group.

The following technical assumptions were used in evaluation of the SAWS ASR with Pumping Trade-Off Option:

- Irrigation leases and options are obtained on 50,000 acft/yr of Initial Regular Permits (IRPs) for irrigation and other use types. The leases and options will be divided into thirds (tiers). The first third, approximately 16,667 acft/yr, will be leased at all times for "relaxed" filling of SAWS ASR. The middle third of the options will be implemented in the year after the 10-year moving annual average of Edwards recharge is lower than 572,000 acft/yr and is likely to continue to decrease. The last third will be implemented when the 10-year moving recharge average is less than 472,000 acft/yr. When the options are implemented, this water will either be pumped to fill SAWS ASR or not pumped at all. When the SAWS ASR is in recovery mode, the leased water will not be pumped. When the options are not implemented, the irrigation water is assumed to be pumped by the owner of the permit. It's well understood that future droughts will not replicate the historic Drought of Record. With this in mind, the SAWS ASR Advisory Group may convene at any time to address on-going drought situations by reviewing the rolling-average of recharge triggers and other drought indicators, or potentially accelerating the implementation of the options. Decisions will be guided by Adaptive Management.
- Water to fill SAWS ASR may be provided by SAWS from any existing unused Edwards supplies and from leases and options under the Bottom-Up Program. These two sources of water for SAWS ASR provide an additional element of protectiveness for the springs and the endangered species. Simulations for the EARIP, however, assume that all stored Edwards water in excess of initial storage is obtained under leases associated with the SAWS ASR component of the Bottom-Up Program.
- It's assumed that the leases and options with be distributed evenly among all existing irrigation wells.
- Preliminary operational and modeling procedures are for "dynamic sharing" of injection, recovery, and transmission capacities associated with SAWS ASR facilities. In this context, "dynamic sharing" means that the maximum commitment of SAWS ASR recovery and transmission capacity for direct springflow protection is 100 percent during severe drought.
- Once a severe drought appears to threaten springflow protection, as declared by the SAWS ASR Advisory Group, EARIP may use up to 100 percent of the conveyance capacity of existing (2011) SAWS ASR facilities to off-set Edwards Aquifer demand by SAWS when the monthly average groundwater levels at J-17 are below 630 ft-msl. The selected wells with reduced demand (trade-off or off-set) include Maltsberger, Naco, Stahl, and Randolph, which are located in the northeast part of SAWS distribution system.
- The storage and recovery schedules, including the rates of Edwards pumping off-set will be based on preliminary Bottom-Up Program simulations and limited by the storage, recovery, and transmission capacities of existing facilities. The episodic recovery schedule from SAWS ASR presented herein is limited to 46,000 acft/yr and 126,000 acft of water for a major drought.
- Other major SAWS ASR assumptions include:
  - The initial storage is 80,000 acft;
  - The targeted storage capacity is 120,000 acft during normal and wet conditions and 200,000 acft during severe drought conditions;

  - Guidelines for filling will be at an annual average of 20 MGD (22,400 acft/yr) subject to increase as necessary;
  - Topping-off the ASR to stored volumes between 120,000 acft and 200,000 acft will begin when the 10-year moving recharge average is less than 572,000 acft/yr (based on climatic conditions identical to those that occurred during the Drought of Record) or as decided by the SAWS ASR Advisory Group;
  - There are no water losses from SAWS ASR; and
  - Guidelines for the filling schedule were taken from pages 6 and 7 in concept document with a file name of: *05-17-11 Attachment 5b EARIP SAWS ASR Concept 051211 Final.pdf.*

- The recovery rate for stored water from SAWS ASR is limited to the current transmission capacity from SAWS ASR to Seale and Artesia Pump Stations, which is 60 million gallons per day (MGD), or 5,600 acre-feet per month (acft/mo).
- Cost estimates for this program element are based on the 1947-2000 simulation period and definition provided in SAWS' document named: *05-17-11 Attachment 5b EARIP SAWS ASR Concept 051211 Final.pdf.* Since issuance of the referenced document, however, SAWS has agreed to absorb depreciation costs for existing facilities. The remaining cost (operations, maintenance, and power) will be considered EARIP expenses.
- All permitted withdrawals as constrained by CPM or affected by dedication to Bottom-Up Program activities (i.e., VISPO, Conservation, leased water for the SAWS ASR Project, and Stage V) are identified as firm supplies and are pumped in the model in accordance with the baseline established by the EARIP Steering Committee.

3.1.4 CPM Stage V

In the event that implementation of the first three alternatives (layers) of the Bottom-Up Program is not sufficient for springflow protection, an additional CPM stage (Stage V) is added as an "emergency" measure.

The following technical assumptions were used in evaluation of CPM Stage V:

- Permitted pumping during Stage V will be reduced by 44 percent from the IRP values in both the San Antonio and Uvalde Pools. Domestic and livestock pumping are not restricted. Federal pumping, which is unpermitted, is assumed to be reduced in critical period by the same percentages as permitted pumping.
- The percentage reductions are equal for the San Antonio and Uvalde pools. CPM Stage V is considered to be an "emergency" situation and all permit holders would be required to make an equal sacrifice. The reduction factor for the two pools is 44 percent based on the percentage reduction to move from an IRP total of approximately 572,000 acft/yr to a critical period floor of 320,000 acft/yr. The associated reductions in permitted pumping during Stage V (relative to Stage IV) in the San Antonio and Uvalde Pools are 19,200 acft/yr and 8,200 acft/yr, respectively.

- Stage V is in effect in the San Antonio Pool when the water level at J-17 is lower than 625 ft-msl and in the Uvalde Pool when the water level in J-27 is lower than 840 ft-msl. Stage V would not be triggered in the Uvalde Pool when the San Antonio Pool is not triggered.
- A range of potential costs attributable to Stage V are estimated using available information from the 2011 South Central Texas Regional Water Plan. Approximate costs for demand reduction include: conservation, drought management, and replacement water supplies delivered to Bexar County as necessary to produce about 27,400 acft/yr.

3.1.5 Refinement of the Bottom-Up Program

The Bottom-Up Program described in this document and adopted by the EARIP is built on two earlier tests. Major assumptions in these two tests are summarized in Table 3-1.

Table 3-1
Summary of Technical Assumptions in Two Previously Proposed Bottom-Up Programs

Alternative	Test	
	First	**Second**
VISPO	• Irrigation Suspensions: o Medina Co.: 20,000 acft/yr o Uvalde Co.: 15,000 acft/yr o Bexar Co.: 5,000 acft/yr • Trigger: o September 1 when J-17 is lower than 650 ft-msl • Annual Cost: $10,216,000	• Same as first test
Conservation	• Unchanged	• Unchanged
SAWS ASR	• Lease 50,000 acft/yr • Leases are not pumped except to fill ASR • Recovery begins when flow from Comal Springs is less than 50 cfs • ASR Storage: Starts empty, Full Capacity is 200,000 acft • Recovery Off-Sets SAWS pumping in NE section • Can utilize up to 100% of transmission capacity • Annual Cost: $14,336,000	• Same as first test, except: o ASR Storage: Starts at 40,000, Full Capacity is 150,000 acft o Annual Cost: $10,070,000
Stage V	• Permitted pumping reduction is 44% • Triggers: o San Antonio Pool: J-17 at 625 ft-msl o Uvalde Pool: J-27 at 840 ft-msl	• Same as first test, except: o Both pools are triggered by J-17 at 625 ft-msl

A comparison of the technical assumptions for the tentatively adopted Bottom-Up Program, as described in Section 3.1.4 with the first two iterations shows the greatest changes were in the VISPO and SAWS ASR components of the program. For VISPO, the major changes were implementation triggers and geographic distribution of pumping reductions. For SAWS ASR, the greatest change was implementing the 10-year moving average of Edwards recharge to trigger leasing of permits and filling of ASR.

More details and results of these first two iterations are summarized in presentations posted on the EARIP web site.

3.2 Layers

Springflow protection at Comal and San Marcos Springs from the Bottom-Up Program is assessed on the basis of a series MODFLOW simulations. These simulations include baseline conditions and the successive stacking of four layers. As implied, the baseline represents conditions with full IRP pumping that is constrained only by EAA CPM rules. Successive layers are added one at a time in the Bottom-Up Program. Incrementally, one may estimate the degree of improvement in springflow protection for a layer by comparison with the results for a previous layer. It's important to note that performance of Bottom-Up Program components in the stacked layer approach may be different if components are examined individually or in a different sequence.

The selected measures or indicators of springflow protection for Comal and San Marcos Springs are simulated hydrographs from MODFLOW; numbers of months below preselected springflow thresholds; and minimum monthly springflow, minimum 6-month moving average springflow, and long-term average springflow. The periods of particular interest are 1947-1957 (drought of record) and 1947-2000 (MODFLOW simulation period).

3.2.1 Voluntary Irrigation Suspension Program Option (Layer #1)

Pumping reductions attributable to VISPO are triggered for years when drought conditions are anticipated. Figure 3-2 illustrates years during the MODFLOW simulation period when this option is in standby or implementation mode. As illustrated, the option was implemented and irrigation suspended 15 years during 1947-1973 and 1 year during 1974-2000.

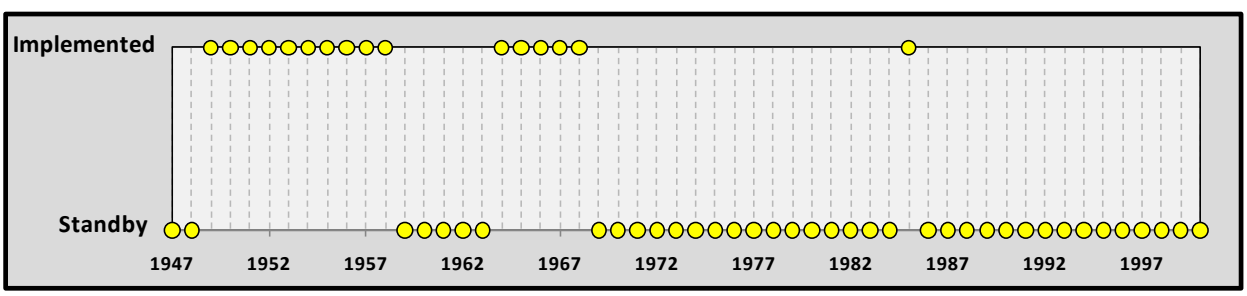


Figure 3-2. Annual Status of VISPO Operations (1947-2000)

The permitted pumping for participants in VISPO is subject to suspension and any simulated pumping reductions are consistent with CPM stage. For example, if suspension was triggered and there were no CPM restrictions for entire year (highly unlikely), the full IRP pumping reductions would be 40,000 acft. On the other hand, if CPM Stage IV were in effect for

the entire year that suspension was triggered, the actual reductions in Edwards withdrawals would be 24,750 acft. It's important to note that pumping reductions due to VISPO may allow some increases in other permitted pumping, which can change CPM duration and stage. For example, if baseline pumping (without VISPO) caused the San Antonio Pool to be in Stage IV for eight months in a given year, and reductions in pumping (with VISPO) were sufficient to reduce the duration in Stage IV to four months, the Stage IV restrictions would have been relaxed by four months for all permits in the San Antonio pool.

For the periods 1947-1957 and 1947-2000, VISPO pumping reductions and increases in allowable pumping due to less time in given CPM stages are presented in Table 3-2. This table shows that the average VISPO net pumping reductions were 20,540 acft/yr for the 1947-1957 period. For the 1947-2000 period, VISPO net pumping reductions averaged 10,427 acft/yr. The average VISPO net pumping reductions are less for the 1947-2000 period than the 1947-1957 period because of the intense drought in the latter period.

Table 3-2.
Average Annual Pumping Reductions for Layer #1

Units: acft/year

Condition	San Antonio Pool	Uvalde Pool	Total
Potential Reductions (IRP Face Value)	25,000	15,000	40,000
1947-1957	12,443	8,097	20,540
1947-2000	4,716	3,011	10,427

3.2.2 VISPO + Municipal Water Conservation (Layer #2)

In the adopted Bottom-Up concept, a Municipal Conservation component is added to the VISPO component. The Municipal Conservation component is active each year and the net reductions in pumping are consistent with concurrent CPM stage. The full potential pumping reductions for Layers #1 and #2 total 50,067 acft/yr.

For the periods 1947-1957 and 1947-2000, cumulative net pumping reductions for VISPO and Municipal Conservation (Layer #2) are presented in Table 3-3. This table shows that average pumping reductions through Layer #2 were 26,965 acft/yr for the 1947-1957 period. For the 1947-2000 period, net pumping reductions through Layer #2 averaged 15,390 acft/yr. During the drought of record, the net effect of the Municipal Conservation layer was a pumping reduction of 6,425 acft/yr.

Table 3-3.
Average Annual Pumping Reductions through Layer #2*

Units: acft/year

	San Antonio Pool	Uvalde Pool	Total
Potential Reductions (IRP Face Value)	34,803	15,264	50,067
1947-1957	18,749	8,216	26,965
1947-2000	12,233	3,157	15,390

* Note: Cumulative Adjustments for VISPO and Municipal Conservation

3.2.3 VISPO + Conservation + SAWS ASR with Trade-Off Option (Layer #3)

In Layer #3 of Bottom-Up Program, the SAWS ASR with Trade-Off component is added to the VISPO and Municipal Conservation components. Three key elements of the SAWS ASR with Trade-Off Option include: (1) leasing of IRPs to either fill SAWS ASR or to suspend the permitted pumping, (2) filling SAWS ASR, and (3) recovering stored water for trade-off (off-set) of SAWS permitted pumping at selected pump stations. A schematic of the SAWS ASR with Trade-Off operational concept is presented in Figure 3-3.

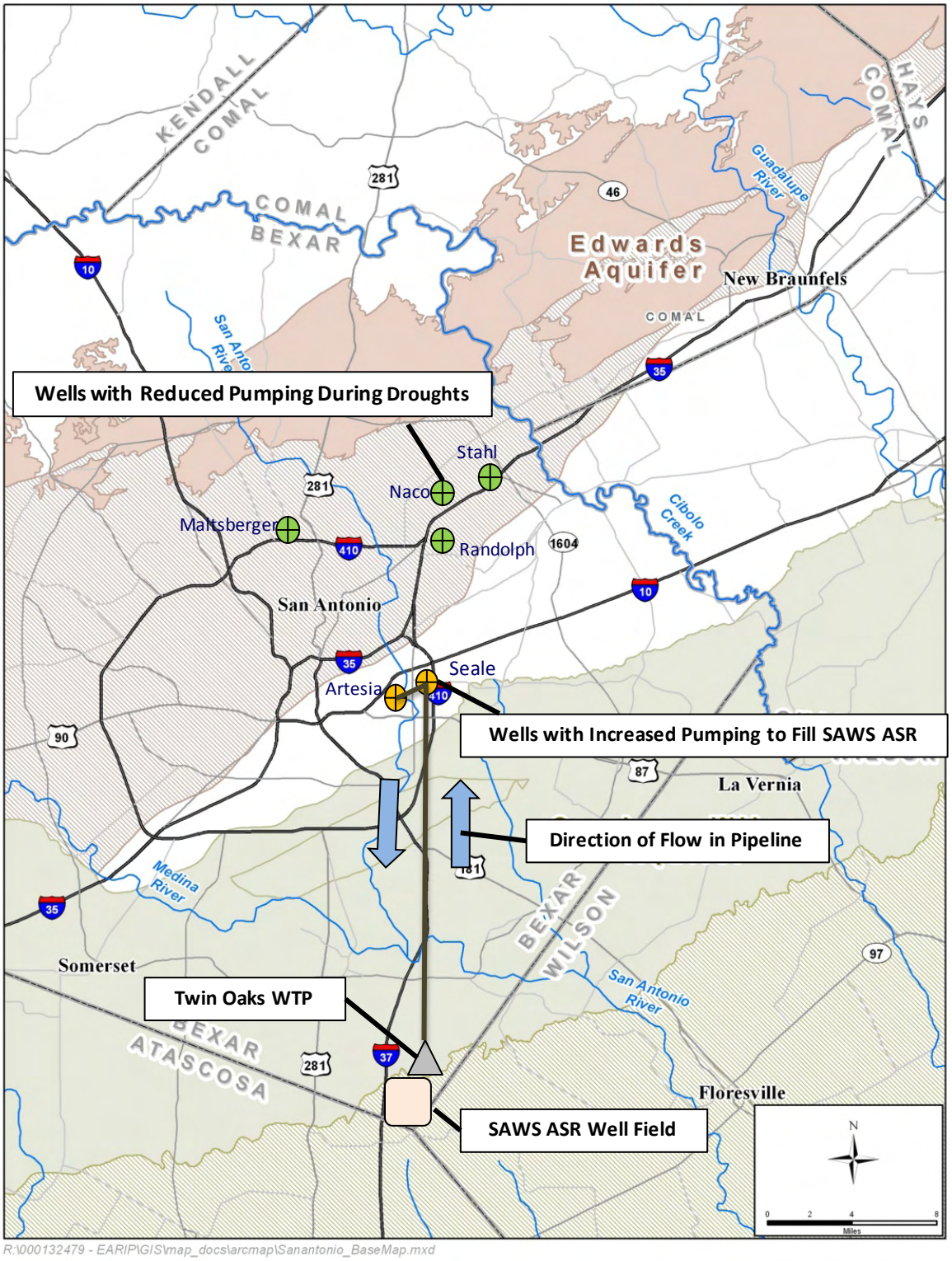


Figure 3-3. SAWS ASR Operational Concept

As formulated by SAWS, the 50,000 acft/yr of IRPs associated with Layer #3 is divided equally into three tiers. The first tier is to be active at all times. Activation of the second and third tiers is based on a 10-year moving average of Edwards recharge. When the 10-year moving average recharge is between 472,000 and 572,000 acft/yr, the second tier of leases are implemented. When the 10-year moving average recharge is less than 472,000, the second and third tiers of leases are implemented. Figure 3-4 illustrates the annual Edwards recharge, the 10-year moving recharge average, and the three tiers. Figure 3-5 illustrates the activation of these tiers during the simulation period. As shown, all three tiers were implemented for 10 years; the first two tiers were implemented for 9 years; and only tier 1 was implemented for the remaining 35 years.

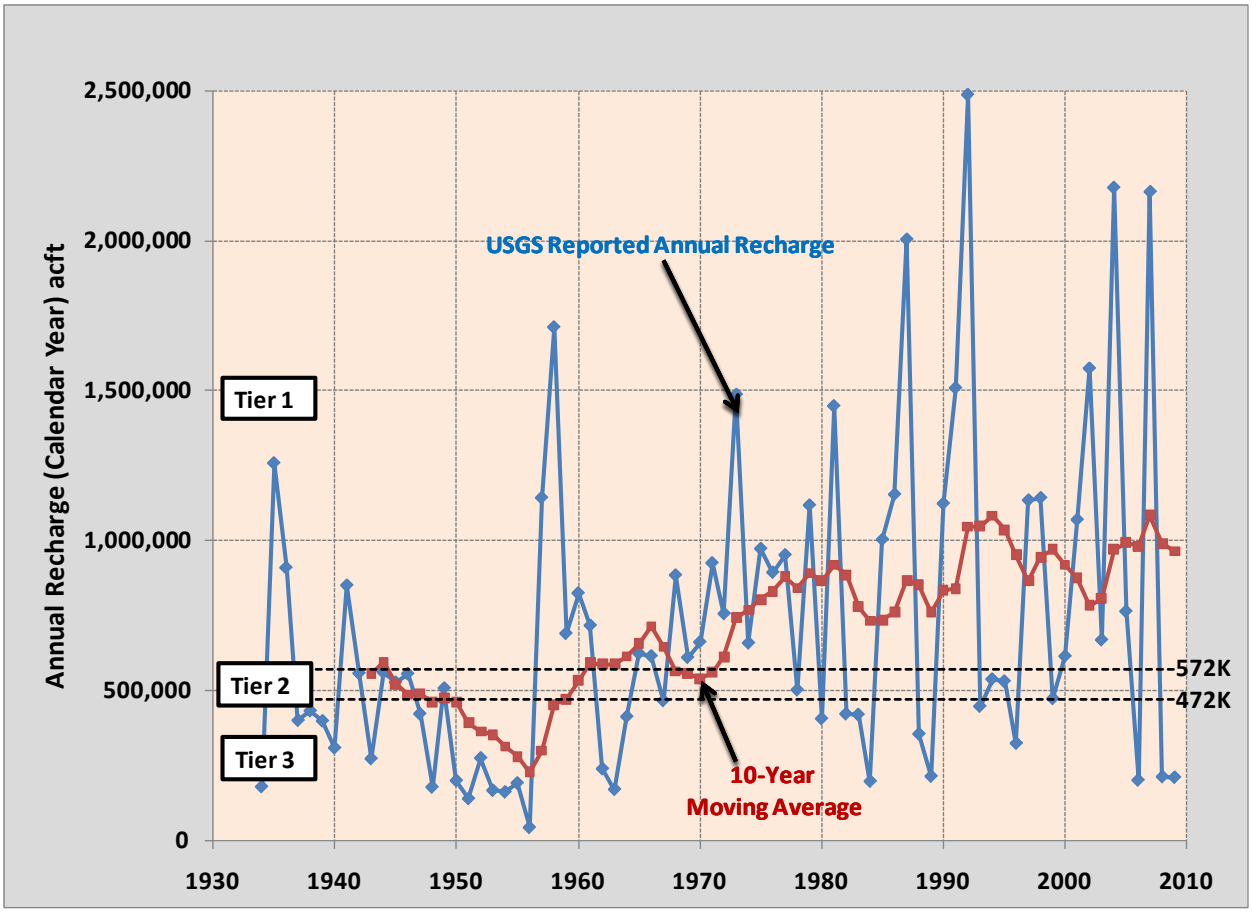


Figure 3-4. Edwards Recharge and Tiers for Operation of SAWS ASR

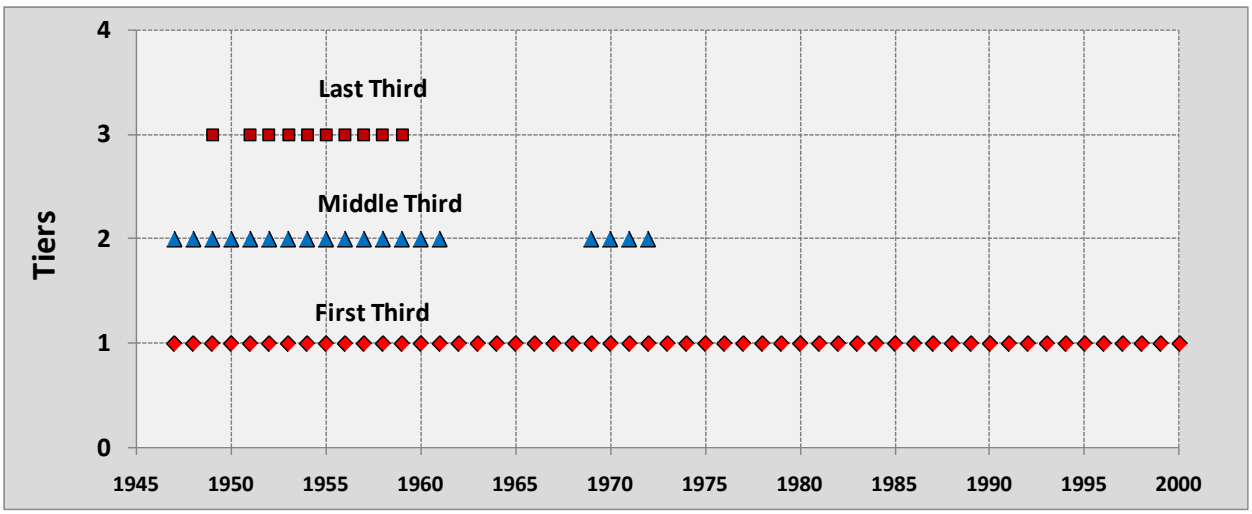


Figure 3-5. Occurrence of Tiers for Operation of SAWS ASR

Filling of SAWS ASR utilizes water that is available from the leases described above. To stay well within the guidelines provided by SAWS, the filling rate was limited to tier 1, which is implemented at all times. If leases from all tiers were utilized for filling, the rates could have been much higher much of the time, which would have greatly shortened the fill and refill times thereby reducing the risk insufficient water in storage at inception of a subsequent drought. The greatest fill rate was 14.9 million gallons per day (MGD). During the fill months for the period 1947-1957, the average filling rate was 11.2 MGD with pumping of this leased water at SAWS Artesia and Seale stations. The capacity of the transmission facilities is limited to about 60 MGD (5,600 acft/mo). The schedule and rate for the filling is shown in Figure 3-6. For operational purposes, the filling is suspended when there is recovery for springflow protection. As discussed earlier, it was assumed that 80,000 acft of water was in SAWS ASR storage at the beginning of the simulation. ASR storage thresholds, as defined by SAWS, were 120,000 acft for tier 1 and 200,000 acft for tiers 2 and 3. Water delivery to SAWS ASR for the 1947-2000 period occurred for 162 months and totaled 120,000 acft. As shown in Figure 3-6, most of the filling occurred from 1947-1965.

Recovering the Edwards stored water from ASR utilizes SAWS existing East-Side pipeline and water transmission facilities. Operationally, the water is delivered back to Artesia and Seale Stations; and SAWS moves this water within their existing distribution system to reduce the total pumping at the Maltsberger, Naco, Stahl, and Randolph stations by an equal amount. The schedule and rate for recovery is shown in Figure 3-6 and is an attempt to optimize

springflow protection and minimize the demand for water stored in SAWS ASR. During the 1947-2000 period, about 126,000 acft were recovered for SAWS pumping trade-off. This recovery for springflow protection occurred for 63 months, the vast majority of which were during the 1950s drought.

Figure 3-7 illustrates the storage balance in SAWS ASR for the 1947-2000 period. As shown, initial storage was 80,000 acft. Storage was capped at about 120,000 acft in the early 1950s and increased to about 127,000 when tiers 2 and 3 were in place. At the end of the drought, about 21,000 acft remained in storage. It was replenished by early 1965. Again, there is an opportunity to replenish ASR storage in a much shorter period of time if the lease water is more fully utilized.

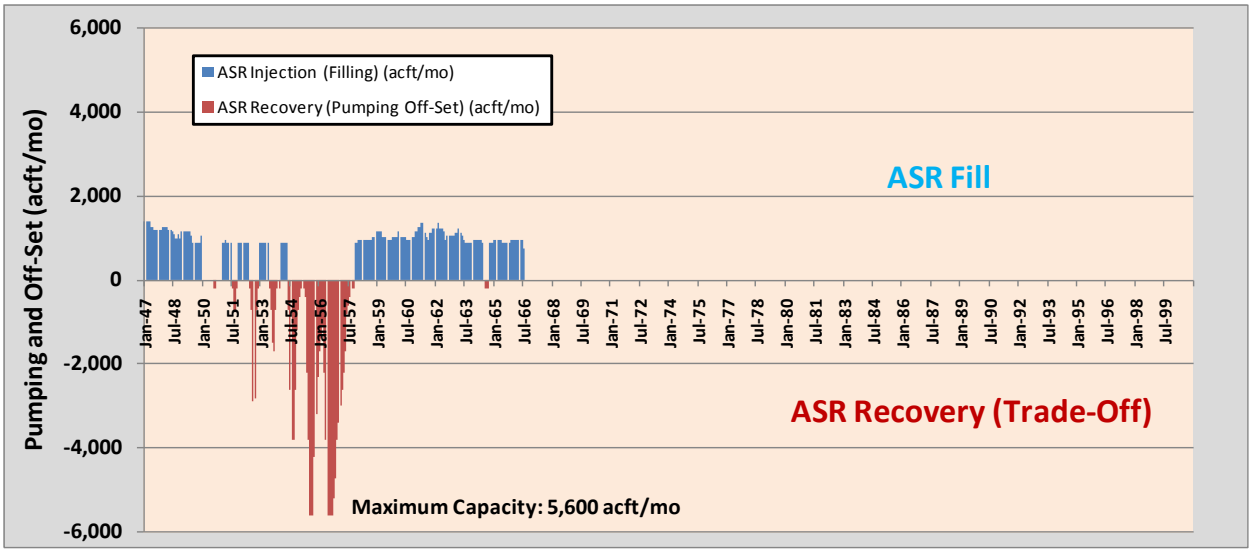


Figure 3-6. Rate and Schedule of SAWS ASR Injection and Recovery (1947-1957)

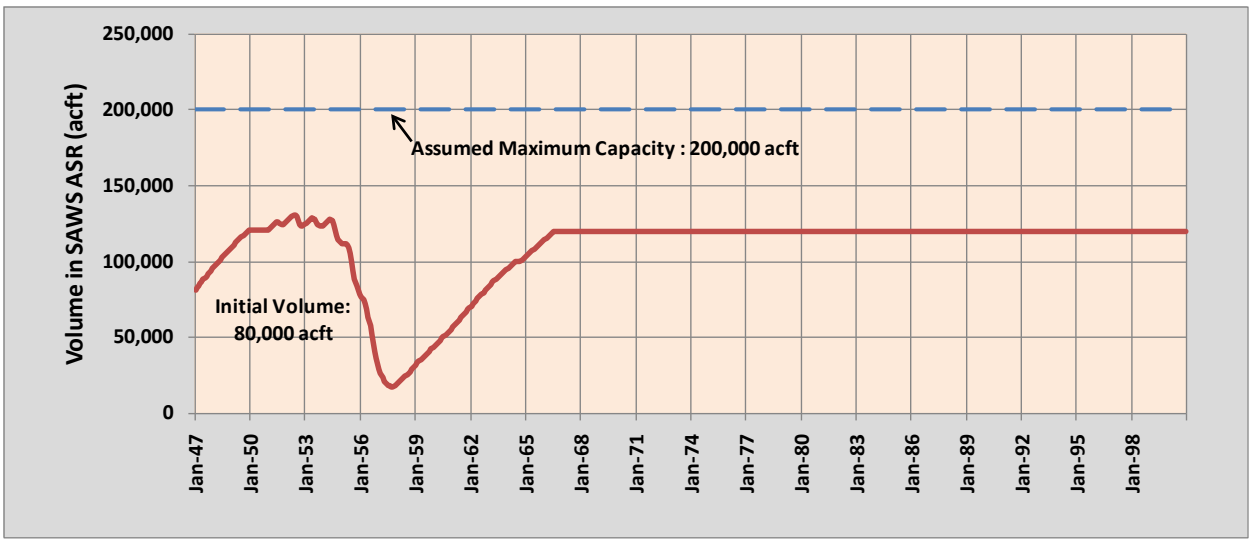


Figure 3-7. Storage of EARIP Water in SAWS ASR

For the periods 1947-1957 and 1947-2000, cumulative net pumping reductions for VISPO, Municipal Conservation, and SAWS ASR (Layer #3) are presented in Table 3-4. This table shows that, for the 1947-1957 period, the average cumulative pumping reduction through Layer #3 was 52,663 acft/yr. For the 1947-2000 period, cumulative pumping reductions through Layer #3 averaged 32,686 acft/yr. During the drought of record period, the net effect of the SAWS ASR alternative was a pumping reduction of 25,698 acft/yr. The occurrences of lease implementation and CPM are strong controlling factors in the pumping reductions.

Table 3-4.
Average Annual Pumping Reductions for Layer #3*

Units: acft/year

	San Antonio Pool	Uvalde Pool	Total
Potential Reductions (IRP Face Value)	59,659	40,408	100,067
1947-1957	28,167	24,496	52,663
1947-2000	18,938	13,748	32,686

* Note: Cumulative Adjustments for VISPO, Conservation and SAWS ASR

3.2.4 VISPO + Conservation + SAWS ASR with Trade-Off Option + Stage V (Layer #4)

In Layer #4 of Bottom-Up Program, CPM Stage V is added to the VISPO, Municipal Conservation, and SAWS ASR with Trade-Off components. Key elements of Stage V are triggering this emergency action primarily off of J-17 water levels and applying an equal 44 percent reduction to permitted wells in both the San Antonio and Uvalde pools. This CPM stage is implemented when J-17 water levels are lower than 625 ft-msl, which is approximately

equivalent to 40 cfs at Comal Springs. Based on the Bottom-Up Program and the J-17 results of Layer #3, Stage V was activated for 6 months, of which, two months were in 1955 and four months were in 1956, as illustrated in Figure 3-8.

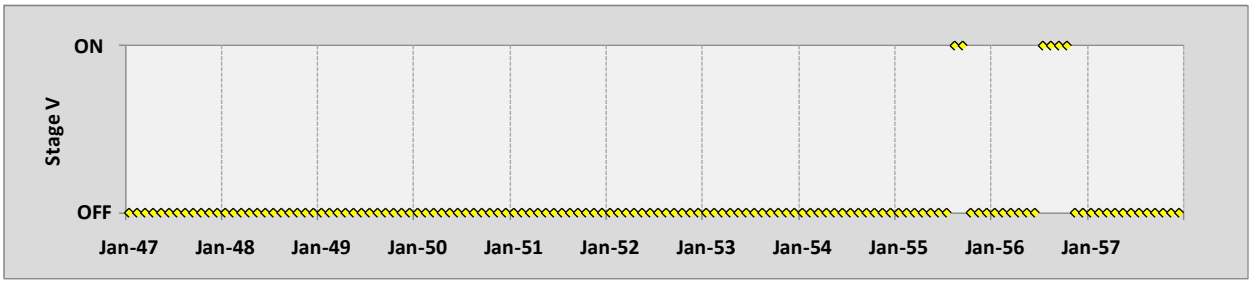


Figure 3-8. Monthly Occurrences of Stage V

For the periods 1947-1957 and 1947-2000, cumulative net pumping reductions for VISPO, Municipal Conservation, SAWS ASR, and Stage V (Layer #4) are presented in Table 3-5. This table shows that, for the 1947-1957 period, the average Layer #4 net pumping reductions were 53,830 acft/yr. For the 1947-2000 period, Layer #4 net pumping reductions averaged 32,923 acft/yr.

Table 3-5.
Average Annual Pumping Reductions for Layer #4

Units: acft/year

	San Antonio Pool	Uvalde Pool	Total
Potential Reductions (IRP Face Value)	78,859	48,608	127,467
1947-1957	29,145	24,685	53,830
1947-2000	19,137	13,786	32,923

3.3 Results

3.3.1 Springflow Hydrographs

Hydrographs from the MODFLOW model simulations are used for a temporal display of the variations in magnitude of springflow. For comparison purposes, hydrographs are presented for five scenarios (baseline and each of the four Bottom-Up Program layers). Study of the hydrographs provides qualitative information on the increase in springflow for each additional layer of the Bottom-Up Program.

MODFLOW calculated springflows for the 1947-1960 period for Comal and San Marcos Springs are presented in Figures 3-9 and 3-10, respectively. Observations upon review of Figures 3-9 and 3-10 focusing on the drought of record include the following: (1) modest improvement in springflow when Municipal Conservation is added; (2) substantial improvements from the VISPO and SAWS ASR components for 1951-1957 at Comal Springs and for 1955-1957 at San

Marcos Springs; and (3) substantial improvement in Comal Springs flow due to implementation of Stage V during the summer of 1956. These hydrographs indicate that the Bottom-Up Program limited the minimum springflows at Comal and San Marcos Springs to about 27 and 51 cfs, respectively. A study of the recovery schedule from SAWS ASR (Figures 3-6 and 3-7) shows that the capacity of the SAWS ASR water transmission facilities (pipelines and pumps) is the limiting factor in the level of springflow protection at Comal Springs. If the capacity of the east-side water transmission system had been greater, additional springflow protection at Comal Springs could have been achieved. However, this enhancement depends on SAWS having the operational capability to move recovered water from the Artesia and Seale pump stations to parts of their distribution system normally served by other SAWS stations that are subject to trade-offs.

MODFLOW calculated springflows for the entire 1947-2000 simulation period for Comal and San Marcos Springs are presented in Figures 3-11 and 3-12, respectively. These hydrographs show that the Bottom-Up Program usually increases springflow by small amounts in periods other than the drought of record. Most of the increases are attributable to adding VISPO and SAWS ASR alternatives, which lead to significantly less Edwards pumping during critical drought conditions. Further study of Figures 3-11 and 3-12 suggests that Comal Springs has a much more direct response to water management alternatives than San Marcos Springs. This is mostly attributable to: (1) a strong hydrogeologic connection between Comal Springs and the main body of the Edwards; and (2) discharge from San Marcos Springs being subject to discharge from Comal Springs and faults located between Comal and San Marcos Springs that function as partial barriers to groundwater flow.

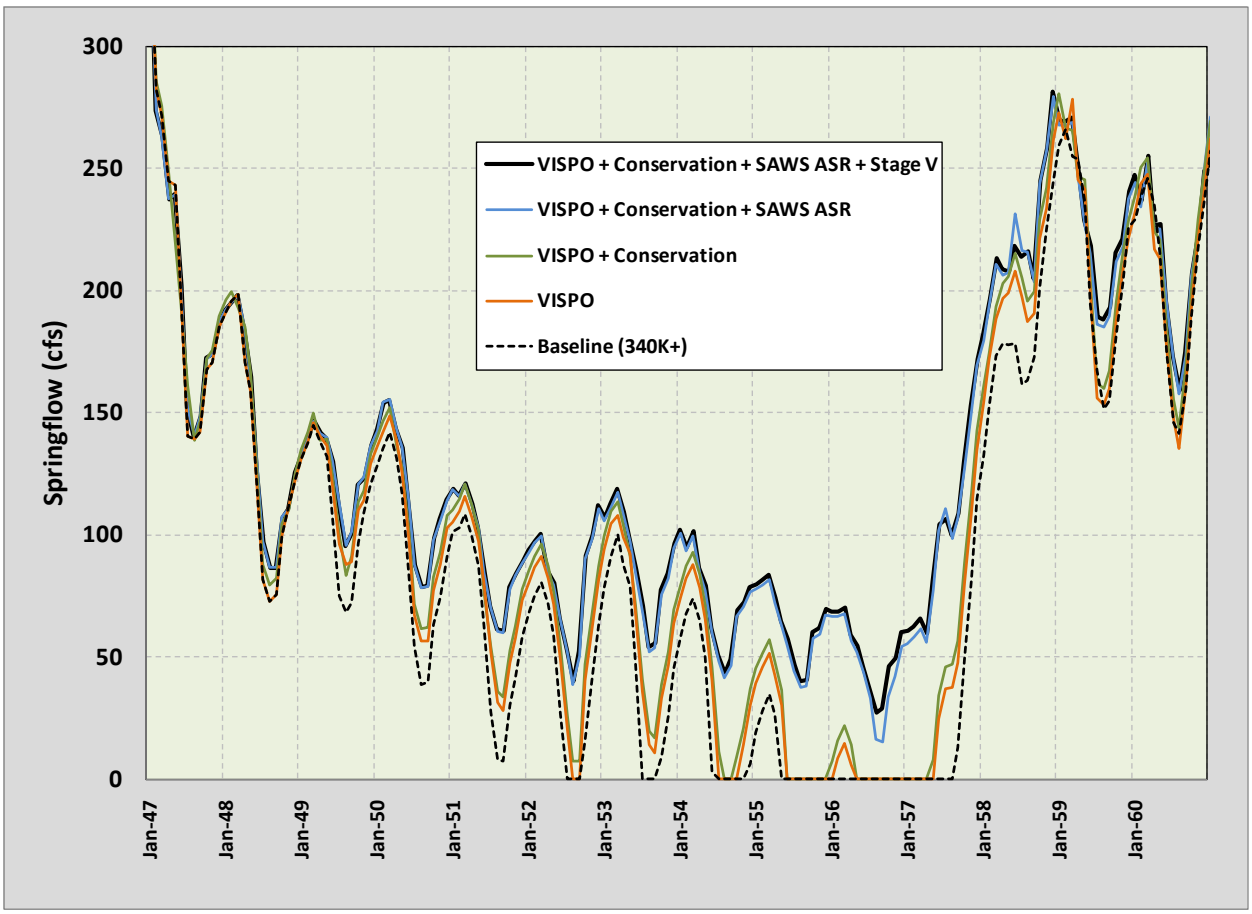


Figure 3-9. Simulated Springflow at Comal Springs (1947-1960)

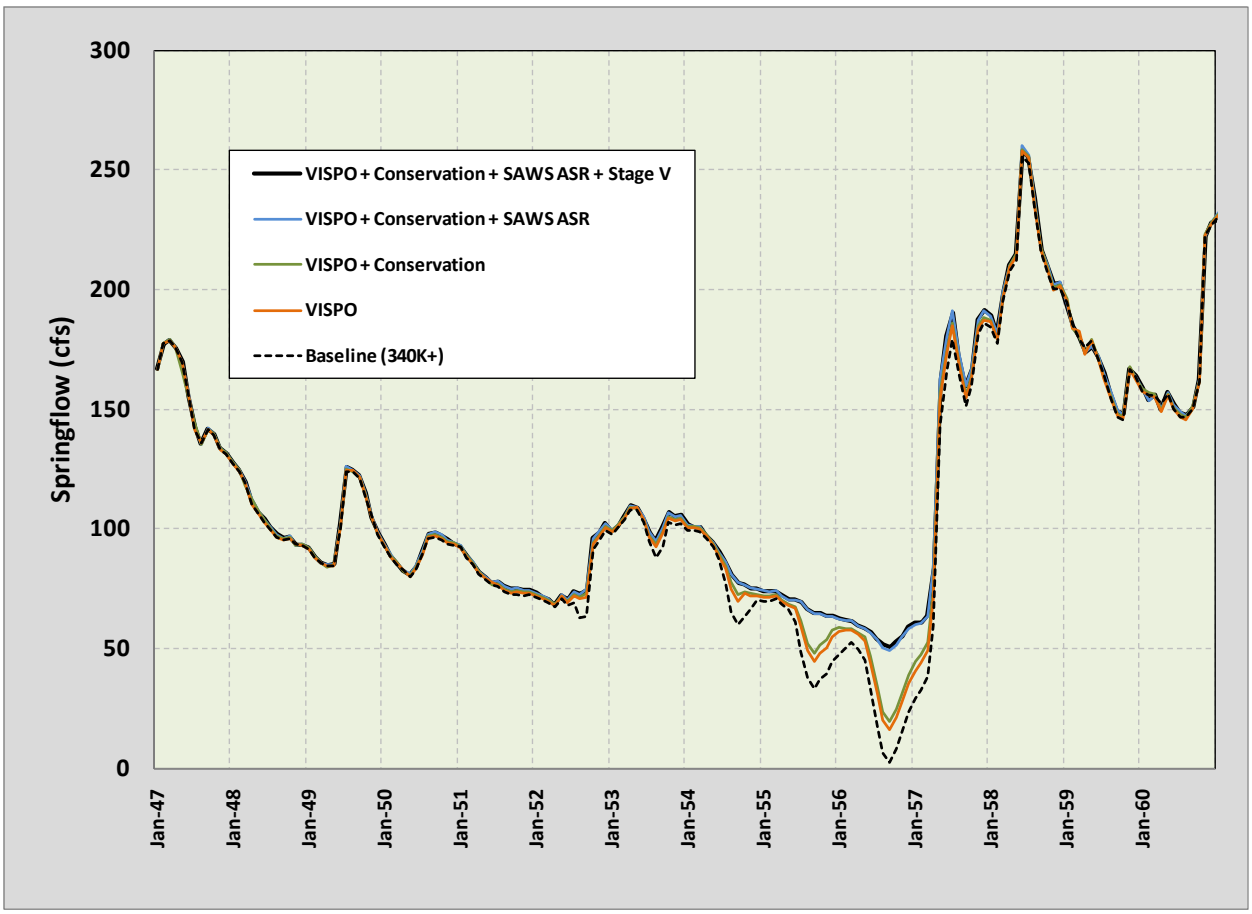


Figure 3-10. Simulated Springflow at San Marcos Springs (1947-1960)

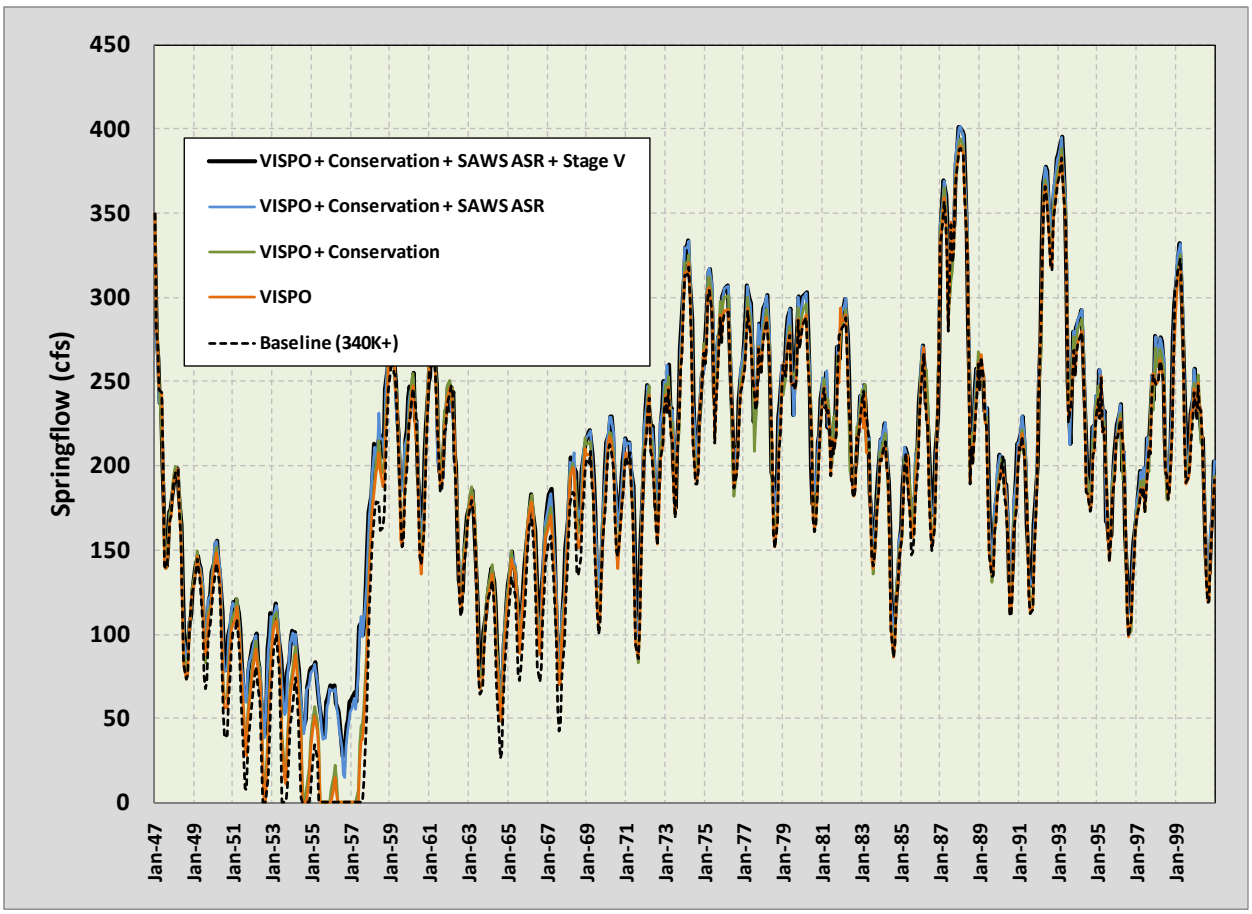


Figure 3-11. Simulated Springflow at Comal Springs (1947-2000)

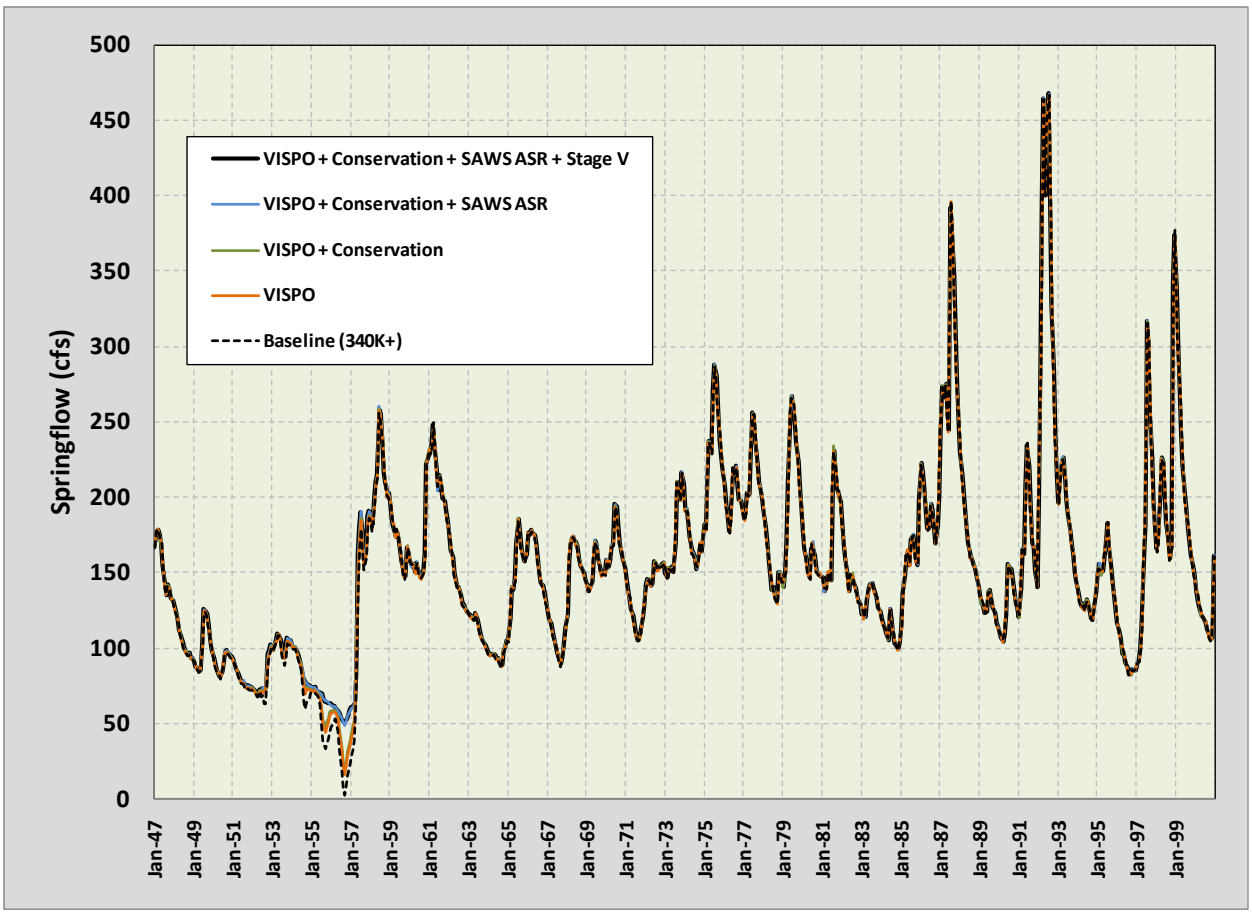


Figure 3-12. Simulated Springflow at San Marcos Springs (1947-2000)

3.3.2 Frequency of Springflow below Thresholds

A measure of considerable importance in the protection of endangered species is the number of months that springflow at Comal Springs and San Marcos Springs is below selected thresholds. Counts of the monthly occurrences for the selected thresholds of springflow are presented in Table 3-6 for the period 1947-2000. Review of these results shows very substantial improvement in springflow protection with VISPO and SAWS ASR. Selected critical thresholds are 45 cfs at Comal Springs and 52 cfs at San Marcos Springs. This table of monthly values from the model shows that there were no months of zero springflow and seven and two months below the thresholds at Comal and San Marcos, respectively, for these critical conditions. Earlier studies of low flow conditions suggest that the minimum daily flow at Comal Springs and San Marcos Springs may be about 15 cfs and 8 cfs, respectively, lower than the monthly value calculated by MODFLOW.

Table 3-6.
Number of Occurrences of Springflow Below Selected Thresholds (1947-2000)

Spring	Threshold (cfs)	Number of Months				
		Baseline	VISPO	VISPO + Conservation	VISPO + Conservation + SAWS ASR	VISPO + Conservation + SAWS ASR + Stage V
Comal	**0**	38	26	21	0	0
	30	54	36	34	2	2
	45	62	47	41	11	7
	60	73	59	56	27	21
	100	122	112	101	90	84
San Marcos	**0**	0	0	0	0	0
	25	6	3	3	0	0
	52	20	14	12	3	2
	75	47	47	46	39	39
	100	121	118	116	114	114

3.3.3 Frequency of CPM

Water users in the Edwards are interested in the amount of time that their permits will have CPM restrictions. These results for the period 1947-2000 are summarized for the San Antonio Pool on the basis of J-17 water levels for all CPM stages for the Bottom-Up Program in Table 3-7. These results show that the number of months with no CPM constraints generally increased for each Bottom-Up layer, which, obviously is an improvement over the baseline conditions. However, the amount of time in Stage I increased in an amount that generally offset the improvement for no CPM conditions. In the more severe Stage II to IV CPM restrictions, the number of months generally became less with each successive Bottom-Up layer. Stage V only applies to the last layer of the Bottom-Up Program.

Table 3-7.
Number of Occurrences of CPM in San Antonio Pool (1947-2000)

Stage, as indicated by Comal Springs, except for Stage V	Number of Months				
	Baseline	VISPO	VISPO + Conservation	VISPO + Conservation + SAWS ASR	VISPO + Conservation + SAWS ASR + Stage V
None	205	207	214	226	227
I	71	77	84	96	96
II	151	155	151	140	140
III	99	97	98	96	101
IV	122	112	101	90	78
V	0	0	0	0	6

3.3.4 Springflow Statistics

A few key statistics of importance to biologists in evaluating the performance of springflow protection from the Bottom-Up Program are minimum springflow, minimum 6-month moving average springflow, and long-term average springflow. These statistics are presented for the period 1947-2000 in Table 3-8 for Comal and San Marcos Springs. As shown in this summary, the minimum monthly average springflows for Comal Springs and San Marcos Springs are 27 and 51 cfs, respectively, for the full Bottom-Up Program. The minimum 6-month moving average springflows for Comal Springs and San Marcos Springs are 39 and 53 cfs, respectively. The long-term average springflows are 196 cfs at Comal Springs and 155 cfs at San Marcos Springs.

3.3.5 Impact on Surface Water Rights

In addition to benefiting endangered species at and near Comal and San Marcos Springs, the Bottom-Up Program also provides benefits to environmental flows and holders of water rights in the Comal, Guadalupe, and San Marcos Rivers downstream of the springs. As expected, this benefit is most significant during severe droughts when one or more layers of the Bottom-Up Program are active.

Table 3-8.
Selected Springflow Statistics (1947-2000) in Cubic Feet per Second

Spring	Statistic	Baseline (348K+)	VISPO	VISPO + Conservation	VISPO + Conservation + SAWS ASR	VISPO + Conservation + SAWS ASR + Stage V
Comal	Minimum Month	0	0	0	15	27
	Minimum 6-Month Moving Average	0	0	0	31	39
	Long-Term Average	178	182	186	195	196
San Marcos	Minimum Month	2	16	19	49	51
	Minimum 6-Month Moving Average	12	25	29	53	53
	Long-Term Average	153	153	154	154	155

Benefits to streamflow and water rights are based on hydrologic simulations and water availability calculations performed using the Guadalupe – San Antonio River Basin Water Availability Model (GSA WAM)[7] as modified and refined for use in development of the 2011 South Central Texas Regional Water Plan[8]. The GSA WAM is a monthly time-step computer model used to estimate regulated streamflow and water available for diversion under existing water rights on a priority basis subject to technical assumptions regarding natural, anthropogenic, and legal factors. Changes in streamflow and water availability can be expressed with several statistics. Considering the local setting, the most significant statistics for indicating streamflow changes associated with implementation of the Bottom-Up Program are: (1) minimum month, (2) minimum year, and (3) long-term average. The most representative statistic for indicating changes in water available for diversion or water availability is assumed to be minimum year.

[7] HDR Engineering, Inc., "Water Availability in the Guadalupe – San Antonio River Basin," Texas Natural Resource Conservation Commission (Contract# 9880059200), December 1999.
[8] South Central Texas Regional Water Planning Group, "South Central Texas Regional Water Planning Area, 2011 Regional Water Plan," Texas Water Development Board, San Antonio River Authority, HDR Engineering, Inc., et al., September 2010.

Simulated benefits to streamflows are shown in Table 3-9 for the San Marcos River at Luling, Guadalupe River at Victoria, and freshwater inflow to the Guadalupe Estuary. These benefits are constrained by GSA WAM design and operational procedures. During the most critical month, which is assumed to be August 1956, the monthly average streamflow increased by 40 cfs, 8 cfs, and 0 cfs at Luling, Victoria, and the Estuary, respectively. For the minimum year (1956), streamflow increased by 24 cfs, 41 cfs, and 18 cfs at these three locations, respectively. For the 1947-1989 period, long-term average flows increased by 2 cfs, 16 cfs, and 18 cfs at Luling, Victoria, and the Estuary, respectively. Surface water analyses were performed prior to final simulation of the adopted Bottom-Up Program so non-substantive differences may be apparent in comparison of springflow values in Table 3-9 with others in Section 3.3.

Table 3-9.
Improvement of Streamflows at Selected Locations Due to Bottom-Up Program

	Comal Springs Discharge (cfs)	San Marcos Springs Discharge (cfs)	San Marcos River at Luling Streamflow (cfs)	Guadalupe River at Victoria Streamflow (cfs)	Freshwater Inflow to the Guadalupe Estuary (cfs)
Minimum Month (August 1956) Springflows and Streamflows					
Baseline	0	7	21	27	1
Bottom Up Program	25	51	61	34	1
Increase	25	45	40	8	0
Average during Minimum Year (1956) Springflows and Streamflows					
Baseline	0	29	44	83	76
Bottom Up Program	50	57	68	125	94
Increase	50	27	24	41	18
Annual Average (1947-1989) Springflows and Streamflows					
Baseline	167	146	351	1,550	2,264
Bottom Up Program	189	189	352	1,568	2,280
Increase	22	43	2	18	16

The primary benefits to holders of surface water rights in the Guadalupe - San Antonio River Basin are assumed to be represented by the minimum annual diversion. These benefits are summarized for the top ten beneficiaries or holders of municipal, industrial/steam-electric, irrigation, hydropower, and other water rights in Tables 3-10a-e, respectively. The greatest beneficiary category in terms of reliable water supply is industrial/steam-electric use with four rights each gaining more than 3,200 acft during the minimum year (Table 3-10b). The greatest

benefits for municipal and irrigation water rights during this minimum year are increases of 1,725 acft (Table 3-10a) and 1,941 (Table 3-10c) acft, respectively. In summary, the annual benefits to the top ten municipal, industrial/steam-electric, and irrigation water rights total 2,666 acft, 15,608 acft, and 2,530 acft, respectively. Benefits to hydropower water rights are summarized in Table 3-10d and based on unappropriated flow passing the hydropower facility location rather than consumptive use of diverted and/or impounded water. Results in Table 3-10d should not be directly compared to those for all other surface water use types because hydropower is a non-consumptive water use. Benefits to water rights with other purposes (Table 3-10e) are limited.

Table 3-10.
Benefits to Holders of Surface Water Rights for Minimum Year

a. Municipal

Owner	Water Right	Authorized Permitted Diversion (acft/yr)	Use Type	Minimum Annual Diversion (acft/yr)		
				Baseline	Bottom Up Program	Increase
GUADALUPE-BLANCO RIVER AUTH (Canyon)	C2074	90,000	Municipal	87,675	89,400	1,725
SEGUIN MUNICIPAL UTILITIES	C3839	7,000	Municipal	6,454	7,000	546
GUADALUPE-BLANCO RIVER AUTH (Luling)	C3896	1,500	Municipal	99	216	117
GUADALUPE-BLANCO RIVER AUTH (Luling)	C3896	1,300	Municipal	0	86	86
JOHN F BAUGH (CRWA)	C3888	320	Municipal	112	158	46
STATE BANK & TRUST COMPANY (Victoria)	C3895	580	Municipal	37	78	42
COMAL CO FRESH WSD #1	P4491	120	Municipal	23	60	37
W L LIPSCOMB ET AL (Victoria)	C3860	260	Municipal	145	174	29
CITY OF SAN ANTONIO	C2162	100	Municipal	72	100	28
PRESBYTERIAN MO-RANCH ASSEMBLY	C1932	60	Municipal	40	50	10

b. Industrial/Steam-Electric

Owner	Water Right	Authorized Permitted Diversion (acft/yr)	Use Type	Minimum Annual Diversion (acft/yr)		
				Baseline	Bottom Up Program	Increase
CITY OF SAN ANTONIO (CPS, Calaveras)	C2162	36,900	Steam-Electric	32,739	36,900	4,162
CITY OF SAN ANTONIO (CPS, Braunig)	C2161	12,000	Steam-Electric	6,484	10,591	4,106
GBRA - Exelon	C5178	75,000	Steam-Electric	47,642	51,363	3,721
INVISTA (DU PONT)	C3861	33,000	Industrial	26,117	29,365	3,248
MISSION VALLEY TEXTILES, INC	C3829	500	Industrial	289	500	211
SOUTH TEXAS ELECTRIC COOP INC	C3859	1,900	Steam-Electric	456	589	133
STRUCTURAL METALS INC	C3837	34	Industrial	21	34	13
SOUTHWEST TEXAS STATE UNIV	C3866	60	Industrial	22	31	9
CPS ENERGY (CITY OF SAN ANTONIO)--CALAVERAS	C2162	11	Steam-Electric	8	11	3
TOMMIE SMITH BLACKBURN	C1969	15	Industrial	9	11	2

c. Irrigation

Owner	Water Right	Authorized Permitted Diversion (acft/yr)	Use Type	Minimum Annual Diversion (acft/yr)		
				Baseline	Bottom Up Program	Increase
GBRA - Irrigation	C5178	11,000	Irrigation	5,830	7,771	1,941
WILLIAM K ANDERSON ET UX	P5107	518	Irrigation	23	140	118
KING RANCH INC	C3848	1,800	Irrigation	1,694	1,800	106
SEGUIN MUNICIPAL UTILITIES	C3839	200	Irrigation	121	200	79
KENNETH W WHITEWOOD ET UX	C2006	320	Irrigation	51	109	58
HARRY J WRAY	C2025	155	Irrigation	48	100	51
MIGUEL CALZADA URQUIZA ET UX	C3899	1,180	Irrigation	168	215	47
BOENING ENTERPRISES	P3994	1,056	Irrigation	24	70	45
ERWIN KLEMSTEIN	C2050	136	Irrigation	31	75	43
ZARCO FOWARDING, INC	C2052	232	Irrigation	37	79	42

d. Hydropower

Owner	Water Right	Authorized Permitted Diversion (acft/yr)	Use Type	Minimum Annual Diversion (acft/yr)		
				Baseline	Bottom Up Program	Increase
NEW BRAUNFELS UTILITIES	C3824	124,870	Hydroelectric	2,511	38,585	36,074
GUADALUPE-BLANCO R A TP-1	C5488	663,892	Hydroelectric	1,321	24,964	23,643
GUADALUPE-BLANCO R A TP-5	C5488	624,781	Hydroelectric	2,333	25,960	23,626
GUADALUPE-BLANCO R A TP-3	C5488	659,995	Hydroelectric	1,310	24,766	23,456
GUADALUPE-BLANCO R A TP-4	C5488	655,323	Hydroelectric	1,305	24,662	23,358
GUADALUPE-BLANCO R A H-4	C5172	585,599	Hydroelectric	4,608	27,358	22,751
GUADALUPE-BLANCO R A H-5	C5172	574,832	Hydroelectric	4,892	27,292	22,400
SOUTHWEST TEXAS STATE UNIV	C3865	64,370	Hydroelectric	22,137	41,991	19,854
CITY OF GONZALES	C3846	796,363	Hydroelectric	0	1,554	1,554
CUERO HYDROELECTRIC, INC.	C3853	538,560	Hydroelectric	0	1,392	1,392

Note: Minimum Annual Diversion values reported in this table are unappropriated streamflows passing through hydropower facilities and do not include concurrent appropriated streamflows passing through hydropower facilities while in delivery to downstream senior water rights.

e. Other

Owner	Water Right	Authorized Permitted Diversion (acft/yr)	Use Type	Minimum Annual Diversion (acft/yr)		
				Baseline	Bottom Up Program	Increase
TEXAS PARKS & WILDLIFE DEPT	C3869	500	Fish Hatchery	418	500	82
JIM STORY	STORY	400	Unknown	0	20	20
SHELTON RANCH CORPORATION	C2003	10	Mining	6	8	3
DARRELL G LOCHTE ET AL	C1997	20	Mining	10	10	0.1

3.4 Cost Estimates

As discussed earlier, the Bottom-Up Program is a key component of the Initial Adaptive Management Phase. Accordingly, the concept is to postpone decisions regarding the need for engineering solutions to later phases and adopt management alternatives to the extent possible. Using this concept for guidance, none of the selected alternatives in the Bottom-Up Program requires new facilities. Instead, the water management alternatives can be developed under existing EAA rules and with SAWS existing facilities. As a result, the cost basis for the water management alternatives was largely prepared by EARIP work groups. The cost estimates presented herein for the Bottom-Up Program do not include administrative or management costs, which are assumed to be provided by the sponsoring stakeholders and without cost to the EARIP.

3.4.1 Assumptions and Definitions

The costs bases for the VISPO, Municipal Conservation, and SAWS ASR components of the Bottom-Up Program were provided by EARIP Work Groups and processed by HDR. Where Edwards irrigation IRPs are to be procured, the contractual arrangements are assumed to be leases or temporary contracts instead of purchases. A background summary for the cost of each program component follows:

- **VISPO:** The tentative working proposal for the VISPO Work Group is to offer holders of irrigation permits either a 5-year or 10-year option under which EARIP would pay a standby fee and an implementation fee. For a 5-year commitment, the standby fee ($50.00/ acft/yr) would escalate at a rate of 1.5 percent per year for 10 years in the program, and the implementation fee ($150.00/ acft/yr) would escalate at the rate of 3 percent per year. For the 10-year commitment, the standby fee would be $57.50/ acft/yr for the first five years and $70.20/acft/yr for the second five years; and, the implementation fee would be $172.50/ acft/yr for the first five years and $210.60/ acft/yr for the second five years. For purposes of this EARIP report, it is assumed that: (1) 70 percent of the leases are in the 5-year option and 30 percent are in the 10-year option, and (2) the annual fee per acft of water for the 1947-2000 period is the composite average fee for the first ten years for leases under 5-year option and the first 10 years for leases under the 10-year option. The long-term average annual cost is based on an annual calculation that considers the standby each year and the and whether or not the implementation fee as needed.
- **Municipal Conservation:** The Conservation Work Group provided the following guidelines:

  List of elements and their initial cost and annual pumping reductions:

  - High Efficiency Toilets: $12,000,000 (1,531 acft/yr)
  - High Efficiency Water Fixtures: $480,000 (1,286 acft/yr)

- Lost Water (Reducing leaks or lost water in small municipal water systems): $3,750,000 (3,750 acft/yr)
- Large Scale Retrofit (Supporting industries): $2,500,000 (2,500 acft/yr)
- Landscape: $1,000,000. (1,000 acft/yr)

Implementation of the 10-year option is assumed to occur evenly over 10 years.

As envisioned by the Conservation Work Group, these are incentive programs so the costs shown are those potentially borne by the EARIP. Total costs to obtain water savings and pumping reductions may be substantially greater.

- **SAWS ASR with Trade-Off Option:** The concept is to obtain leases and options on 50,000 acft/yr of Initial Regular Permits (IRPs) on Edwards Aquifer irrigation and other permits. The leases and options will be divided into thirds (tiers). The first third, approximating 16,667 acre-feet of permits, will be leased at all times. The middle third and final third of the leases would be implemented during moderate and severe drought conditions, respectively. The first third of the leases (continual) are assumed to cost $125/ acft/yr. For the second and third tiers, lease costs have two elements. One is a standby cost, which is assumed to be $40/acft/yr, and would occur each year; and the other is an implementation cost of $150/acft/yr, which would be paid only when the second and third tiers are implemented. The tentative working EARIP-SAWS agreement is that SAWS would: (1) waive costs equivalent to depreciation of a third of the $250,000,000 asset over 30 years on a straight line basis, and (2) be reimbursed $3,080,000 per year for water treatment, power, and other operations and maintenance expenses.
- **Stage V:** The EARIP did not develop guidelines on an appropriate method of estimating these costs. As general information, HDR has presented a range of water supply alternatives that may be considered to replace an equivalent of 27,400 acft/yr on an intermittent basis. The unit costs for these alternatives are from the 2011 South-Central Texas Regional Water Plan. These alternatives and the assumed unit cost include:
  - Irrigation water conservation ($160/acft/yr),
  - Municipal water conservation ($600/acft/yr),
  - Near-term water management strategies for SAWS ($1,300/acft/yr),
  - Long-term water management strategies for SAWS ($2,300/acft/yr), and
  - Drought management ($150/acft/yr to $15,000+/acft/yr).

One concept for implementing the SAWS water management strategies is for the EARIP or others to sponsor a new water supply for SAWS. In exchange, SAWS would temporarily transfer a prorated amount of their Edwards permits or leases to these sponsors (e.g., outlying municipalities).

3.4.2 Summary

A summary of the estimated cost, not including administrative and management costs, is provided in Table 3-11 for layers 1-3 and Table 3-12 for layer 4. The greatest annual cost is for

Edwards water leases, which average $12,395,000 per year over 1947-2000 conditions. The total annual cost is estimated to be $15,475,000. The most costly layers are VISPO and SAWS ASR. It's important to note that these two program components also have the greatest impact on springflow protection.

Table 3-11.
Estimated Costs for Layers 1-3 of Bottom-Up Program

Program Component	Investment	Annual (54-Year Average)			
		Edwards Water Leases	Depreciation	O&M	Total
Layer 1: VISPO (10-Year Option)	N/A	$4,172,000	N/A	N/A	$4,172,000
Layer 2: Municipal Conservation (10-Year Program)	$19,730,000	$1,973,000	N/A	N/A	$1,973,000
Layer 3: SAWS ASR	N/A	$6,250,000	Waived	$3,080,000	$9,330,000
Total (Layers 1-3)	**$19,730,000**	**$12,395,000**	**$0**	**$3,080,000**	**$15,475,000**

Table 3-12.
Range of Estimated Costs for Layer 4 of Bottom-Up Program

Alternative (from 2011 Region L Water Plan)	Unit Cost (acft/yr)	Annual Cost
Irrigation Water Conservation	$140	$3,836,000
Municipal Water Conservation	$600	$16,440,000
Near-Term Water Management Strategies for SAWS	$1,300	$35,620,000
Long-Term Water Management Strategies for SAWS	$2,300	$63,020,000
Drought Management	$150 to $15,000+	$4,110,000 to $411,000,000+
Note: Annual cost is based on acquiring 27,400 acft/yr.		

4 Technical Evaluations of Alternative Programs

The exploratory process leading up to the selection of the Bottom-Up Program consisted of identifying and conducting technical evaluations of five alternative programs, with each having one or more options (also called optimization runs). These alternative programs, descriptions of optimization runs, and very brief descriptions of the concepts are presented in Table 4-1. They are discussed in more detail in the following sections.

Table 4-1.
Listing of Alternative Programs and Optimization Runs

Program Name	Concept	Optimization Runs
Aquifer Storage and Recovery (ASR)	• Pumps leased or purchased Unrestricted Edwards Irrigation Permits. • Stores Edwards water in the Carrizo Aquifer in the vicinity of Cibolo Creek in Wilson County. • Recovers the Edwards water for direct springflow protection during droughts. • Injects the water into the Edwards Aquifer with wells between Cibolo Creek and Comal Springs.	1. Baseline pumping restrictions by CPM set to SB3, which is about a 348,000 acft/yr "floor" in Stage IV. 2. Increase CPM Stage IV pumping restrictions to result in about a 320,000 acft/yr "floor." 3. Increase CPM Stage IV pumping restrictions to result in about a 286,000 acft/yr "floor." Options: a) Lease Irrigation Permits. b) Purchase Irrigation Permits.
Combination	• Concept is similar to the Bottom-Up Program in that alternatives are incrementally stacked in a cumulative process. • As with the Bottom-Up Program, the cumulative results would be different if the four alternatives were analyzed individually and then added together.	1. Enhanced recharge at selected Type II structures. 2. Combination Run #1 plus VISPO. 3. Combination Run #2 plus Land Stewardship. 4. Combination Run #3 plus SAWS ASR.

Table 4-1. (Continued)

Program Name	Concept	Optimization Runs
Recharge and Recirculation (R&R)	• Integrates recharge enhancement from selected Type II structures and unrestricted irrigation permits. • From a well field in Medina County and under selected criteria, pump (recirculate) the permitted water and enhanced recharge water from Type II structures to recharge structures. • When Comal trigger is in effect, cease recirculation, but continue to pump irrigation permits and recharge the water at Hondo and Verde recharge sites. • Enhanced recharge that is missed when trigger is in effect, but remaining in the aquifer, can be recovered and recirculated under selected criteria, including recovery and recirculation having to occur within 2 years of recharge.	1. Comal trigger is set at 150 cfs and Recharge is split 50-50 between Hondo and Verde recharge sites. 2. Comal trigger is set at 100 cfs and Recharge is split 50-50 between Hondo and Verde recharge sites. 3. Comal trigger is set at 100 cfs and Recharge is split 75-25 between Hondo and Verde recharge sites. 4. Comal trigger is set at 30 cfs and Recharge is split 75-25 between Hondo and Verde recharge sites.

Table 4-1. (Concluded)

Trade-Off: Bexar County	• Pumps leased, unrestricted Edwards Irrigation Permits. • Stores the water in SAWS ASR facility in South Bexar County. • Recovers the water for springflow protection during droughts. • Evaluates three ways to provide water for springflow protection: o Trade-off o Direct Recharge o Indirect Recharge • Each variant is evaluated with either an ON-OFF switch or episodic recharge pattern.	1. Trade-Off: Uses SAWS ASR to Offset SAWS Pumping that would otherwise occur 2. Direct Recharge: Uses SAWS ASR to provide direct recharge of recovered water via an injection well field near Comal Springs 3. Indirect Recharge: SAWS ASR recovered water is delivered to Artesia and Seale and an equal amount of water is transferred from Naco and Stahl to direct recharge via an injection well field near Comal Springs Options: a) ON-OFF: SAWS ASR water recovery is either off or at full capacity b) Episodic recovery pattern to Optimize water requirements and springflow protection
Trade-Off: Comal and Hays Counties	• Increase CPM pumping reductions for Municipal and Industrial users near New Braunfels and San Marcos and replace the amount of curtailed pumping that is below SB3 pumping reductions with an outside supply. • The framework of this concept utilizes enhanced recharge from selected Type II structures, stores this water in a Carrizo ASR well field, recovers the water during severe drought and delivers this water as a replacement to New Braunfels and San Marcos in exchange for additional CPM restrictions.	1. Approximate balance of ASR storage and off-set water requirements.

The measure of springflow protection for each of the alternatives and options under consideration is summarized by tabulating the number of months that Comal and San Marcos Springs have monthly springflow less than selected thresholds and important springflow

statistics for each model run. These results are based on the 1947-1973 simulation period including the drought of record. For comparison purposes, results of the baseline simulation are included. Springflow hydrographs are not included in this report, but are available in HDR presentations on the EARIP web site.

4.1 Springflow Protection Alternatives

4.1.1 Aquifer Storage and Recovery (ASR)

The overall concept of ASR is to store water during times of plenty and to recover stored water in times of shortage.

Major assumptions for the ASR alternative program include:

- The overall baseline pumping in the Edwards is IRPs to the extent available subject to Critical Period Management (CPM). This results in a minimum (nominal) permitted pumping level of approximately 348,000 acft/yr (excluding domestic and livestock and Federal uses) during Stage IV.
- The selected supply of water for storage in ASR is unrestricted Edwards irrigation permits; and, the amount is assumed to be 66,700 acft/yr (approximately equivalent to 40,000 acft/yr during CPM Stage IV), which will be leased from irrigators in Uvalde, Medina, and Bexar Counties. The necessary leases will only be procured and pumped as needed to fill the ASR and to replace minor losses from ASR storage. Leases instead of purchases are selected because the water is only needed temporarily to fill or refill ASR storage.
- The leased irrigation permits will be pumped from Edwards wells in northeastern Bexar County. The allowable pumping will be subject to CPM rules, hence associated withdrawals range from 40,000 to 66,700 acft/yr.
- The pumped water will be stored in the Carrizo Aquifer in Wilson County near Cibolo Creek using conventional ASR facilities.
- Water leases will be on an annual basis.

ASR operational plans are:

- At the beginning of the model simulation, acquired permits are pumped from a northeast Bexar County well field until the estimated amount of water needed to fill storage for springflow protection is achieved. Allowable pumpage is to be consistent with CPM rules.
- Transport pumped Edwards water by pipeline to the Carrizo ASR facilities in Wilson County.
- Store the Edwards water in the ASR facilities until needed. After being filled, a small percentage of Edwards water will continue to be pumped and stored in ASR to overcome any losses and to maintain the Edwards water bubble around the ASR wells.

- When the flow from Comal and San Marcos Springs nears appropriate trigger levels, begin recovering the water from ASR storage and deliver to Edwards recharge facilities near Cibolo Creek. Edwards recharge will be accomplished using injection wells and/or surface recharge structures.
- Experimental MODFLOW simulations show that recharge in the Edwards outcrop in the area between Cibolo Creek and Comal Springs has substantial benefit to San Marcos Springs and limited benefit to Comal Springs. The use of injection wells in the confined portion of the Edwards aquifer targeting a conduit between Cibolo Creek and Comal Springs greatly benefits Comal and has lesser benefits to San Marcos.
- The schedule of recovery of the stored water was developed to nearly optimize the storage of water in ASR while maintaining minimum Comal springflow at rates between 30 and 60 cfs during the drought of record.

The physical facilities associated with the ASR Program (Figure 4-1) include:

- An Edwards well field and raw water collection system is to be located in the general vicinity of Loop 1604 and I-35 in northeast Bexar County.
- An ASR well field will be constructed in the Carrizo Aquifer and is expected to be located in northwest Wilson County and in the vicinity of Cibolo Creek.
- A main pipeline will deliver water from the Edwards well field to the ASR well field for storage during the fill cycle. During the recovery cycle, the direction of flow in part of this main pipeline will be reversed for the delivery of recovered water from ASR to recharge facilities between Cibolo Creek and Comal Springs. One pump station is needed for the fill cycle; and, two pump stations will be required for the recovery cycle.
- Experimental MODFLOW simulations suggest that injection wells will be required for the desired springflow enhancement at Comal Springs. These injection wells are expected to be northeast of Cibolo Creek.

Scale optimization runs include:

- Run #1: Maintain current SB3/EAA CPM pumping restrictions.
- Run #2: Revise Stage IV CPM pumping reductions so that the minimum permitted pumping during severe drought is 320,000 acft/yr.
- Run #3: Revise Stage IV CPM pumping reductions so that the minimum permitted pumping during severe drought is 286,000 acft/yr.
- These three scale optimization runs are made for: (1) purchase of the irrigation permits and (2) leasing of irrigation permits. When the permits are purchased, they are permanently assigned to ASR and are only used to fill ASR storage or to overcome losses. Otherwise, they are not pumped. When the permits are leased, the water is procured on an annual basis as needed (when not needed for ASR, it is assumed to be used by irrigators). As a result, less water is being pumped from the aquifer with the purchase arrangement than with the lease arrangement.

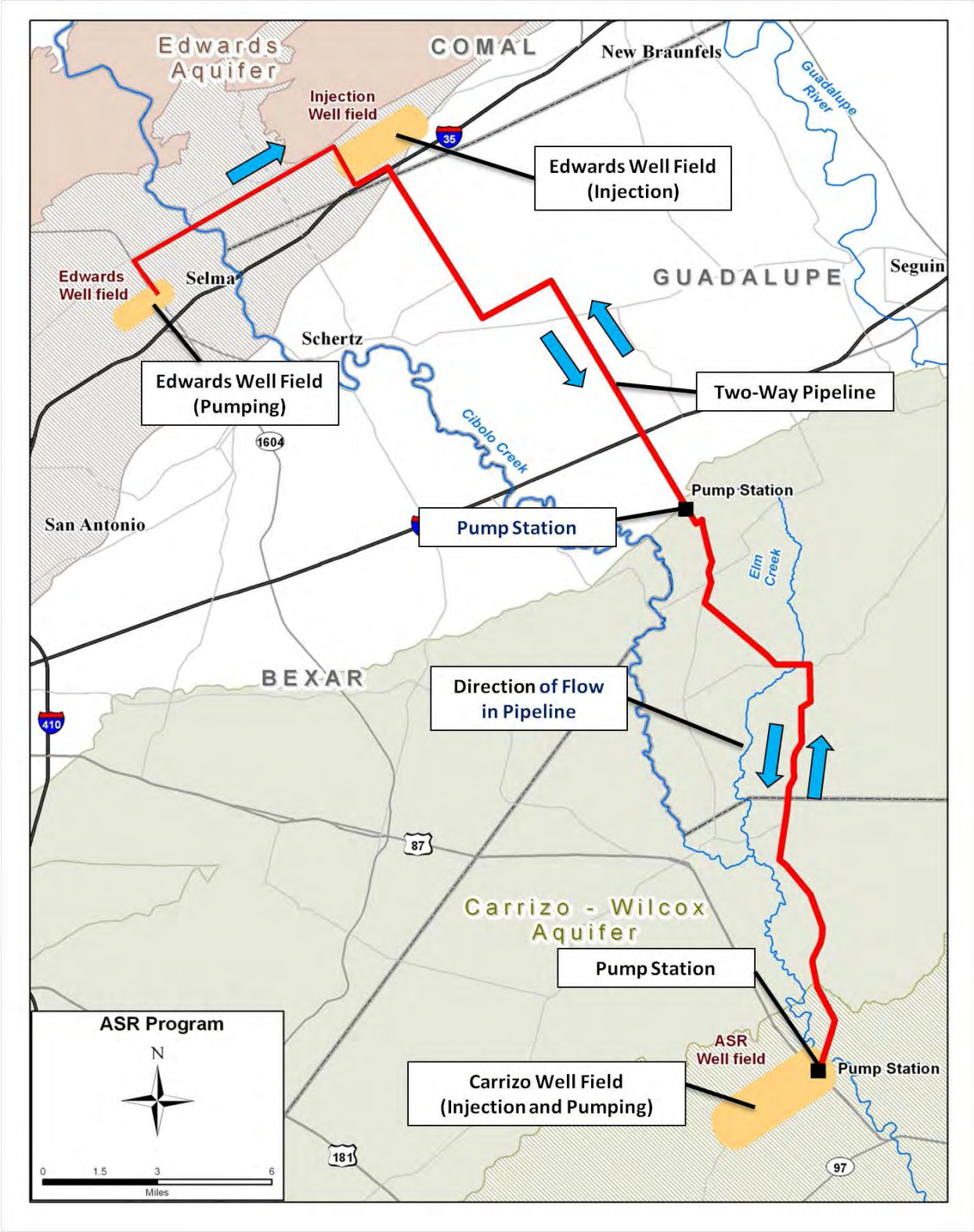


Figure 4-1. Schematic of ASR Program

Results summarizing the number of months when simulated springflows at Comal and San Marcos Springs are below given thresholds for the baseline and Runs #1, #2, and #3 with the irrigation purchase and lease options are presented in Tables 4-2a and 4-2b, respectively. These results suggest the following:

- Comal Springs:
  - Both the purchase and lease irrigation permit options for all three runs can keep the springs flowing during the drought of record. Minimum monthly average flow is greater than 30 cfs only for Run #3 in which Stage IV CPM reductions result in permitted pumping of about 286,000 acft/yr.
  - For the 30 cfs threshold, the springflow results are sensitive to the selected ASR recovery rates and schedule, called episodic recharge. This episodic recharge was developed in a trial and error process of making estimates of the rates and schedule and running MODFLOW. The selected episodic recharge reflects a reasonable level of optimization in consideration of the available water supply, water system limitations, and springflow protection. Minor irregularities in the statistics among the ASR simulations are attributed to the limited effort to optimize the episodic recharge among the various simulations.
  - The purchase of irrigation permits, in comparison to leased permits, noticeably reduces the number of months below given thresholds at 60 cfs and greater.
- San Marcos Springs:
  - The results throughout the range of thresholds show substantial improvement in springflow over the baseline conditions for flow thresholds less than 80 cfs.
  - Little to no improvement in springflow is noted for higher springflow thresholds.

Selected statistical summaries for Comal and San Marcos Springs for the baseline and Runs #1, #2, and #3 with the irrigation purchase and lease arrangements are presented in Tables 4-3a and 4-3b, respectively. These results suggest the following:

- Comal Springs:
  - No flow occurred under the baseline scenario for more than six consecutive months. With the ASR alternative, minimum springflow increased to at least 23 cfs, and minimum 6-month moving average springflow increased to at least 30 cfs.
  - Increasing the reduction percentages in Stage IV in Runs #2 and #3 tended to cause the minimum springsflows to increase.
  - The purchase of irrigation permits, in comparison to leaseing permits, noticeably increases long-term average springflows.
- San Marcos Springs:
  - The results for the minimum and 6-month minimum moving average are substantially improved over baseline conditions.

- Increasing the reduction percentages in Stage IV in Runs #2 and #3 increased the minimum springflows for the minimum and 6-month minimum moving average by about 5 cfs.
- Little to no improvement in springflow is noted for the long-term average.
- The purchase and lease of irrigation water produces almost identical results.

Table 4-2.
Number of Months with Springflow below Selected Thresholds for ASR Program (1947-1973)

a. Purchase of Water Rights

Spring	Threshold (cfs)	Number of Months					
		Baseline (348K)	Baseline (320K)	Baseline (286K)	Run #1-Purchase (348K Base)	Run #2-Purchase (320K Base)	Run #3-Purchase (286K Base)
Comal	0	38	22	10	0	0	0
	30	54	34	18	6	3	0
	60	73	60	37	44	28	20
	90	110	93	74	89	64	55
	120	145	139	135	134	121	111
San Marcos	0	0	0	0	0	0	0
	52	20	12	5	4	3	0
	80	52	51	46	49	48	46
	100	108	103	97	104	102	95
	120	147	146	146	146	146	145

b. Lease of Water Rights

Spring	Threshold (cfs)	Number of Months					
		Baseline (348K)	Baseline (320K)	Baseline (286K)	Run #1-Lease (348K Base)	Run #2-Lease (320K Base)	Run #3-Lease (286K Base)
Comal	0	38	22	10	0	0	0
	30	54	34	18	1	2	0
	60	73	60	37	56	43	25
	90	110	93	74	107	88	69
	120	145	139	135	150	139	134
San Marcos	0	0	0	0	0	0	0
	52	20	12	5	4	2	0
	80	52	51	46	50	48	46
	100	108	103	97	106	101	97
	120	147	146	146	146	146	146

Table 4-3.
Selected Springflow Statistics for ASR Program (1947-1973)

a. Purchase of Water Rights

Springflow for Selected Conditions (1947-1973)							
Spring	**Statistic**	**Springflow (cfs)**					
		Baseline (348K)	**Baseline (320K)**	**Baseline (286K)**	**Run #1-Purchase (348K Base**	**Run #2-Purchase (320K Base**	**Run #3-Purchase (286K Base)**
Comal	Minimum Month	0	0	0	23	25	40
	Minimum 6-Month Moving Average	0	0	0	30	31	44
	Long-Term Average	126	134	141	142	151	156
San Marcos	Minimum Month	2	19	37	48	50	53
	Minimum 6-Month Moving Average	12	29	45	51	53	56
	Long-Term Average	127	129	131	130	131	131

b. Lease of Water Rights

Springflow for Selected Conditions (1947-1973)							
Spring	**Statistic**	**Springflow (cfs)**					
		Baseline (348K)	**Baseline (320K)**	**Baseline (286K)**	**Run #1-Lease (348K Base**	**Run #2-Lease (320K Base**	**Run #3-Lease (286K Base)**
Comal	Minimum Month	0	0	0	30	25	38
	Minimum 6-Month Moving Average	0	0	0	35	41	46
	Long-Term Average	126	134	141	132	139	145
San Marcos	Minimum Month	2	19	37	48	50	53
	Minimum 6-Month Moving Average	12	29	45	51	54	56
	Long-Term Average	127	129	131	130	130	131

4.1.2 Combination

The alternative Combination Program consists of four major components, including: (a) Selected Type II Recharge Structures, (b) Voluntary Irrigation Suspension Program Option (VISPO), (c) Land Stewardship in the Guadalupe River watershed upstream of Canyon Reservoir, and (d) SAWS ASR Trade-Off Option with supplies coming from SAWS existing ASR well field in South Bexar County.

Major assumptions for the Combination program include:

- Selected Type II Recharge Structures
  - Frio, Sabinal, Hondo, Verde, San Geronimo, Cibolo, and Salado-Flood Retarding Structures, identified as Program C in the 2011 Region L Water Plan.
  - Mitigation of impacts to Corpus Christi surface water rights in the Nueces River Basin and freshwater inflows to the Nueces Estuary.
  - Honor surface water rights in Guadalupe – San Antonio River Basin.
  - Consensus Criteria for Environmental Flow Needs (CCEFN) used to calculate surface water availability.
- Voluntary Irrigation Suspension Program Option (VISPO)
  - The schedule, rate of irrigation reduction, and costs were provided by the VISPO Work Group.
  - VISPO applies to about 20,000 acft/yr (IRP value) of Edwards pumping rights with 15,000 acft/yr in Medina County and 5,000 acft/yr in Bexar County.
  - Suspensions triggered on January 1 if the water level in J-17 is below 650 ft-msl on September 1 of the previous year.
- Land Stewardship
  - This component is adapted from the 2011 Region L Water Plan *(Section 4C.7 Brush Management (Above Canyon Reservoir)*).
  - The selected scenario for this water management strategy assumes 25 percent land-owner participation. For this level of participation, the Region L analysis shows that the firm yield of Canyon Reservoir may be increased by about 5,600 acft/yr (about 7.7 cfs).
  - Preliminary plans are to store and accrue the additional surface water supplies in Canyon Reservoir for subsequent delivery to the recharge zone for protection of San Marcos Springs.
  - A few months before anticipated critical springflow levels at San Marcos Springs, releases of the stored water will be made to the Guadalupe River for delivery by “bed and banks” (with due accounting for losses) to a tentative diversion point near New Braunfels.
  - From this point, the water would be delivered to York Creek for recharge facilitated in part by existing small reservoirs.
  - Element is intended to provide springflow protection to San Marcos Springs.

- SAWS ASR
  - 30 MGD for up to 200 days during Stage III.
  - 30 MGD for up to 200 days during Stage IV.
  - Total allocation of water stored in SAWS ASR facilities for this program is not to exceed 40,000 acft during a drought.
  - This supply will be used as source water for trade-off with SAWS, which will result in an equivalent reduction in SAWS' permitted Edwards pumping. Thus, it will not be delivered to recharge facilities near the springs for direct springflow protection. Instead, springflow protection will be accomplished through reduced pumping in Bexar County.

The physical facilities (Figure 4-2) include:

- Type II Enhanced Recharge: Construction of dams and other facilities.
- VISPO: None.
- Land Stewardship:
  - A program to be developed and administered with land management practices,
  - Facilities to divert water from Guadalupe River to York Creek for recharge enhancement.
- SAWS South Bexar ASR: No new facilities.

The stacking of the elements in the Combination Program includes:

- Run #1: Selected Type II structures.
- Run #2: Run #1 plus VISPO.
- Run #3: Run #2 plus Land Stewardship.
- Run #4: Run #3 plus SAWS ASR Trade-Off Option.

Results summarizing the number of months when springflows at Comal and San Marcos Springs are below specified thresholds for the baseline and Runs #1-#4 are presented in Table 4-4. These results suggest the following:

- Comal Springs:
  - The cumulative (stacked) runs with all components results in 17 months of no flow, which is down from 38 months in the baseline.
  - As compared to the baseline, the stacked runs produce improvement for all thresholds.
  - Land stewardship provides the least incremental improvements in number of months below springflow thresholds.
- San Marcos Springs:
  - The most significant improvements in springflow are apparent at the 52 cfs threshold.

- Little improvement is noted for springflow thresholds greater than 52 cfs.

Selected statistical summaries for Comal and San Marcos Springs for the baseline and Runs #1-#4 are presented in Table 4-5. These results suggest that:

- Comal Springs:
  - Flows during baseline conditions are zero for the minimum and 6-month minimum moving average for all layers in the stack.
  - The long-term average springflow is improved by up to 23 cfs.
- San Marcos Springs:
  - The results for the minimum and 6-month minimum moving average springflows are substantially improved over baseline conditions.
  - The long-term average springflow is improved by up to 6 cfs.

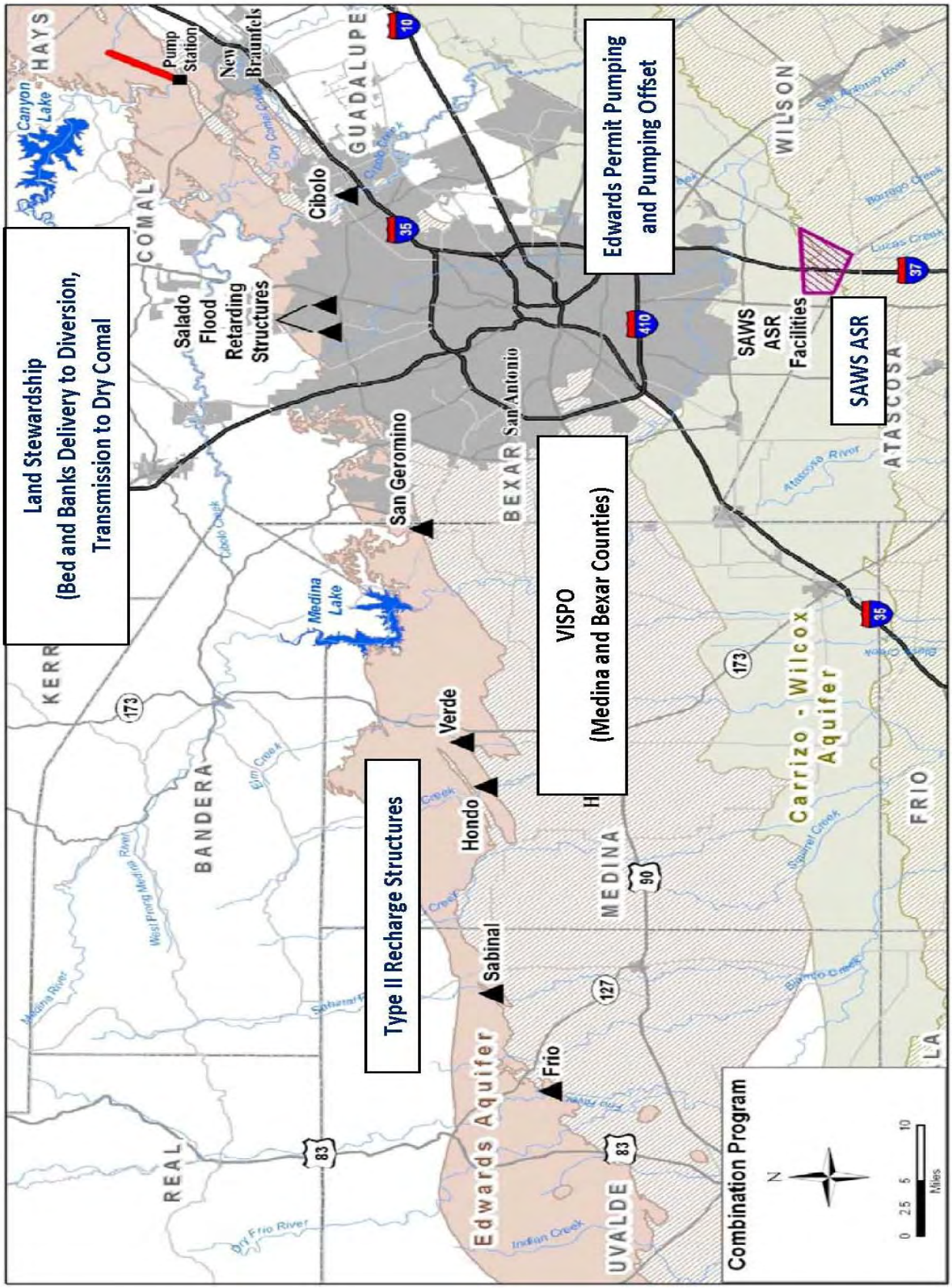


Figure 4-2. Schematic of Combination Program

Table 4-4.
Number of Months with Springflow below Selected Thresholds for Combination Program (1947-1973)

Springflow Duration below Given Thresholds (1947-1973)						
Spring	**Threshold (cfs)**	**Number of Months**				
		Baseline (348K)	**Run #1-Type II Structures**	**Run #2-Type II and VISPO**	**Run #3-Type II, VISPO and Land Stewardship**	**Run #4-Type II, VISPO, Land Stewardship and SAWS ASR**
Comal	0	38	34	26	23	17
	30	54	43	36	35	33
	60	73	66	56	56	51
	90	110	98	87	85	84
	120	145	131	122	122	122
San Marcos	0	0	0	0	0	0
	52	20	17	14	8	6
	80	52	50	50	49	48
	100	108	102	101	99	98
	120	147	143	143	141	141

Table 4-5.
Selected Springflow Statistics for Combination Program
(1947-1973)

Springflow for Selected Statistics (1947-1973)						
Spring	**Statistic**	**Springflow (cfs)**				
		Baseline (348K)	**Run #1- Type II Structures**	**Run #2- Type II and VISPO**	**Run #3- Type II, VISPO and Land Stewardship**	**Run #4- Type II, VISPO, Land Stewardship and SAWS ASR**
Comal	Minimum Month	0	0	0	0	0
	Minimum 6-Month Moving Average	0	0	0	0	0
	Long-Term Average	126	141	147	148	149
San Marcos	Minimum Month	2	6	14	25	27
	Minimum 6-Month Moving Average	12	16	23	35	37
	Long-Term Average	127	131	131	132	133

4.1.3 Recharge and Recirculation (R&R)

During the April 8, 2010 EARIP workshop, a special meeting was scheduled for April 21, 2010 with the purpose of providing some measure of consensus and direction to HDR and Todd Engineers regarding the definition of this alternative. Decisions from this meeting were intended to formulate fundamental assumptions for testing the performance of a preliminary technical evaluation of the R&R alternative. In advance of the April 21, 2010 meeting, Kirk Patterson provided an April 18, 2010 document entitled *RECHARGE & RECIRCULATION BASIC OPTION PACKAGE* for distribution to interested EARIP participants as well as HDR and Todd Engineers. Although there were many different views expressed, the following fundamental assumptions are believed to adhere to the general consensus.

Fundamental assumptions for each of these subject areas include:

- Source Water

- Irrigation Permits.
  - For the purposes of this technical evaluation only, it is assumed that approximately 66,700 acft/yr at full IRP, which is equivalent to about 40,000 acft/yr under Stage IV, irrigation use will not be pumped by irrigators, but will be available for recovery in an eastern Medina County well field and available for recharge and recirculation.
  - No distinction is made between unrestricted and restricted (base) IRPs and base conservation potential is assumed to be part of the above listed values.
  - Bexar, Medina, and Uvalde County irrigation permits will be considered.
  - Cost estimates based on current prices for IRP purchase is $5,500/acft and lease is $125/acft/yr.
- Type 2 Recharge Projects
  - Hondo and Verde sites are included for both natural recharge enhancement and recirculation recharge purposes.
  - Frio and Sabinal sites are included for natural recharge enhancement purposes only.
  - Mitigation of Corpus Christi surface water rights in Nueces River Basin.
  - Surface water rights in Guadalupe – San Antonio River Basin honored.
  - Region L Consensus Criteria for Environmental Flow Needs (CCEFN) used for surface water availability.

- Recharge Recovery
  - Actual permitting of aquifer storage, recharge recovery, and/or R&R projects may involve additional EAA restrictions.
  - Recovery rates based on recently developed factors, as defined in Appendix C.
  - Recovery must occur within 24 months after recharge.

The physical facilities (Figure 4-3) include:

- Well field and collection system in eastern Medina County for recovery of enhanced recharge, unused permits, and recharge credits.
- Pump station and pipeline for transmission of recovered enhanced recharge from well field to recharge sites on Hondo and Verde Creeks.
- Recharge enhancement structures (dams) on Hondo and Verde Creeks and the Frio and Sabinal Rivers.

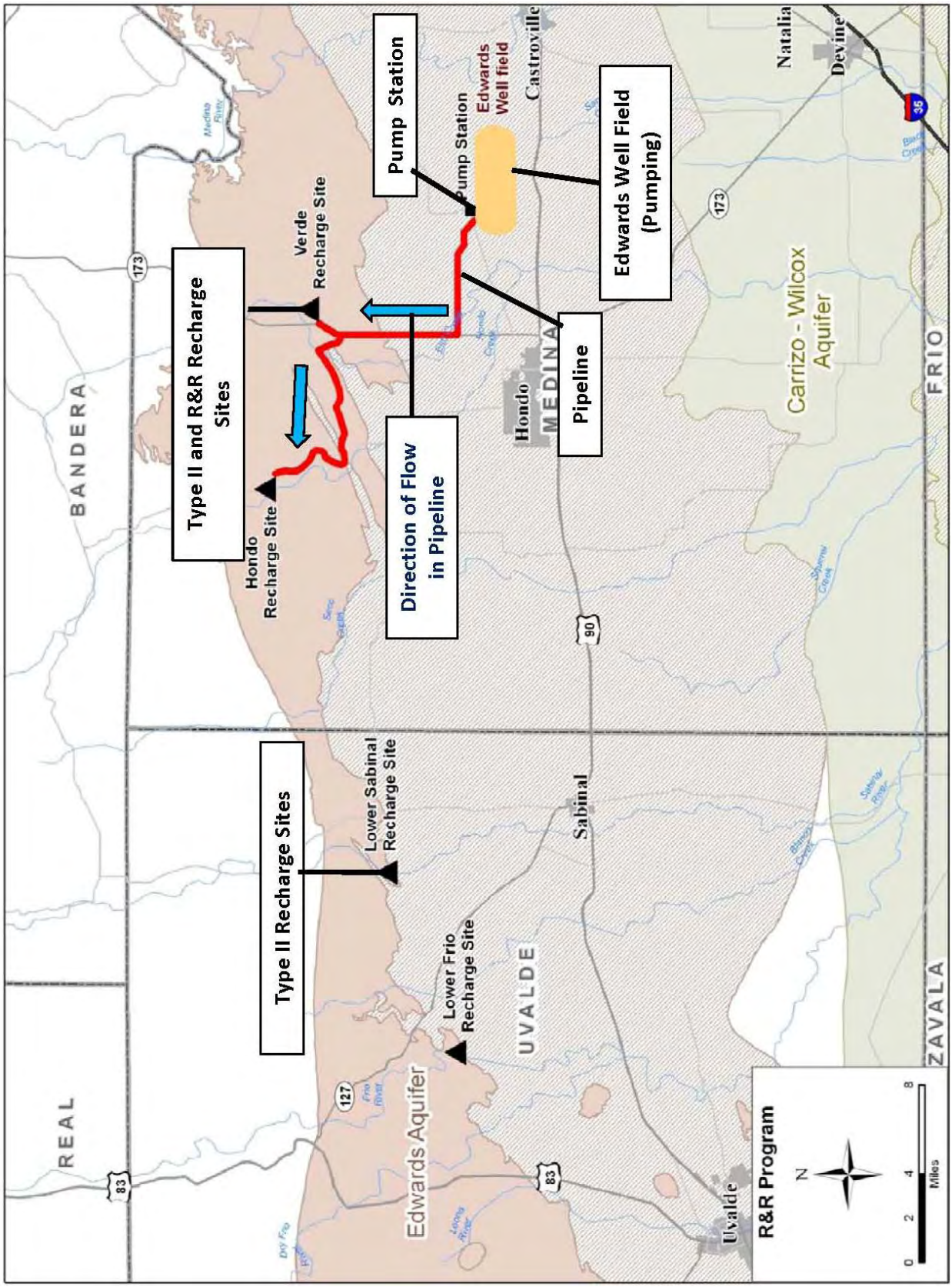


Figure 4-3. Schematic of R&R Program

Operational plan includes:

- Recirculation system will be operated during periods when the J-17 monitoring well level, Comal Springs discharge, and San Marcos Springs discharge are above CPM Stage III levels.
- Fundamental assumptions for R&R operations approximate those provided in Mr. Patterson's April 18, 2010 document. As directed, HDR and Todd Engineers exercised some measure of professional judgment in application of these fundamental assumptions subject to modeling and budgetary constraints.

Scale optimization runs include:

- Run #1: Simulation with a trigger of 150 cfs at Comal Springs and R&R recharge equally split between the Lower Hondo and Lower Verde recharge sites.
- Run #2: Same as Run #1, but with Comal Springs trigger set at 100 cfs.
- Run #3: Similar to Run #2, but with distribution of R&R adjusted to 75 percent going to Hondo and 25 percent going to Verde. The trigger remains at 100 cfs.
- Run #4: Same as Run #3, but with the Comal Springs trigger set at 30 cfs.

Results summarizing the number of months when springflow at Comal and San Marcos are below selected thresholds for the baseline and Runs #1-#4 are presented in Table 4-6. These results suggest the following:

- Comal Springs:
  - Run #4 is the most effective in reducing the number of zero springflow months. However, there are still nine months of zero flow.
  - All runs produced a similar improvement in the number of months for thresholds greater than 30 cfs.
  - None of the runs produced results significantly better for all categories than the others.
- San Marcos Springs:
  - With the exception of the 52 cfs threshold, results for all the runs and throughout the range of thresholds show little improvement in springflow conditions.

Selected statistical summaries for Comal and San Marcos Springs for the baseline and Runs #1-#4 are presented in Table 4-7. These results suggest the following:

- Comal Springs:
  - Flows under the baseline scenario and for the minimum and 6-month minimum moving average for all runs are zero, except the 6-month minimum moving average for Run #4, which is 2 cfs.
  - The long-term average springflow is improved up to 26 cfs.

- San Marcos Springs:
  - The results for the minimum and 6-month minimum moving average are substantially improved over baseline conditions.
  - The long-term average springflow is improved by up to 3 cfs.

Table 4-6.
Number of Months with Springflow below Selected Thresholds for R&R Program (1947-1973)

Springflow Duration below Given Thresholds (1947-1973)						
Spring	**Threshold (cfs)**	**Number of Months**				
		Baseline (348K)	**Run #1: 150 cfs trigger w/ 50-50 split**	**Run #2: 100 cfs trigger w/ 50-50 split**	**Run #3: 100 cfs trigger w/ 25-75 split**	**Run #4: 30 cfs trigger w/ 25-75 split**
Comal	0	38	16	12	13	9
	30	54	31	20	20	20
	60	73	43	38	39	43
	90	110	66	66	67	91
	120	145	101	122	122	134
San Marcos	0	0	0	0	0	0
	52	20	8	6	6	5
	80	52	51	51	51	50
	100	108	103	104	103	104
	120	147	146	146	146	146

Table 4-7.
Selected Springflow Statistics for R&R Program (1947-1973)

Springflow for Selected Statistics (1947-1973)						
Spring	**Threshold (cfs)**	**Springflow (cfs)**				
		Baseline (340K)	**Run #1: 150 cfs trigger w/ 50-50 split**	**Run #2: 100 cfs trigger w/ 50-50 split**	**Run #3: 100 cfs trigger w/ 25-75 split**	**Run #4: 30 cfs trigger w/ 25-75 split**
Comal	Minimum Month	0	0	0	0	0
	Minimum 6-Month Moving Average	0	0	0	0	2
	Long-Term Average	126	152	150	150	148
San Marcos	Minimum Month	2	25	28	27	36
	Minimum 6-Month Moving Average	12	34	37	37	45
	Long-Term Average	127	129	129	129	130

4.1.4 Trade-Off: Bexar County

The concept for the Bexar County trade-off alternative is to use SAWS ASR facilities in South Bexar County for storage and recovery of Edwards water and to use the recovered water for springflow protection. The concept is to: (1) pump water obtained from irrigation leases at the Artesia and Seale Stations, (2) transport the water through the east side pipeline to Twin Oaks, (3) store the water in the ASR well field via ASR wells, (4) recover the water with the ASR wells and deliver to Twin Oaks, (5) transport the water back to Artesia and Seale Stations during severe drought, and (6) make water available for springflow protection in one of three ways. These three ways include: (1) trade-off, (2) direct recharge, and (3) indirect recharge.

Major technical assumptions include:

- Lease 50,000 acft/yr of irrigation IRP for storage in SAWS ASR facilities for springflow protection. Any portion of the leased rights not being used for storage in SAWS ASR facilities will be unused (not pumped). The actual supply of water from the leases will be subject to CPM rules, left in the aquifer when SAWS ASR is full, and fully curtailed when ASR water is being recovered for springflow protection.
- ASR assumptions include: (a) initial storage of 80,000 acft; (b) full storage capacity of 200,000 acft; and (c) there is no water loss.

- The recovery rate for the stored water from SAWS ASR is limited to the current transmission capacity from SAWS ASR to Seale and Artesia Stations, which is 60 million gallons per day (MGD), or 5,600 acft/mo.
- The schedule and rate of water recovery for springflow protection is evaluated for two options. One is to trigger recovery to ON at full capacity when Comal Springs is flowing less than 50 cfs and to turn the recovery OFF when the flow is 50 cfs or more. The second is to develop an episodic schedule and rate of delivery for springflow protection while conserving water in storage. However, only limited effort was made to optimize the schedule and rate of water recovery from SAWS ASR. Additional effort could have improved the level of springflow protection. It's important to note that the ON-OFF option used up the full supply of stored water before the most intense part of the drought occurred. Thus, it did not provide any protection at this critical time. Also, the pipeline capacity was the most limiting constraint during the most intense part of the drought for the episodic option. Episodic recharge was applied with direct recharge facilities and with indirect recharge facilities.

The physical facilities for the trade-off, direct recharge, and indirect recharge (Figure 4-4a, 4-4b, and 4-4c, respectively) include:

- SAWS ASR existing water collection, transmission, and storage facilities.
  - Trade-Off: SAWS existing distribution system that allows recovered water from SAWS ASR that is initially delivered to Artesia and Seale stations to be delivered to customers normally served by SAWS well fields in northeast Bexar County with SAWS existing distribution system.
  - Direct Recharge: Water recovered from SAWS ASR at Artesia and Seale Stations is to be transported by a new pipeline and transmission facilities to a new Edwards injection well field between Cibolo Creek and Comal Springs.
  - Indirect Recharge: Water recovered from SAWS ASR at Artesia and Seale Stations is to be indirectly picked up (pumped) by the Naco and Stahl Stations, and delivered by a new pipeline and transmission facilities to an Edwards injection well field, which is located between Cibolo Creek and Comal Springs. Also, SAWS existing distribution system is assumed to have the capacity to deliver the recovered water from SAWS ASR that is initially delivered to Artesia and Seale stations to customers normally served by SAWS' Naco and Stahl Stations.

a. Trade-Off

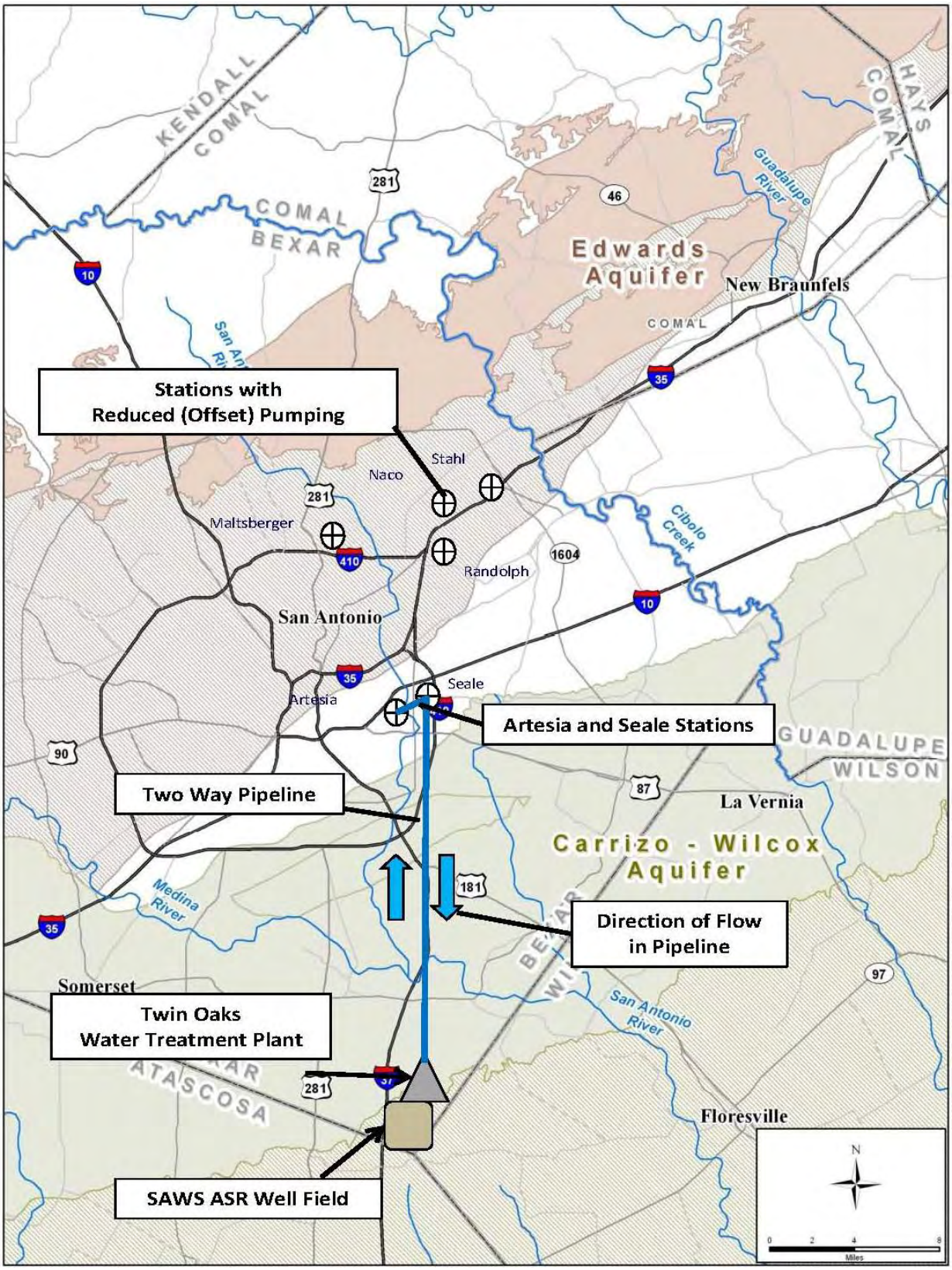


Figure 4-4. Schematic Trade-Off: Bexar County Program

b. Direct Recharge

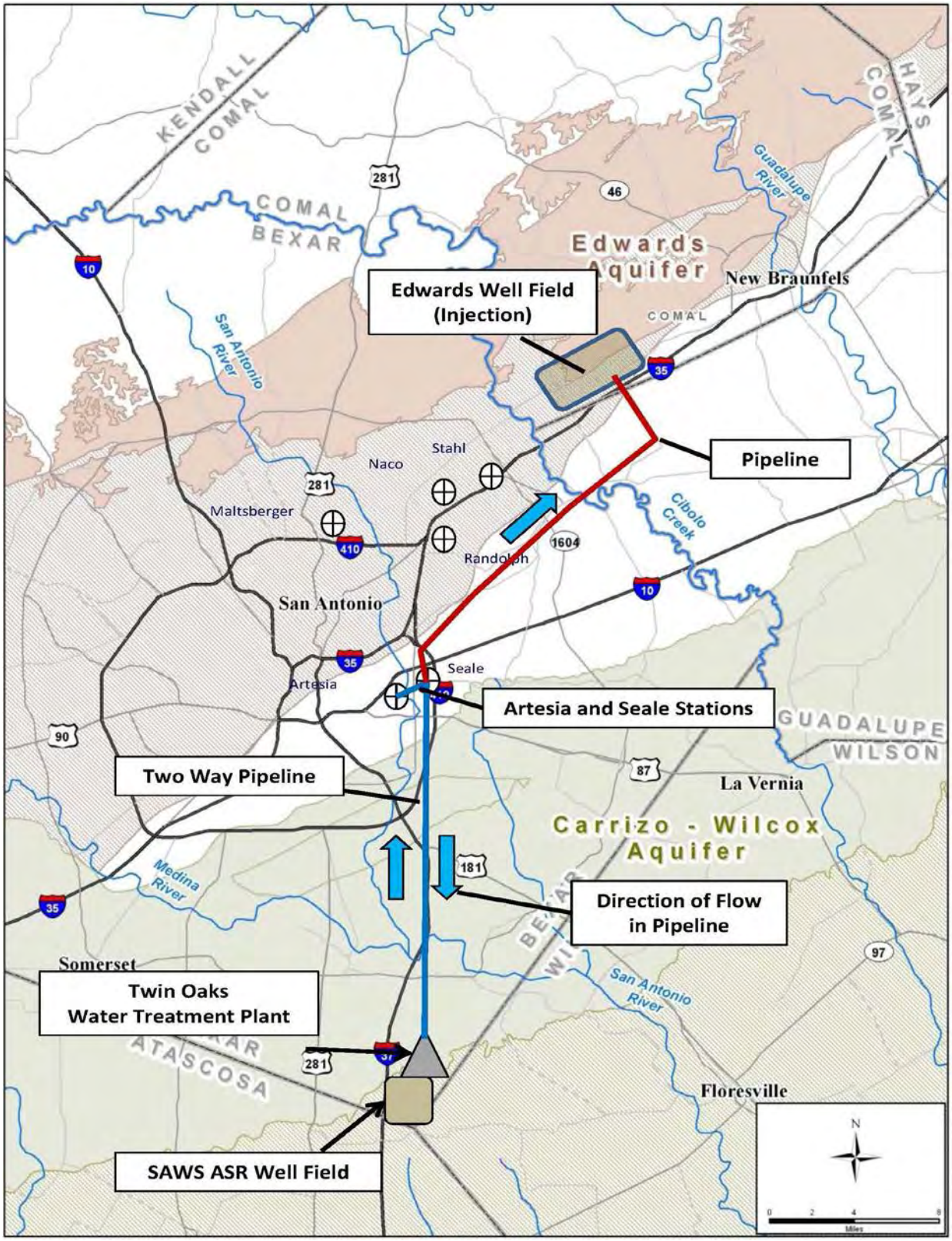


Figure 4-4. Schematic Trade-Off: Bexar County Program (Continued)

c. Indirect Recharge

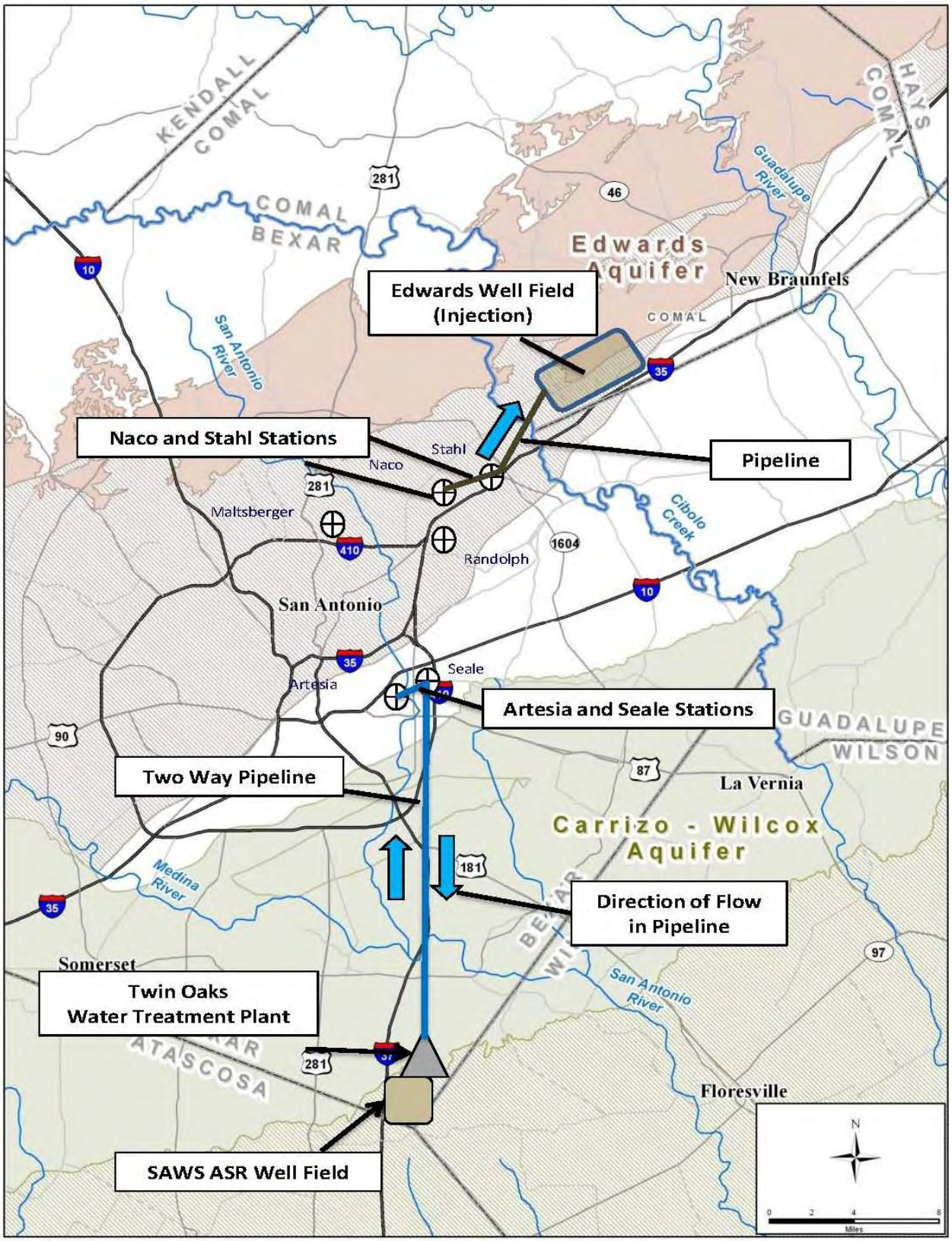


Figure 4-4. Schematic Trade-Off: Bexar County Program (Concluded)

Results summarizing the number of months when springflow at Comal and San Marcos Springs are below selected thresholds for the baseline and Runs #1-#6 are presented in Table 4-8. These results suggest the following:

- Comal Springs:
  - None of the runs and options fully eliminates the occurrence of zero flow months at Comal Springs.
  - Results for the ON-OFF option are very similar for all three runs, as they are for the episodic option for all three runs.
  - Overall, the episodic option provides considerably fewer no flow months than the ON-OFF option. This is caused by the ON-OFF option draining of the available ASR storage prior to the most intense part of the drought.
- San Marcos Springs:
  - The results show considerable reduction (relative to the baseline) in the number of months with springflows less than 52 cfs for all runs and options.
  - The program shows little change from baseline conditions for thresholds greater than 52 cfs.

Selected statistical summaries for Comal and San Marcos Springs for the baseline and Runs #1-#6 are presented in Table 4-9. These results suggest the following:

- Comal Springs:
  - No flow conditions exist for all runs and options.
  - The 6-month minimum flow is 8 cfs for the direct and indirect recharge options.
  - The ON-OFF option noticeably increases the long-term average, while the episodic option increases the long-term average by a very small amount.
- San Marcos Springs:
  - Results for the minimum month and minimum 6-month moving average are similar for all runs with the ON-OFF option and with the episodic option.
  - Overall, the episodic option provides considerably higher minimum springflows than the ON-OFF option.
  - None of the runs and options significantly increases the long-term average springflow.

Table 4-8.
Number of Months with Springflow below Selected Thresholds for Trade Off: Bexar County Program (1947-1973)

Springflow Duration below Given Thresholds (1947-1973)								
Spring	Threshold (cfs)	Number of Months						
		Baseline (348K)	Run #1: Trade-off (On-Off)	Run #2: Trade-off (Episodic)	Run #3: Direct Recharge (On-Off)	Run #4: Direct Recharge (Episodic)	Run #5: Indirect Recharge (On-Off)	Run #6: Indirect Recharge (Episodic)
Comal	0	38	8	11	10	2	10	2
	30	54	13	39	12	37	14	37
	60	73	37	65	30	67	32	67
	90	110	85	106	80	106	82	106
	120	145	145	148	136	148	141	148
San Marcos	0	0	0	0	0	0	0	0
	52	20	6	5	8	5	8	5
	80	52	51	50	50	50	51	50
	100	108	104	107	106	108	106	108
	120	147	146	146	146	146	146	146

Table 4-9.
Selected Springflow Statistics for Trade Off: Bexar Program (1947-1973)

Springflow for Selected Statistics (1947-1973)

Spring	Threshold (cfs)	Springflow (cfs)						
		Baseline (348K)	Run #1: Trade-off (On-Off)	Run #2: Trade-off (Episodic)	Run #3: Direct Recharge (On-Off)	Run #4: Direct Recharge (Episodic)	Run #5: Indirect Recharge (On-Off)	Run #6: Indirect Recharge (Episodic)
Comal	Minimum Month	0	0	0	0	0	0	0
	Minimum 6-Month Moving Average	0	0	0	0	8	0	8
	Long-Term Average	126	136	129	138	129	137	129
San Marcos	Minimum Month	2	31	37	23	46	23	46
	Minimum 6-Month Moving Average	12	40	45	34	50	34	50
	Long-Term Average	127	130	129	130	130	129	130

4.1.5 Trade-Off: Comal and Hays Counties

The concept for the Trade-off for Comal and Hays Counties is to: (1) operate selected Type II recharge structures, (2) capture the enhanced recharge, less losses, at an Edwards well field in northeast Bexar County, (3) transport the water to a new Carrizo ASR well field in Wilson County, (4) store the water in the new Carrizo ASR well field, (5) add Stage V pumping restrictions on municipal and industrial wells in Comal and Hayes Counties, (6) recover stored water during severe drought, and (7) use this water to replace the lost water attributed to the Stage V restrictions.

Major technical assumptions include:

- Source of water:
  - Type II Recharge Structures include: Frio, Sabinal, Hondo, Verde, San Geronimo and Salado-Flood Retarding Structures.

- Pumping Reductions:
  - When critical springflow conditions at Comal and San Marcos Springs are being approached during a drought, the Edwards water supply for major municipal and industrial permit holders in New Braunfels and San Marcos is to be replaced with water in ASR storage.
  - The ASR recovered water is to be delivered at rates that are equivalent to allowable Edwards pumping for these permit holders.
  - In other words, the utilities are to be provided an alternative water supply in exchange for curtailing their allowable pumping from the Edwards during critical springflow conditions.

- ASR Operation
  - At the beginning of the model simulation, the enhanced recharge from the Type II structures will be pumped until the estimated amount of storage needed for springflow protection is achieved. The water will be stored in the ASR facilities. After being filled, a small percentage will be pumped and injected into the ASR wells to overcome any losses and to maintain the Edwards water bubble around the ASR wells.
  - The overall permitted level of pumping in the Edwards will be at IRP rates, which produces a minimum (nominal) permitted pumping level of approximately 348,000 acft/yr (excluding domestic and livestock and Federal uses).
  - Set triggers for recovery and Stage V restrictions to maintain Comal springflows between 30 and 60 cfs.
  - When the flow from Comal and San Marcos Springs nears appropriate trigger levels, water is to be recovered from ASR storage and delivered to major distribution centers in New Braunfels and San Marcos.

The physical facilities (Figure 4-5) include:

- A well field and collection system is to be located in the general vicinity of Loop 1604 and I-35 in northeast Bexar County.
- An ASR well field is tentatively planned for northwestern Wilson County. The storage will be in the Carrizo Aquifer.
- Pipelines for transmission of the source Edwards water from the Edwards well field to the ASR well field in Wilson County and from the ASR well field to interconnects with major water utilities in New Braunfels and San Marcos. Part of the pipeline will be two-way with water flowing to the ASR well field in the fill cycle and returning to major distribution centers in the recovery cycle. Pump stations are required.

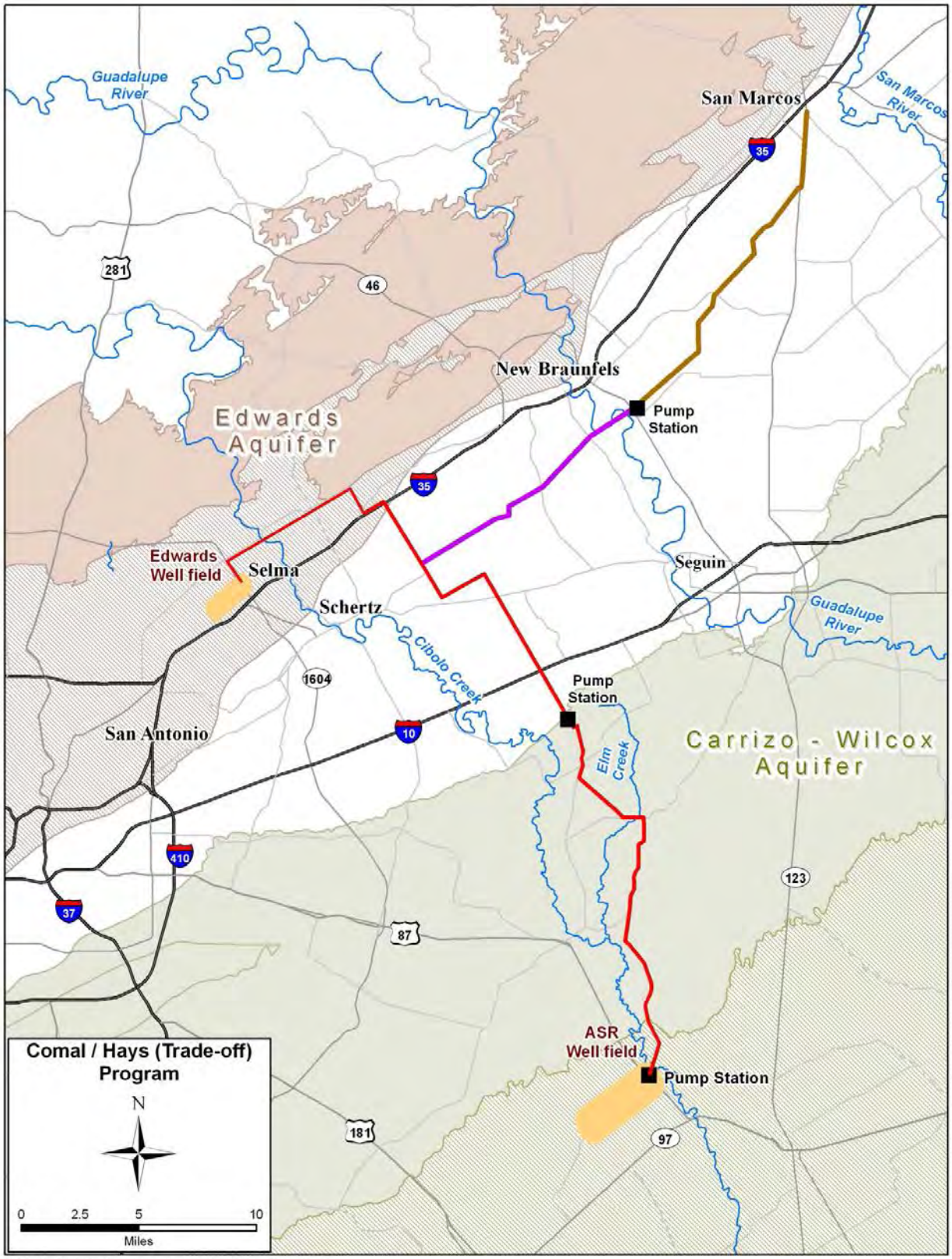


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Figure 4-5. Schematic of Trade Off: Comal and Hays Counties Program

Results summarizing the number of months when springflows at Comal and San Marcos Springs are below given thresholds for the baseline and alternative run #1 are presented in Table 4-10. These results suggest the following:

- Comal Springs:
  - The program reduces the number of zero flow months by only 6.
  - The number of months with flows less than 60 cfs is improved slightly.
- San Marcos Springs:
  - The results for the range of thresholds less than 100 cfs show some improvement in springflow conditions.

Table 4-10.
Number of Months with Springflow below Selected Thresholds for Trade Off: Comal and Hays Program (1947-1973)

Spring	Threshold (cfs)	Number of Months	
		Baseline (348K)	Run #1
Comal	0	38	32
	30	54	47
	60	73	69
	90	110	109
	120	145	151
San Marcos	0	0	0
	52	20	7
	80	52	39
	100	108	96
	120	147	147

Selected statistical summaries for Comal and San Marcos Springs for the baseline and Run #1 are presented in Table 4-11. These results suggest the following:

- Comal Springs:
  - No flow still occurrs.
  - The minimum 6-month moving average increases from zero to 8 cfs.
- San Marcos Springs:
  - The minimum flow increases substantially for the minimum and minimum 6-month average.
  - There is little improvement in the long-term monthly average.

Table 4-11.
Selected Springflow Statistics for
Trade Off: Comal and Hays Counties Program
(1947-1973)

Spring	Threshold (cfs)	Springflow (cfs)	
		Baseline	Run #1:
Comal	Minimum Month	0	0
	Minimum 6-Month Moving Average	0	8
	Long-term Average	126	132
San Marcos	Minimum Month	2	44
	Minimum 6-Month Moving Average	12	50
	Long-term Average	127	130

4.2 Cost Estimates

Cost estimates for each of the alternatives are based on the following methods and assumptions:

- **Annual cost:** Operating costs are generally averaged over the MODFLOW simulation period (1947-1973).
- **Project Cost:** Includes capital and upfront costs such as facilities, equipment, engineering, environmental studies, land acquisition, permitting, etc. Cost estimating procedures are from those used in the 2011 South Central Texas Regional Water Plan. The costs are in September 2008 dollars.
- **Edwards Water Permit Purchase:** The cost for permanent acquisition is assumed to be $5,500/acft.
- **Edwards Water Permit Lease:** The cost for short-term lease is assumed to be $125/acft/yr.
- **Water Replacement Cost:** Referenced to the 2011 South Central Texas Regional Water Plan.
- **Debt Service:** Interest rate is 6 percent per year. Bond period is 20-years for non-reservoir facilities and 40-years for reservoirs.

- **Operation and Maintenance:** Estimated using procedures from the 2011 South Central Texas Regional Water Plan.
- **Energy:** $0.09/KwHr.

Unlike the Bottom-Up Program, most of these alternatives had extensive facilities such as well fields, pipelines, and pump stations and, as a result, are expected to be considerably more expensive. Also, the long-term cost for these alternatives is based on a 27-year period (1947-1973) instead of the 54-year period (1947-2000) for the Bottom-Up Program.

Cost estimates for each of the runs and options of the alternatives are tabulated in Table 4-12. It's important to note that one cannot readily compare the costs among the many alternatives and options because their effectiveness in terms of springflow protection is not equal. Some of the alternatives are generally effective in springflow protection while others offer marginal improvement over baseline conditions. Without consideration of effectiveness, annual costs of the Recharge & Recirculation Program(s) are the most expensive while the Bexar County Trade-Off with the Trade-Off option is the least expensive. Costs for ASR Program Runs #2 and #3 should not be compared to Run #1 because there is no cost accounting for economic losses that could be attributed to greater withdrawal reductions in CPM Stage IV. Finally, it is noted that the annual cost of purchasing Edwards permits is much more expensive than that for leasing the same amount of water.

Table 4-12.
Estimated Costs for Alternative Programs

Program	Run	Investment		Annual				
		Project, includes Water Purchase	Edward Water Purchase	Edwards Water Lease (27-Year Average) or Replacement	Debt Service or Depreciation	O&M	Energy (27-Yr Average)	Total
ASR: Program #1 with Purchase of 66,700 acft of Irrigation Permits								
1	1-P	$789,262,000	$366,850,000	$0	$68,811,000	$3,094,000	$974,000	$72,879,000
1	2-P	$668,781,000	$366,850,000	$0	$58,307,000	$2,193,000	$547,000	$61,047,000
1	3-P	$620,510,000	$366,850,000	$0	$54,099,000	$1,816,000	$240,000	$56,155,000
ASR: Program #1 with Intermittent Lease of up to 66,700 acft of Irrigation Permits								
1	1-L	$405,880,000	$0	$1,911,000	$35,386,000	$3,224,000	$1,163,000	$41,684,000
1	2-L	$314,639,000	$0	$1,206,000	$27,432,000	$2,545,000	$707,000	$31,890,000
1	3-L	$246,446,000	$0	$734,000	$21,486,000	$2,016,000	$278,000	$24,514,000
Combination: Type II, Dry-Year Option, Land Stewardship and SAWS ASR								
2	1	$162,213,000	$0	$697,000	$10,984,000	$1,166,000	$0	$12,847,000
2	2		$0	$4,341,800	$0	$0	$0	$4,341,800
2	3	$87,372,000	$0	$0	$7,217,000	$1,393,000	$210,000	$8,820,000
2	4		$0	$0	$7,265,000	$529,000	$0	$7,794,000
2	Total	$249,585,000	$0	$5,038,800	$25,466,000	$3,088,000	$210,000	$33,802,800
R&R: Program #3 with Purchase of 66,700 acft of Irrigation Permits								
3	1-P	$790,078,000	$366,850,000	$0	$68,244,000	$3,072,000	$9,160,000	$80,476,000
3	2-P	$790,078,000	$366,850,000	$0	$68,244,000	$3,072,000	$11,938,000	$83,254,000
3	3-P	$811,794,000	$366,850,000	$0	$70,137,000	$3,238,000	$12,221,000	$85,596,000
3	4-P	$811,794,000	$366,850,000	$0	$70,137,000	$3,238,000	$14,920,000	$88,295,000
R&R: Program #3 with Lease of 66,700 acft of Irrigation Permits								
3	1-L	$393,880,000	$0	$8,338,000	$33,701,000	$3,072,000	$9,160,000	$54,271,000
3	2-L	$393,880,000	$0	$8,338,000	$33,701,000	$3,072,000	$11,938,000	$57,049,000
3	3-L	$415,596,000	$0	$8,338,000	$35,595,000	$3,238,000	$12,221,000	$59,392,000
3	4-L	$415,596,000	$0	$8,338,000	$35,595,000	$3,238,000	$14,920,000	$62,091,000
Bexar County Trade-Off with Trade-Off Option								
4	1a	$0	$0	$6,250,000	$7,265,000	$529,000	$1,392,000	$15,436,000
4	1b	$0	$0	$6,250,000	$7,265,000	$529,000	$862,000	$14,906,000
Bexar County Trade-Off with Direct Recharge Option								
4	2a	$132,845,000	$0	$6,250,000	$18,847,000	$1,546,000	$3,021,000	$29,664,000
4	2b	$132,845,000	$0	$6,250,000	$18,847,000	$1,546,000	$1,889,000	$28,532,000
Bexar County Trade-Off with Indirect Recharge Option								
4	3a	$81,331,000	$0	$6,250,000	$14,356,000	$1,186,000	$1,884,000	$23,676,000
4	3b	$81,331,000	$0	$6,250,000	$14,356,000	$1,186,000	$1,172,000	$22,964,000
Comal/Hays M&I Trade-Off								
5	1	$227,636,000	$0	$696,000	$36,358,000	$2,811,000	$950,000	$40,815,000

Appendix A
Application of USGS MODFLOW Model for Evaluation of EARIP Programs

1.0 Introduction

This report evaluates various management programs using the Edwards Aquifer MODFLOW numerical model (EAA model) developed by USGS and others[9]. The EAA model, also called MODFLOW in this report, is a calibrated transient model for the simulation period 1947-2000 with monthly stress periods. The simulation period begins with initial head conditions generated from a steady state simulation of historical conditions, which is assumed to be the average for the 1939–1946 period. The original model estimated hydrologic conditions and pumping on a monthly basis throughout the transient period. For this study, the original model hydrologic conditions were used, but pumping was adjusted to represent the current authorized pumping in the aquifer as discussed in the Section 2: Baseline Conditions.

The model extent, shown in Figure A-1, includes both the San Antonio and Barton Springs segments of the Edwards aquifer in the San Antonio region of Texas. The San Antonio segment of the aquifer primarily includes all or parts of Kinney, Uvalde, Medina, Bexar, Comal, and Hays Counties. This segment is bounded on the west and east by groundwater divides near Brackettville and Kyle, respectively, and contains the most productive and transmissive parts of the aquifer. The Barton Springs segment of the aquifer includes parts of Hays and Travis Counties and is bounded on the southwest by the groundwater divide near Kyle and on the northeast by the Colorado River. No pumping in Travis County is included in the model simulations. The San Antonio segment of the aquifer discharges primarily to Comal and San Marcos Springs, whereas the Barton Springs segment discharges primarily to Barton Springs.

2.0 Model Application

Due to large file sizes, the USGS originally divided the transient EAA model into two halves to allow it to work with pre- and post- processors. The first half of the model (1947-1973) covers much drier hydrologic conditions than the second half (1974-2000), with approximately 30 percent less natural recharge. During the first half of the simulation period, the aquifer is subject to CPM withdrawal reductions for 95 percent of the time (310 months) compared to only 64 percent of the time in the second half of the model (208 months). These differences in recharge and length of time in critical period affect the benefits associated with the management

[9] Lindgren, R.J., Dutton, A.R, Hovorka, S.D., Worthington, S.R.H. and Painter, S., 2004, Conceptualization and simulation of the Edwards Aquifer, San Antonio Region, Texas: U.S. Geological Survey Scientific Investigations Report 2004-5277, 143p.

programs. Since performance of the programs is judged primarily on the benefits during the drought of record (1947-1957), several EARIP Alternatives and Programs were only simulated using the first half of the model (1947-1973).

Due to the large model size, a specific solver, the mathematical process used to solve the numerical questions for each cell at each stress period, was applied in the model to decrease run time. The original USGS model used the algebraic multi-grid solver (LMG). For this study, a more recent and publicly available solver was used, referred to as the geometric multi-grid solver (GMG). Testing conducted for a previous EAA study by Todd Engineers validated the application of GMG for this model. Using GMG, run times for the first half of the model were reduced to around 30 minutes.

In order to simulate EAA CPM rules, EAA retained HydroGeoLogic, Inc. (HydroGeoLogic) to develop computerized management modules to work in concert with the USGS MODFLOW model. These modules read in model output such as head and springflow for assigned triggers as the model is running. Based on the values of these triggers, the management modules can adjust pumping by use or by county, thereby simulating withdrawal reductions associated with CPM. Current CPM triggers and rules are set up in the modules and applied to MODFLOW for each simulation in this study.

To assist with development of the baseline scenario and the analysis of modeling results, several software programs (tools) were created by Todd Engineers that edit MODFLOW recharge and well files as well as the files associated the Management Modules. These tools were mostly developed in the programming language PERL to manipulate the MODFLOW text files directly. They included a program to read the volumetric budget from the *".lst"* file (a model output) and a program to read the CPM stage from the *".log"* file (a management module output). Tools that assisted in the creation of scenario specific files included subroutines to adjust pumping based on certain conditions (hydrologic conditions, ASR status, etc,) and to prepare recharge regimes. The MODFLOW software known as Groundwater Vistas was used to create the recharge packages for each scenario and obtain the water level and spring flow data for each stress period.

For more information about the original model, the reader is referred to the USGS model documentation (Lindgren, et al., 2004). For more information about the management modules, the reader is referred to the documentation prepared by HydroGeoLogic[10]..

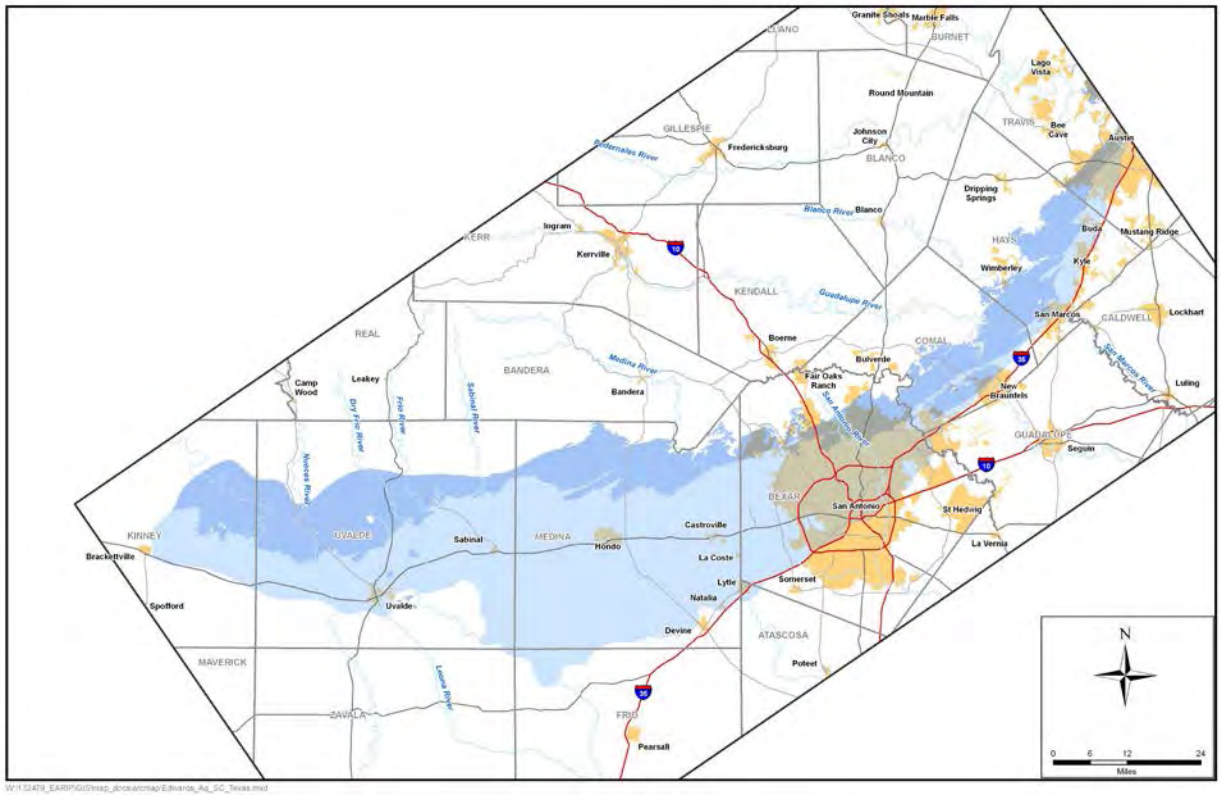


Figure A-1. Extent of the EAA MODFLOW Model

3.0 Limitations

The EAA model, like any numerical model, is a simplified representation of a complex, natural system and has limitations. Although the model represents the best available predictive tool with which to analyze management programs, numerous uncertainties are associated with both the model and the applications for this study. The model uncertainties and limitations are briefly stated here to highlight model application issues.

To simulate current and future pumping, pumping totals were increased above the original EAA model pumping amounts. This increase in pumping may stress the boundary conditions outside the range for which the model was calibrated. The result is that a larger portion of the model may now be subject to cells going dry due to numerical problems than

[10] HydroGeoLogic, Inc., November 2004, Reference Manual for the Groundwater Management Package for MODFLOW-2000: Prepared for Edwards Aquifer Authority.

occurred in the original model. For all simulations in this study, the USGS re-wetting tool was used to prevent this numerical instability. The problem and solution are discussed further in the section describing Section 2: Baseline Conditions.

In addition to the dry cell problem, changes in the distribution of pumping and pumping totals may have unintended consequences. When updating the EAA model, recharge and pumping rates were selected independently to reflect what may happen in the future rather than what has occurred in the past. Although recharge and pumping are decoupled in the model, in reality, the amount of recharge (and precipitation) would have a direct influence on the amount of pumping. For example, wet conditions would likely result in less pumping as precipitation satisfies more of the irrigation water demand; similarly, in dry conditions, more water would likely be pumped for irrigation. By assuming pumping is always at the permitted limit, the total demand is very likely to be an over-estimate, which usually would cause results to be considered "conservative."

The EAA model has other limitations that should be considered when evaluating management programs and analyzing model results. Two fundamental limitations include:

- The model provides a better calibration of the confined zone than the recharge zone, and predictions of head in the recharge area may be less reliable.
- MODLFOW is based on porous media equations. However, the Edwards is a dual-porosity karst system. The model cannot simulate turbulent flow occurring in the conduits. In addition, locations of the simulated conduits have a strong impact on the areas surrounding the conduits. While the model can predict regional variations in water levels and springflow, it probably should not be used to predict the fate and transport of particles of water or contaminants.

Notwithstanding these limitations, the model is considered to be a valuable tool to examine volumetric flow responses in the confined zone, particularly at the major springs. Although enhanced recharge in the unconfined zone is simulated in several programs, the effects are measured in the confined zone through spring discharge and water levels at selected index wells (J-17 and J-27). The observed spring discharge for Comal Springs was well matched by the simulated discharge in the original model. Because simulations are consistent with the regional design of the model, program results are expected to fall within the range of model capabilities.

Appendix B
Comparison of Two Methods of Applying Enhanced Recharge for Springflow Protection at Comal and San Marcos Springs

1.0 Introduction

Some of the engineering solutions considered by the EARIP for springflow protection include recharging the Edwards Aquifer in the vicinity of Comal Springs. The target area considers the potential efficiency and travel time to Comal Springs and San Marcos Springs. In general, one could expect the efficiency to be highest when the recharge site is nearest the target spring. Likewise, one could expect that the recharge water would be better acclimated to native aquifer conditions the farther the site is away from the springs. With these two major considerations, the target recharge sites for Comal and San Marcos Springs are about midway between Cibolo Creek and Comal Springs and to the west of I-35 (Figure B-1). As documented by Maclay, R.W. (1995)[11], Collins, E.W. and Hovorka, S.D. (1997)[12], Small, T.A., and Hanson, J.A. (1994)[13], Small, T.A., and Hanson, J.A. (1995)[14], and others, this target area is geologically very complex because of the numerous faults and zones of very high permeability. The Comal Springs Fault runs southwest-northeast in the area and nearly or completely separates the continuity of the aquifer in the downdip direction and often separates the confined and unconfined zones of the Edwards in this vicinity.

There are two methods of enhancing recharge to the Edwards in the target area. One is to surface recharge in the outcrop (updip zone), either along Dry Comal Creek or its tributaries or in surface reservoirs. The other is to use injection wells in the confined zone. The Comal Springs Fault separates the two potential recharge sites. At this location, the direct injection of recharge would be into a groundwater flowpath from the main body of the Edwards to Comal Springs. From Comal Springs toward San Marcos Springs, this flowpath veers in the downdip direction and terminates in the saline zone of the Edwards. The zone immediately updip of the Comal Springs Fault is sandwiched between this fault and the San Marcos Springs Fault and is the major flowpath to San Marcos Springs. Within this hydrogeologic setting, one would expect that recharge with injection wells would benefit Comal Springs more than San Marcos Springs, and the surface recharge sites would benefit San Marcos Springs more than Comal Springs.

[11] Maclay, R.W., 1995, Geology and hydrology of the Edwards Aquifer in the San Antonio area, Texas: U.S. Geological Survey Water Resources Investigations Report 95-4186.
[12] Collins, E.W. and Hovorka, S.D., 1997, Structure map of the San Antonio Segment of the Edwards Aquifer and Balcones Fault Zone, South-Central Texas: Structural Framework of a Major Limestone Aquifer: Kinney, Uvalde, Medina, Bexar, Comal,and Hays Counties: Bureau of Economic Geology, The University of Texas at Austin Miscellaneous Map No. 38.
[13] Small, T.A., and Hanson, J.A., 1994, Geologic framework and hydrogeologic characteristics of the Edwards Aquifer outcrop, Comal County, Texas: U.S. Geological Survey Water Resources Investigations Report 94-4117.
[14] Small, T.A., and Hanson, J.A., 1995, Geologic framework and hydrogeologic characteristics of the Edwards Aquifer outcrop, Hays County, Texas: U.S. Geological Survey Water Resources Investigations Report 95-4265.

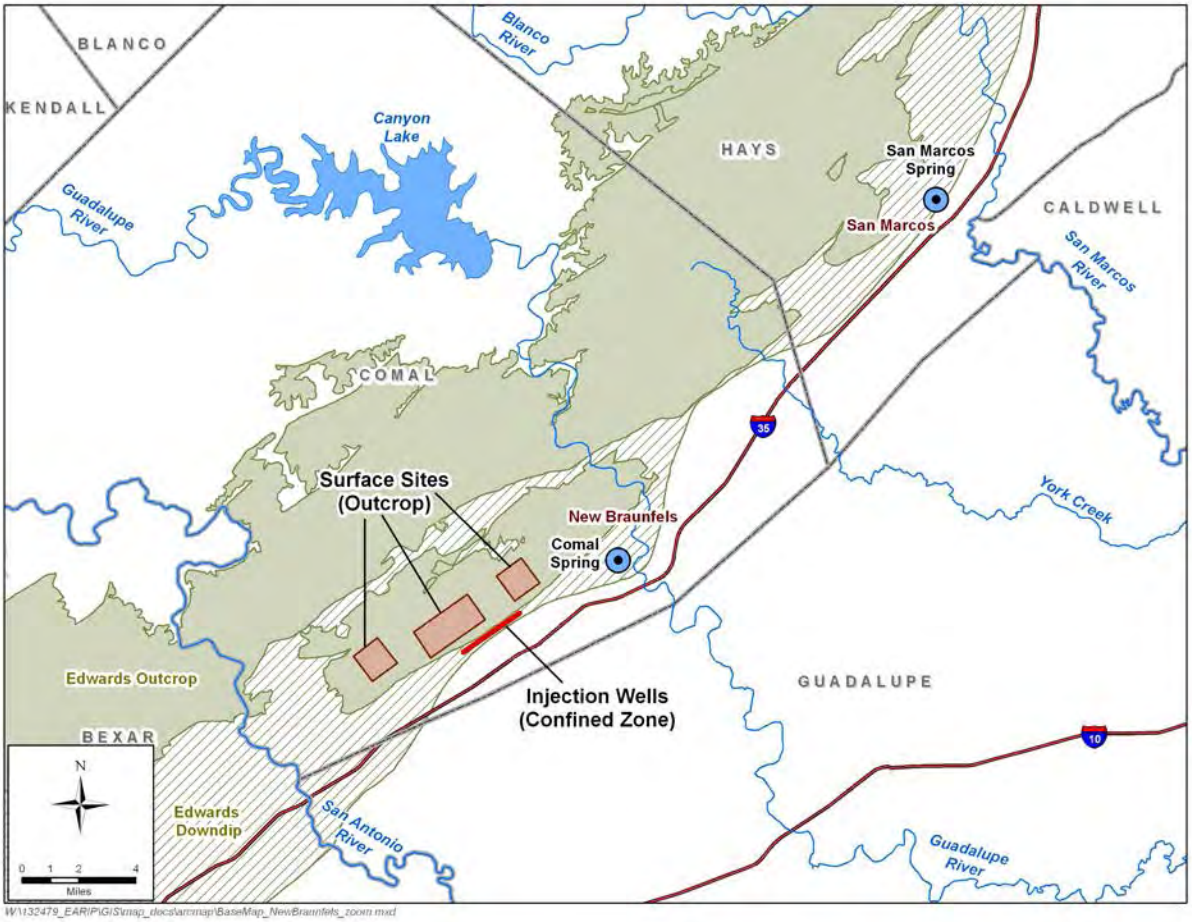


Figure B-1. Location of Test Enhanced Recharge Sites

With this uncertainty as to which method to enhance recharge provides the best springflow protection for both springs, a series of test simulations with MODFLOW were conducted to evaluate the efficiency of the two methods in providing desired springflow protection.

2.0 Model Test Procedures

The preliminary phase of the testing was to conduct a series of experimental model runs that used injection wells into a conduit (major flowpath) in MODFLOW that leads to Comal Springs and to develop an episodic enhanced recharge schedule and rates that would maintain approximately 30 cfs of flow from Comal Springs. The approximate episodic enhanced recharge tested uses about 205,700 acft of water. Figure B-2 shows the selected episodic recharge along with the baseline flow from Comal Springs. The next step was to apply the same episodic recharge to surface water features in the outcrop area (updip of Comal Springs Fault).

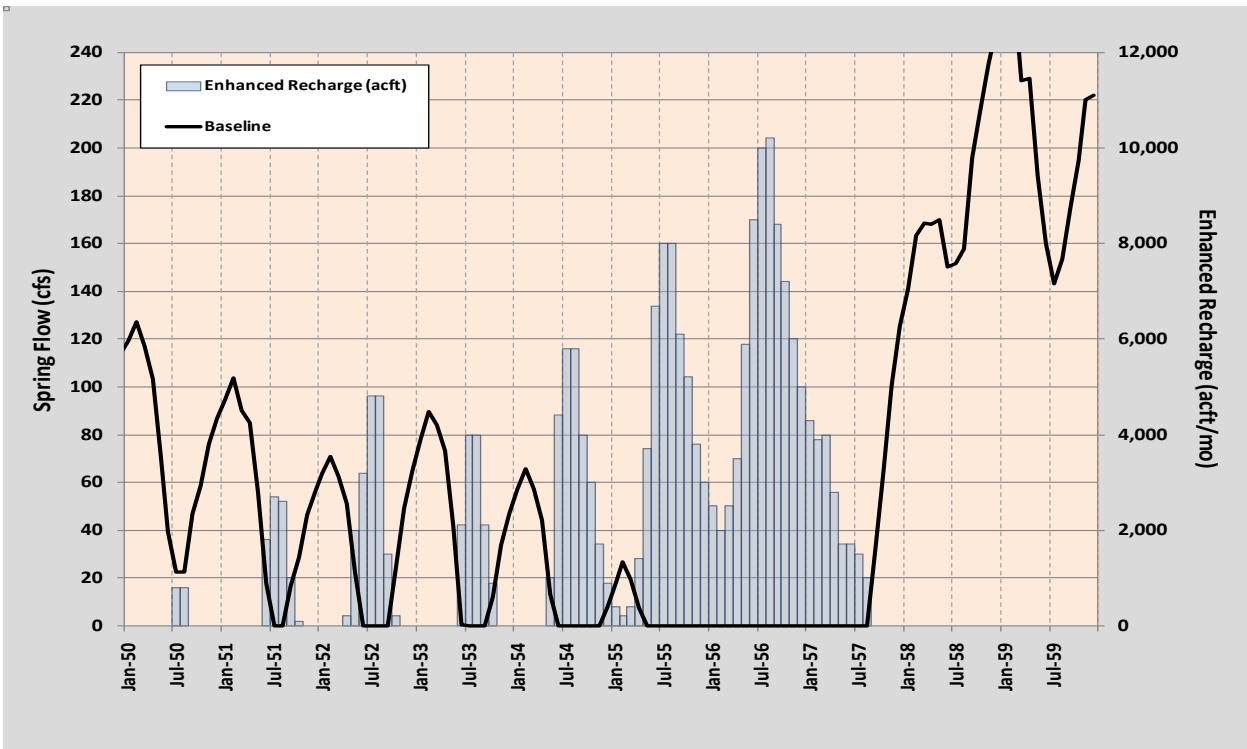


Figure B-2. Episodic Enhanced Recharge and Baseline Flow from Comal Springs

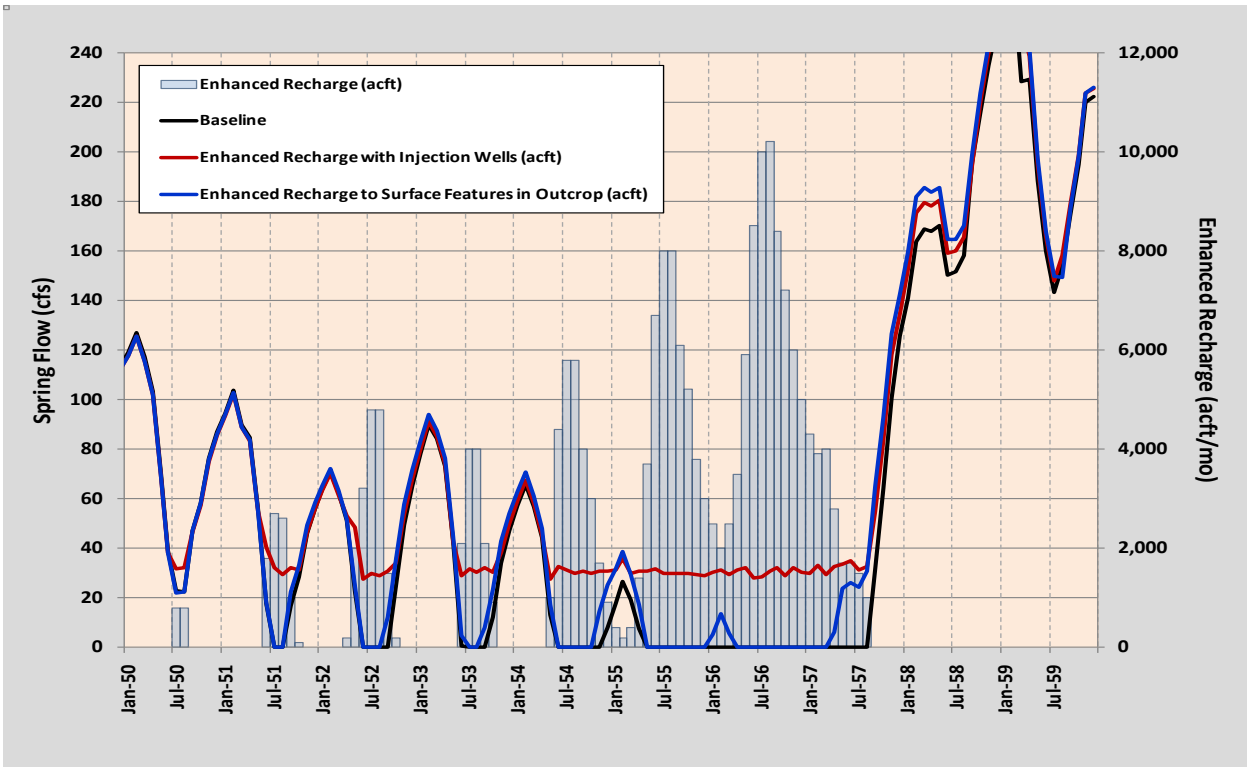


Figure B-3. Episodic Enhanced Recharge and Simulated Flow from Comal Springs

Figures B-3 and B-4 illustrate the episodic recharge sequence and resulting flows from Comal Springs and San Marcos Springs, respectively. Inspection of these charts indicates that the injection wells are much more effective in providing springflow protection for Comal Springs and that the surface recharge is much more effective for San Marcos Springs.

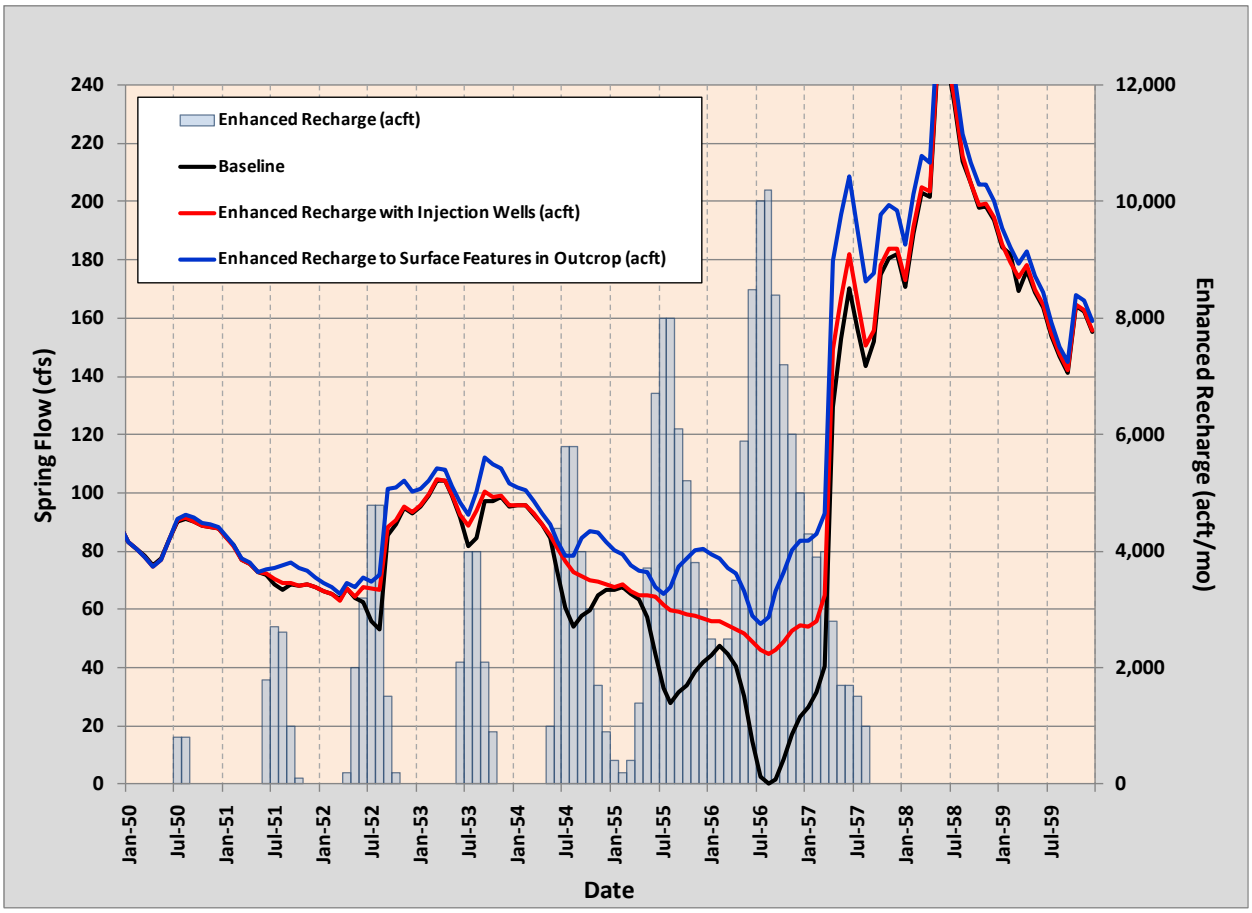


Figure B-4. Episodic Enhanced Recharge and Simulated Flow from San Marcos Springs

3.0 Efficiency of Two Recharge Methods for Springflow Protection

The efficiency of the two enhanced recharge methods is indicated by the percentage of enhanced recharge flowing from the springs. This percentage is calculated by dividing the cumulative enhanced springflow by the cumulative enhanced recharge. Figures B-5 and B-6 show these percentages for enhanced recharge along with the baseline springflow.

The results at Comal Springs (Figure B-5) indicate:

- Comal Springs is much more responsive to recharge with injection wells than through surface features in the outcrop. About 71 percent of the initial slug of recharge in the conduit during 1950, when the baseline springflow was about 25 cfs, promptly discharged from Comal Springs. In contrast, no recharge in the outcrop area discharged during the first year.

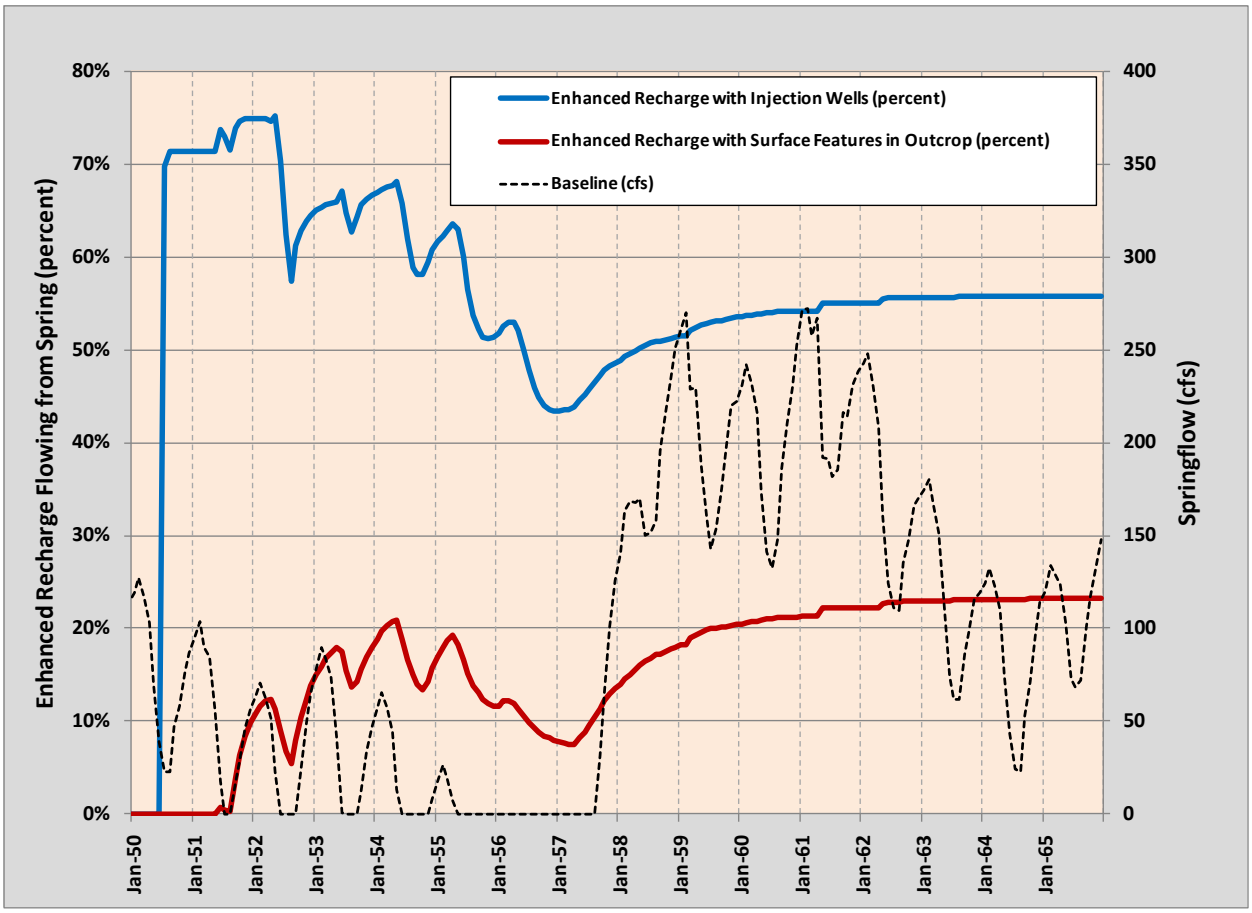


Figure B-5. Comparison of Effectiveness of two Enhanced Recharge Methods at Comal Springs.

- As the drought became more intense from the summer of 1952 to the summer of 1957, the percentage of enhanced recharge that was injected into the conduit and exited the Edwards via Comal Springs generally declined to a low of about 44 percent. This is attributed to some of the water being lost to production wells or remaining in aquifer storage. During this same period, the percentage of enhanced recharge on the outcrop substantially lagged the recharge in the conduit. By the middle of the drought of record, about 20 percent of the enhanced recharge on the outcrop was discharging from Comal Springs. By the summer of 1957, the efficiency was about 8 percent.
- After the drought, the enhanced recharge continued to discharge from the springs for about five years.
- Eventually, about 56 and 23 percent of the enhanced recharge in the aquifer conduit and outcrop, respectively, discharged from the springs. The balance (44 percent or 77

percent) discharged from San Marcos or Barton Springs, was lost to wells, or remained in aquifer storage.

The results at San Marcos Springs (Figure B-6) indicate:

- Both enhanced recharge methods show a much more subdued response than at Comal Springs. This is expected because of the contrast in distances from the recharge sites.
- San Marcos Springs is much more responsive to recharge in the outcrop than recharge in the conduit.
- By the end of the 1956 summer, about 40 and 20 percent of the enhanced recharge in the outcrop and conduit, respectively, flowed from this spring.

By the end of 1965, about 59 percent of the enhanced recharge in the outcrop discharged from San Marcos Springs. For enhanced recharge in the conduit, maximum cumulative discharge was about 25 percent. The balance (41 percent or 75 percent) discharged from Comal or Barton Springs, was lost to wells, or remained in aquifer storage.

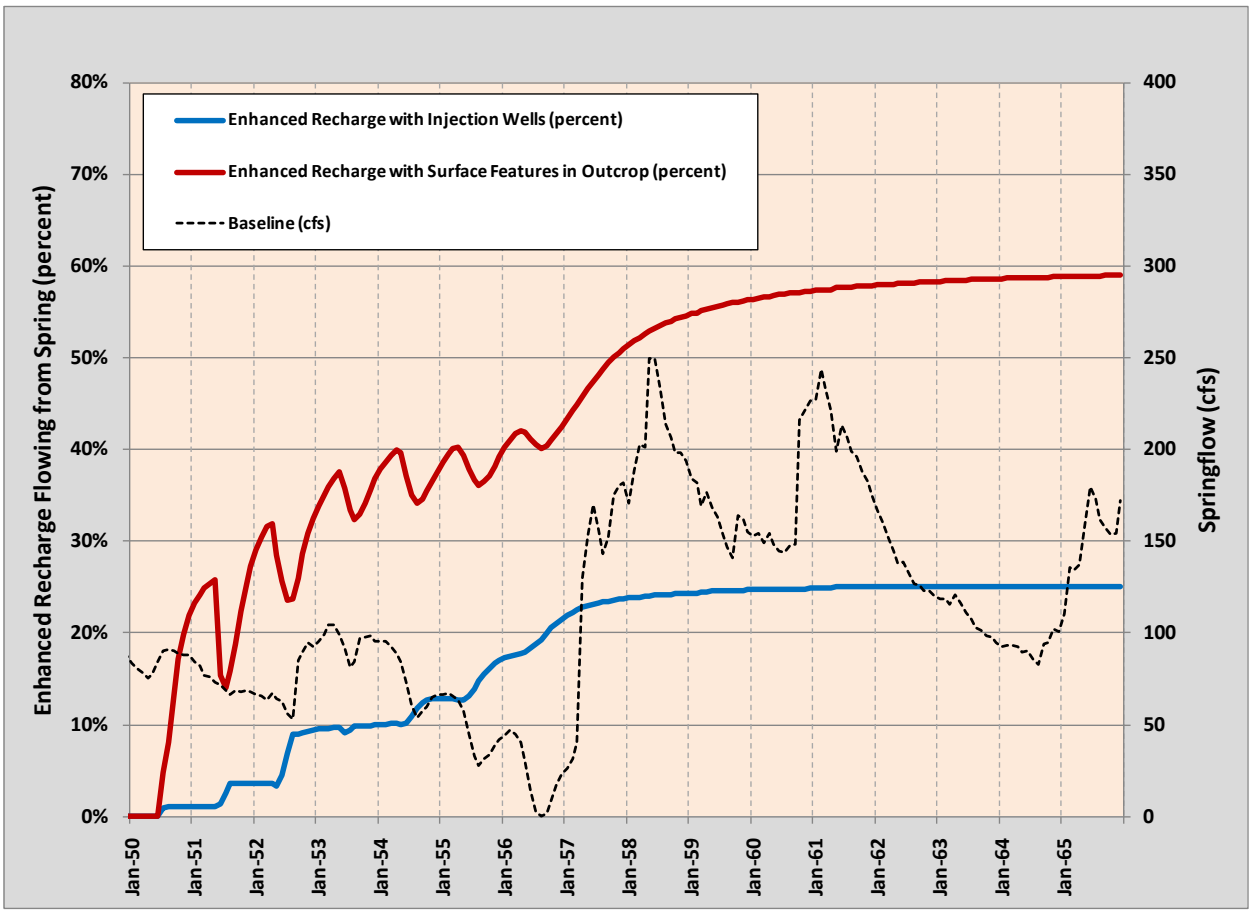


Figure B-6. Comparison of Effectiveness of two Enhanced Recharge Methods at San Marcos Springs.

For either method of episodic recharge enhancement, this analysis suggests that about 80 percent of the enhanced recharge discharges from Comal and San Marcos Springs and about 20 percent is lost to wells or remains in aquifer storage.

In conclusion, the MODFLOW model suggests that recharge in a conduit leading to Comal Springs is relatively effective in providing springflow protection for Comal Springs, but not San Marcos Springs. In contrast, recharge on the outcrop is much more effective for San Marcos Springs than for Comal Springs.

Appendix C
Recovery Factors for Enhanced Recharge at Type II Structures

1.0 Introduction

One management program evaluated in this project involves the concept of recharge and recirculation (R&R). This program examines how enhanced recharge might be extracted downgradient in the aquifer and recirculated back to the recharge zone as a means of dynamically storing the water until needed to augment springflow. However, not all of the water applied to the recharge zone can be captured for recirculation because of almost immediate losses from aquifer storage to springflow and/or to pumping, which may increase locally as recharge results in relief from CPM reductions (i.e., increased withdrawals). Recovery factors were developed to estimate the portion of enhanced recharge that could be recovered by wells prior to such losses. Recovery factors are based on the percentages of enhanced recharge that can be recovered based on recharge and recovery locations and timing.

2.0 Recovery Factors

The factors were developed using the results of preliminary model runs in which slugs of enhanced recharge were introduced separately at selected Type II Recharge Sites during dry (1947) and average hydrologic conditions (1974). In these runs, the percentages of recharge remaining in aquifer storage over time were evaluated. Enhanced recharge initially contributes to groundwater storage, but with time, storage decreases as spring discharge increases or as pumping increases due to relaxed CPM stages. Therefore, the net storage available for recovery and recirculation decreases over time. Using these data, recovery factors were developed for selected recharge sites (Figure C-1) that have been previously identified and used in numerous recharge enhancement studies. These sites were grouped by similar aquifer response. Recovery factors are tabulated in Table C-1.

In developing the factors, the percentages of enhanced recharge remaining in the aquifer were recorded for each elapsed six month period; percentages were developed for each half of the model and averaged. Recharge remaining in the aquifer over two years is assumed to be unrecoverable. Because the retention time and fate of enhanced recharge are similar at the previously-identified western recharge sites (Indian Creek, Lower Frio, and Dry Frio), the factors derived for Lower Frio were applied to all three sites. The central sites (Lower Hondo and Lower Verde) also exhibit similar retention times and aquifer response and, as such, the factors for these two sites were averaged. Factors for Lower Sabinal, San Geronimo, and Cibolo were treated

separately to reflect the different retention times and aquifer responses associated with recharge at each site. No factors were estimated for Lower Blanco since water recharged at Lower Blanco was assumed to be unrecoverable due to its down-gradient location and proximity to San Marcos Springs.

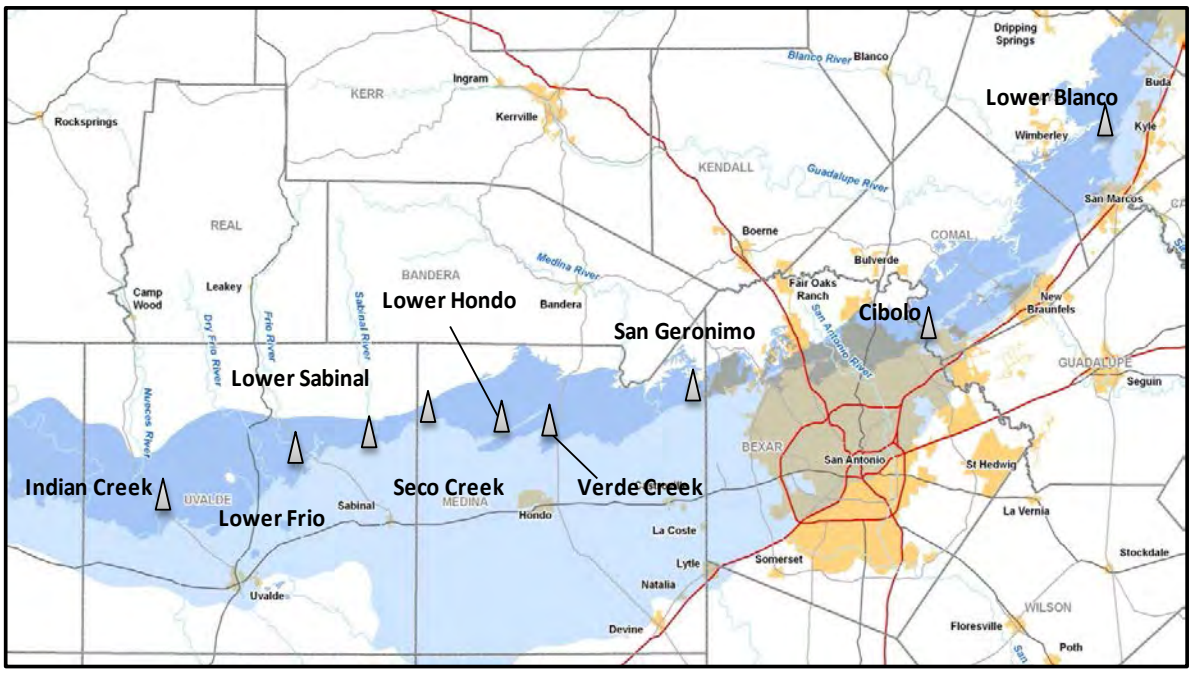


Figure C-1. Location of Selected Type II Recharge Sites

Table C-1.
Recovery Factors for Selected Type II Recharge Structures

Time Delay Between Recharge and Pumping (Months)	Selected Type II Recharge Sites			
	Indian Creek, Dry Frio and Lower Frio (%)	Lower Sabinal (%)	Lower Hondo and Lower Verde (%)	Cibolo and San Geronimo (%)
0	100	98	99	93
6	97	76	87	58
12	90	53	73	40
18	83	45	62	33
24	79	41	53	27

Appendix D
Comparison of Two Levels of Baseline Pumping

1.0 Introduction

As stated in Section 2, the benefits of potential management programs need to be measured against a standard in order to quantify the relative benefits of each program. This standard, or baseline, is represented by groundwater and springflow conditions (i.e., levels and discharges, respectively) that would occur absent implementation of the EARIP management programs being evaluated. The establishment of baseline conditions for evaluation of the water management alternatives and programs by the EARIP participants is consistent with those used in TCEQ WAM (water availability model) and TWDB MAG (managed available groundwater) analyses. In these two cases, model simulations are based on full permitted amounts of water being diverted or pumped each and every year to the extent physically and legally available. Conceptually, this assumption appears to be a worst case scenario. Under drought circumstances, however, assessments of projected water demands and existing supplies for municipalities dependent on the Edwards Aquifer clearly indicate that such existing supplies would be fully used to the extent legally available subject to current Critical Period Management (CPM) reductions.

The purpose of this appendix is to provide results of a study to illustrate differences between baseline pumpage of EAA Initial Regular Permit (IRP) amounts (Table 2-1) and a dataset based on recent annual pumpage.

2.0 Selection of a Representative Baseline for Recent Conditions

The selection of a recent representative pumpage is based on review of EAA reported estimates of Edwards withdrawals from 1980 to 2009. These data are presented in Figure D-1. As shown, pumpage tended to be greater in the 1980s (prior to creation of the EAA and enforcement of critical period management rules) and somewhat lower in the 1990s and 2000s, with the maximum pumpage of 542,400 acft/yr in 1989 and the lowest pumpage of 317,400 acft/yr in 2004. For purposes of comparison to baseline, the selected representative pumpage for recent conditions is the maximum rate in the last decade, which was about 454,500 acft/yr (454K) and occurred in 2006.

Baseline pumpage is subject to CPM, which is applied against the full IRP value. After applying CPM reductions, annual pumping in the model for the 1947-1973 period for the two

tests is shown in Figure D-2. As shown, the pumping in the model is essentially the same for many of the years even though the unrestricted IRP baseline is about 139,000 acft/yr greater than the unrestricted 454K baseline. This is about 24 percent of the IRP and suggests that, when the CPM is in Stages III and IV, the pumpage for the two baselines will be the same.

3.0 Comparison of IRP and 454K Baseline Results

Comparisons of the 454K baseline with the IRP baseline are made for Comal Springs and San Marcos Springs in Figures D-3 and D-4 which show the springflow hydrographs for Comal Springs and San Marcos Springs, respectively. As shown, the springflows are essentially the same, except for transient, unusually high flows. Table D-1 shows the number of months when springflow is below selected thresholds for the 1947-2000 simulation period. For the range of flow, the greatest difference is 3 fewer months for the 454K baseline for Comal Springs when the flow is below thresholds of 60 cfs and below 120 cfs.

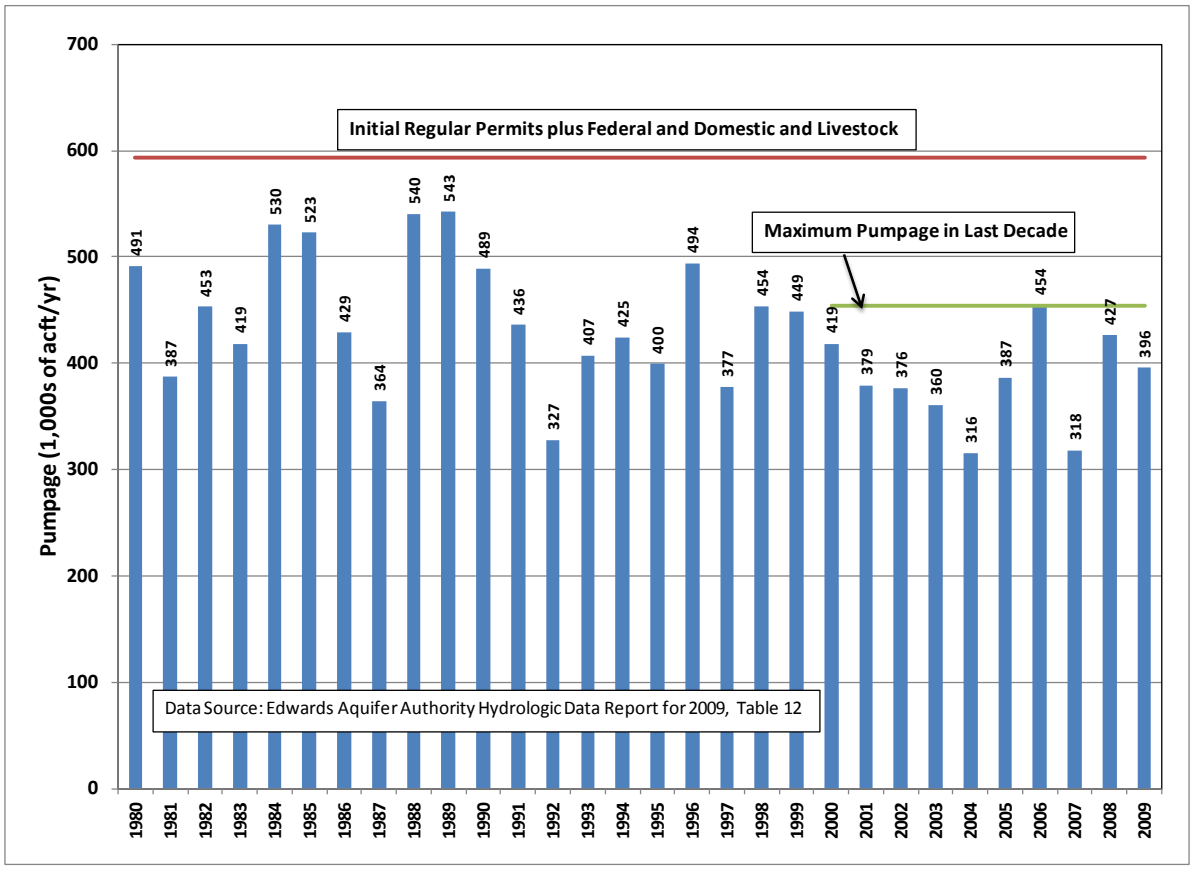


Figure D-1. Annual Edwards Pumping for 1980-2009.

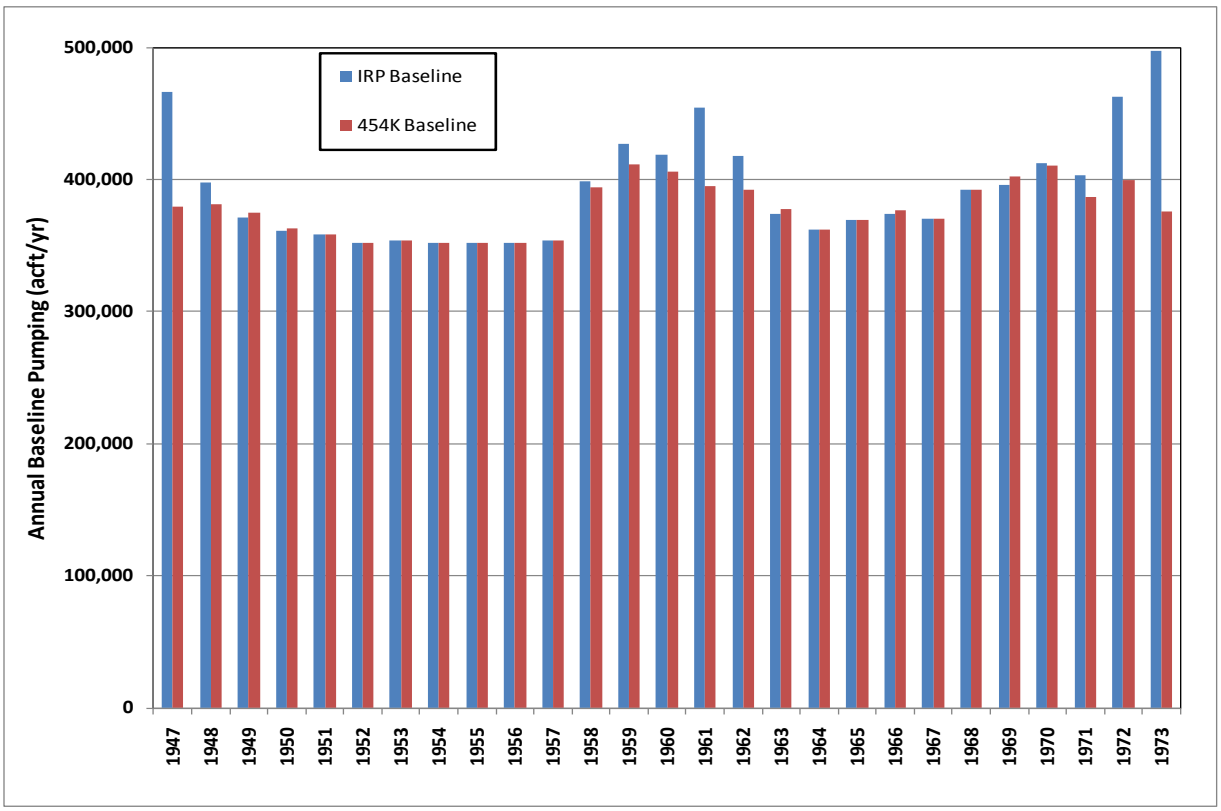


Figure D-2. Annual Pumping in the Two Baselines after CPM is Applied.

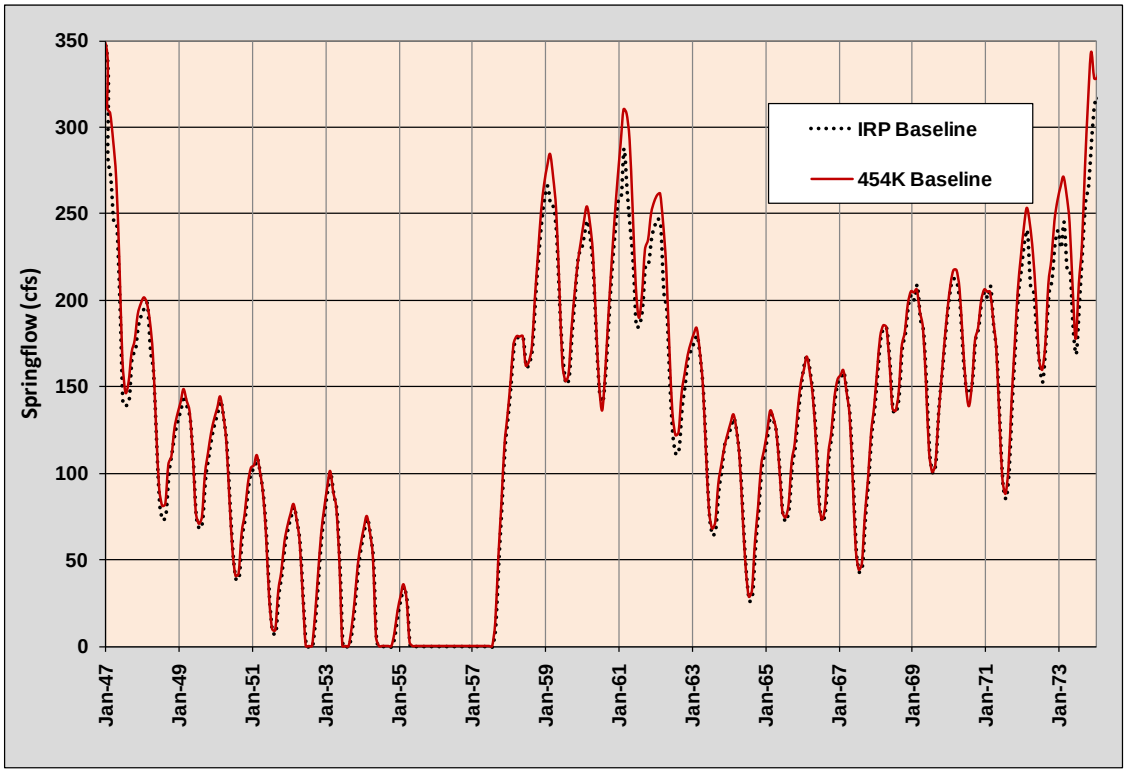


Figure D-3. Comparison Modeled Discharge from Comal Springs for the Two Baselines.

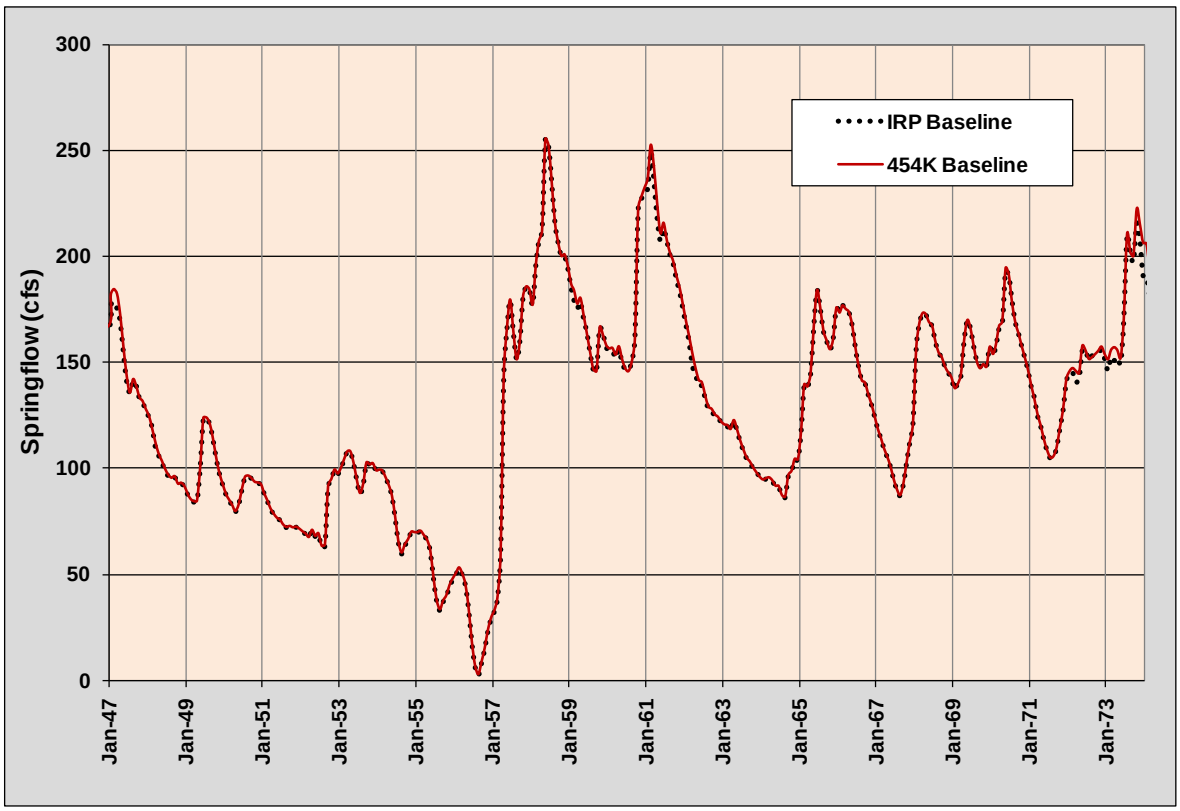


Figure D-4. Comparison Modeled Discharge from San Marcos Springs for the Two Baselines.

Table D-1.
Number of Occurrences of Springflow Below Selected Thresholds (1947-2000)

		Months Below Threshold	Months Below Threshold
Springs	**Threshold (cfs)**	**IRP Baseline**	**454K Baseline**
Comal	**0**	38	37
	30	54	53
	60	73	70
	90	110	108
	120	145	142
SanMarcos	**0**	0	0
	40	14	13
	80	52	52
	120	147	146
	160	242	240

Appendix E
Technical Evaluation of Preliminary Bottom-Up Program Presented to EARIP Participants on January 13, 2011

1.0 Introduction

The design of the preliminary Bottom-Up Program presented to EARIP participants on January 13, 2011 is generally consistent with the description provided in Section 3.

2.0 Water Management Alternatives

The Bottom-Up Program consists of four components, including: (1) Voluntary Irrigation Suspension Program Option; (2) Municipal Conservation; (3) SAWS ASR with Trade-Off Option; and (4) Stage V CPM Emergency Reductions.

2.1 Voluntary Irrigation Suspension Program Option (VISPO)

The operational concept of VISPO is to establish an agreement between irrigators and the EARIP so that irrigation farmers are willing to curtail or eliminate authorized pumping when drought conditions threaten springflow protection. The agreement would pay the farmers a "standby fee" each year for participating in VISPO plus an "implementation fee" for actual curtailment when a drought condition is triggered. In early 2011, five and ten year agreements were under consideration.

Testing of the VISPO component for springflow protection involved the following technical assumptions:

- VISPO applies to about 40,000 acft/yr (IRP value) of Edwards pumping rights with 20,000 acft/yr in Medina County, 15,000 acft/yr in Uvalde County, and 5,000 acft/yr in Bexar County.
- Suspensions are triggered on January 1 if the water level in J-17 is below 650 ft-msl level on September 1 of the previous year.
- Suspensions are assumed to be equally distributed across all irrigation wells in the respective counties.
- Simulated pumping reductions associated with VISPO are consistent with applicable CPM stage.
- Most, if not all, of the Edwards water committed to VISPO is from the base (or restricted) portions of irrigation IRPs.
- The cost estimate is based on information from the VISPO Work Group.

2.2 Municipal Conservation

Municipal water conservation (Conservation) is based on a draft Voluntary Dedicated Water Supply Program developed by a Conservation Work Group of the EARIP, which explored

water conservation potential for small communities and water systems and the agricultural sector. Most opportunities for conservation are assumed to include: residential uses of "exempt" wells, "lost water" through municipal infrastructure deficiencies, industrial and commercial processes, rural and small community residential plumbing technologies, excessive landscape watering, use of gray water, and use of condensate and rainwater harvesting for landscape irrigation.

Testing of the Conservation alternative for springflow protection consisted of the following technical assumptions:

- Total pumping reductions are 10,067 acft/yr when the Edwards Aquifer is not in CPM. These reductions are to be accomplished through: toilet retrofit (1,531 acft/yr); replacement of inefficient fixtures (1,286 acft/yr); leak detection and repair (3,750 acft/yr); large-scale retrofit (2,500 acft/yr); and landscape watering savings (1,000 acft/yr).
- Pumping reductions are geographically distributed in proportion to municipal IRPs. This is considered a reasonable approximation because EARIP modeling assumptions and the MODFLOW management modules do not readily accommodate shifts from initial urban savings to rural communities over time.
- Pumping is reduced according to CPM rules.
- Cost estimates for the conservation layer are calculated using unit rates provided by the Work Group and updated though discussions.

2.3 SAWS ASR with Trade-Off Option

The San Antonio Water System (SAWS) Aquifer Storage & Recovery (ASR) facilities are used for storage and transport of Edwards water. Such water will be obtained by leasing irrigation and other Edwards permits and storing withdrawals under these permits using the SAWS ASR facilities in south Bexar County. When needed for springflow protection, stored water is to be recovered and delivered into SAWS water distribution system to reduce or off-set (trade-off) SAWS pumping of the Edwards Aquifer by equal amounts.

The following technical assumptions are used in evaluation of the SAWS ASR with Pumping Off-Set Option:

- Lease of 50,000 acft/yr of unrestriced irrigation IRP for storage in SAWS ASR facilities for springflow protection. Any portion of the leased rights not being used for storage in SAWS ASR facilities is unused (not pumped). The actual supply of water from the leases is subject to CPM rules and pumped as needed to fill ASR storage, left in the aquifer when SAWS ASR is full and fully curtailed when water is being recovered for springflow protection.

- Preliminary operational and modeling procedures are for "dynamic sharing" of injection, recovery, and transmission capacities between SAWS and EARIP. In this context, "dynamic sharing" means that the maximum commitment of SAWS ASR recovery and transmission capacity for direct springflow protection to EARIP could be 100% during severe drought.
- The total conveyance capacity of existing SAWS ASR facilities would be made available for springflow protection when the monthly average groundwater levels at J-17 are below 630 ft-msl (the corresponding Comal Springs discharge is approximately 70 cfs). The selected wells with reduced pumping (to be off-set) are on the northeast side of SAWS water distribution system.
- SAWS ASR use is based on these assumptions: (a) an initial storage of 40,000 acft; (b) storage capacity available to the EARIP of 150,000 acft; and (c) annual water loss of 10 percent of the volume of water available for recovery.
- The recovery rate for stored water from SAWS ASR is limited to the current transmission capacity from SAWS ASR to the Seale and Artesia Stations, which is 60 million gallons per day (MGD), or 5,600 acft/mo.
- Project and operational cost estimates for this alternative are as provided by SAWS. Annual power costs reflect long-term average storage and recovery operations based on the 1947-2000 simulation period.

2.4 Stage V CPM Reductions

In the event that implementation of the first three components (layers) of the Bottom-Up Program is not sufficient for springflow protection, an additional CPM stage (Stage V) is added as an "emergency" measure.

The following technical assumptions are used in evaluation of Stage V CPM Reductions:

- Permitted pumping during Stage V is reduced by 44 percent from the IRP values in both the San Antonio and Uvalde Pools. Domestic and livestock pumping are not restricted. Federal pumping, which is unpermitted, is assumed to be reduced in critical period by the same percentages as permitted pumping.
- Stage V is in effect in both the San Antonio and Uvalde Pools when the water level at J-17 is lower than 625 ft-msl (the corresponding Comal Springs discharge is approximately 40 cfs). However, Stage V is not triggered in the Uvalde Pool until the Uvalde Pool has been in Stage IV on the basis of J-27 water levels.
- Percentage reductions are equal for the San Antonio and Uvalde pools. Stage V CPM is considered to be an "emergency" situation and all permit holders are required to make an equal sacrifice. The reduction factor for the two pools is 44 percent based on the percentage reduction to move from an IRP total of approximately 572,000 acft/yr to a critical period floor of 320,000 acft/yr. The associated reductions in permitted pumping during Stage V (relative to Stage IV) in the San Antonio and Uvalde Pools are 19,200 acft/yr and 8,200 acft/yr, respectively.

- A range of potential costs attributable to Stage V CPM are estimated using available information from the 2011 South Central Texas Regional Water Plan. Approximate costs for demand reduction include: conservation, drought management, and replacement water supplies delivered to Bexar County as necessary to produce about 27,400 acft/yr.

3.0 Layers

Springflow protection at Comal and San Marcos Springs from the Bottom-Up Program is assessed on the basis a of series MODFLOW simulations. These simulations include baseline conditions and the successive stacking of four layers. As implied, the baseline represents conditions with full IRP pumping constrained only by EAA CPM rules. Successive layers are added one at a time in the Bottom-Up Program. Incrementally, one may determine the degree of improvement in springflow protection for a layer by comparison with the results for a previous layer. It's important to note that performance of Bottom-Up Program components in the stacked layer approach may be different if examined individually or in a different sequence.

The selected measures or indicators of springflow protection for Comal and San Marcos Springs are simulated hydrographs from MODFLOW, numbers of months below preselected springflow thresholds, minimum monthly springflow, minimum 6-month moving average springflow, and long-term average springflow. The periods of particular interest are considered to be from 1947-1957 (drought of record) and from 1947-2000 (MODFLOW simulation period).

3.1 Voluntary Irrigation Suspension Program Option (Layer #1)

Pumping reductions attributable to VISPO are triggered for years when drought conditions are anticipated. Figure E-1 illustrates years in the MODFLOW simulation period during which this option is on standby and implemented. As illustrated, the option was implemented and irrigation suspended in each year from 1947 through 1972 and in 17 of the next 28 years.

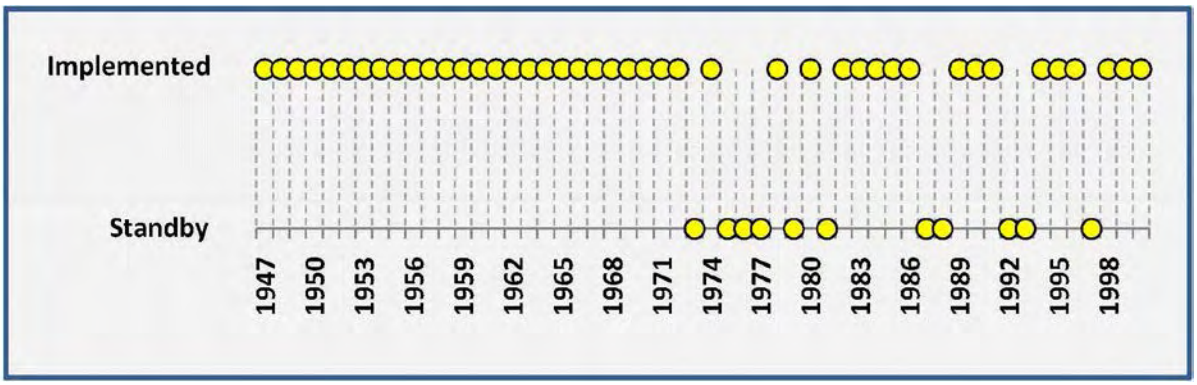


Figure E-1. Annual Status of VISPO Operations (1947-2000)

The permitted pumping for participants in VISPO is subject to suspension and any CPM reductions that may be in effect. For example, if suspension is triggered and there are no CPM restrictions for entire year (highly unlikely), the full IRP pumping reductions would be 40,000 acft. On the other hand, if CPM Stage IV is in effect for the entire year that suspension is triggered, the actual reductions in Edwards withdrawals would be only 25,000 acft. It's important to note that pumping reductions due to VISPO may allow increases in other permitted pumping, which can change CPM duration and magnitude. For example, if baseline pumping (without VISPO) causes the San Antonio Pool to be in Stage IV for eight months in a given year, and reductions in VISPO pumping are sufficient to reduce the duration in Stage IV to 4 months, the Stage V restrictions would be relaxed by 4 months for all permits in the San Antonio pool. For the periods 1947-1957 and 1947-2000, VISPO pumping reductions and increases in allowable pumping due to less time in given CPM stages are presented in Table E-1. This table shows that, for the 1947-1957 period, the average VISPO net pumping reductions are 26,535 acft/yr. For the 1947-2000 period, VISPO net pumping reductions average 23,158 acft/yr. The average VISPO net pumping reductions are less for the 1947-2000 period than the 1947-1957 period because it is activated less frequently due to wetter hydrologic conditions.

Table E-1.
Average Annual Pumping Reductions for Layer #1

Units: acft/year

Condition	San Antonio Pool	Uvalde Pool	Total
Potential Reductions (IRP Face Value)	25,000	15,000	40,000
1947-1957	15,684	10,851	26,535
1947-2000	13,655	9,503	23,158

3.2 VISPO + Municipal Conservation (Layer #2)

In the tentatively adopted Bottom-Up concept, the Municipal Conservation component is added to the VISPO component. The Municipal Conservation component is active each year and the net reductions in pumping are affected by CPM. The full potential pumping reductions for Layer #2 total 50,067 acft/yr.

For the periods 1947-1957 and 1947-2000, cumulative net pumping reductions for VISPO and Municipal Conservation (Layer #2) are presented in Table E-2. This table shows that the average pumping reductions through Layer #2 for the 1947-1957 period were 33,042 acft/yr. For the 1947-2000 period, net pumping reductions through Layer #2 averaged 31,030 acft/yr. During the drought of record period, the net effect of the Municipal Conservation alternative was a pumping reduction of 6,507 acft/yr.

Table E-2.
Average Annual Pumping Adjustments through Layer #2*

Units: acft/year

	San Antonio Pool	Uvalde Pool	Total
Potential Reductions (IRP Face Value)	34,803	15,264	50,067
1947-1957	22,060	10,983	33,042
1947-2000	21,355	9,676	31,030

* Note: Cumulative Adjustments for VISPO and Municipal Conservation

3.3 VISPO + Municipal Conservation + SAWS ASR with Trade-Off Option (Layer #3)

In Layer #3 of Bottom-Up Program, the SAWS ASR with Trade-Off component is added to the VISPO and Municipal Conservation components. Key elements of the SAWS ASR with Trade-Off Option alternative are: (1) leasing of IRPs to either fill SAWS ASR or to suspend the permitted pumping, (2) filling SAWS ASR, and (3) recovering stored water for trade-off (off-set) of SAWS permitted pumping at selected pump stations. An illustration of the SAWS ASR facilities is presented in Figure E-2.

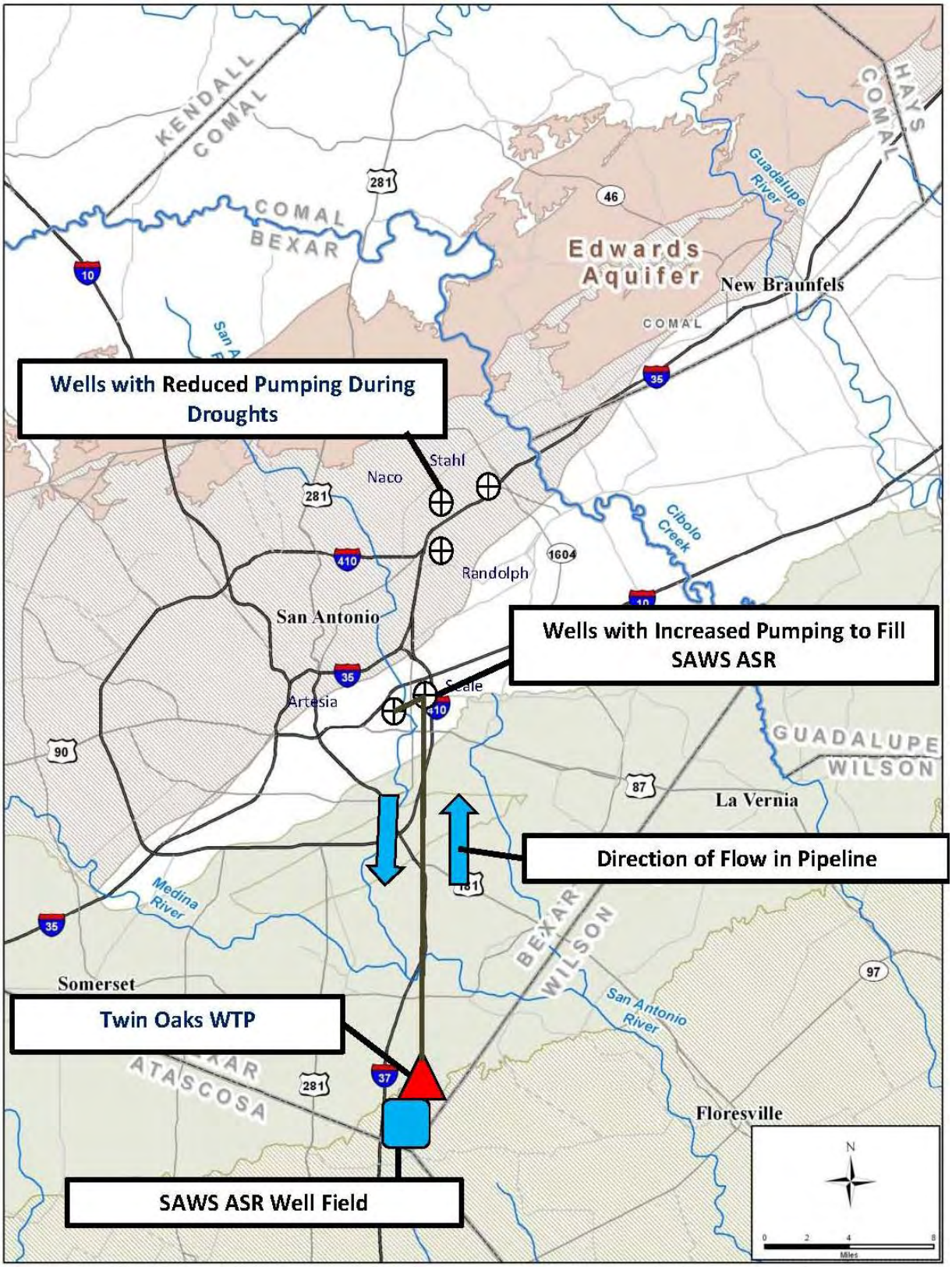


Figure E-2. SAWS ASR Operational Concept

Figure E-3 illustrates the monthly pumping of Edwards lease water to SAWS ASR and the recovery of water for springflow protection. For the 1947-1957 period, about 201,000 acft of Edwards leases were pumped to SAWS ASR during 72 months and about 125,000 acft were recovered for pumping off-set during 60 months. Due to limitations of the transmission facilities, the monthly flow rates are capped at 5,600 acft/mo. Figure E-4 illustrates the storage balance in SAWS ASR for the 1947-2000 period. This chart illustrates that the initial storage started at 40,000 acft, nearly reached the ASR allocated capacity to EARIP of 150,000 acft in 1952 and was nearly emptied in the summer of 1957. The recovery shown in Figure E-4 reflects near optimization of maximizing springflow protection and utilizing the capacity of SAWS ASR that is available to EARIP.

For the periods 1947-1957 and 1947-2000, cumulative net pumping reductions for VISPO, Municipal Conservation, and SAWS ASR (Layer #3) are presented in Table E-3. This table shows that, for the 1947-1957 period, the average cumulative pumping reduction through Layer #3 was 68,664 acft/yr. For the 1947-2000 period, cumulative pumping reductions through Layer #3 averaged 74,733 acft/yr. During the drought of record period, the net effect of the SAWS ASR alternative was a pumping reduction of 35,622 acft/yr. CPM is a strong controlling factor in the pumping reductions.

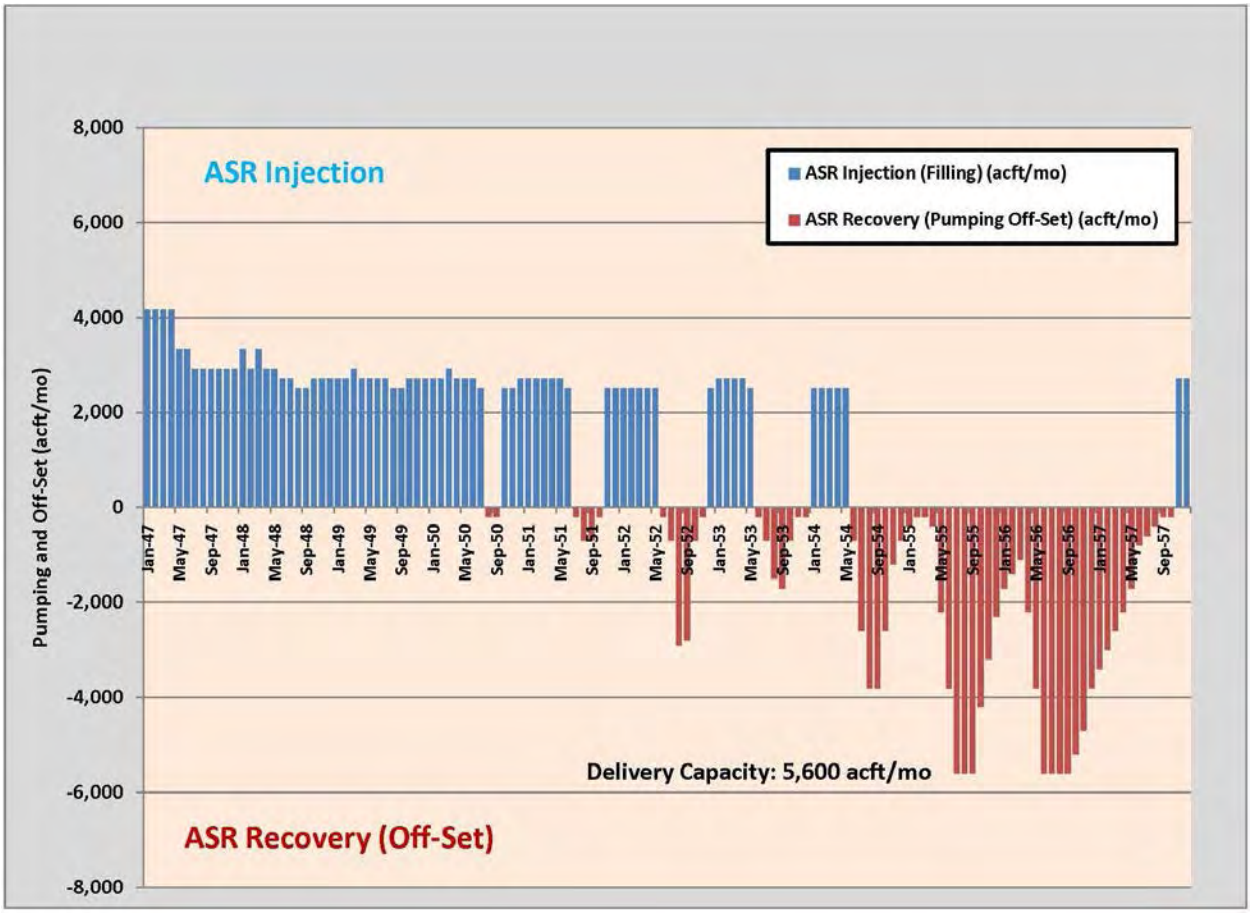


Figure E-3. Rate and Schedule of SAWS ASR Injection and Recovery (1947-1957)

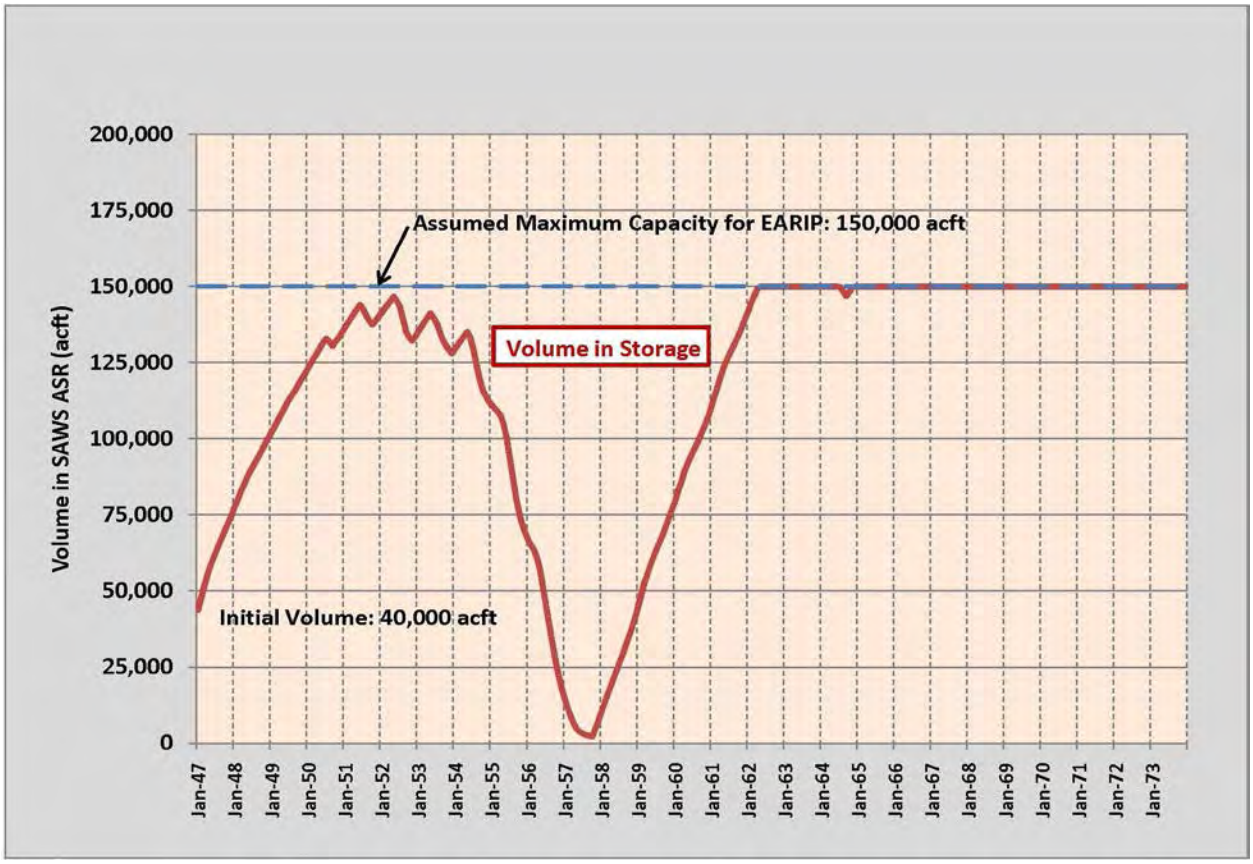


Figure E-4. Storage of EARIP water in SAWS ASR

Table E-3.
Average Annual Pumping Adjustments for Layer #3*

Units: acft/year

	San Antonio Pool	Uvalde Pool	Total
Potential Reductions (IRP Face Value)	59,659	40,408	100,067
1947-1957	35,680	32,984	68,664
1947-2000	38,835	35,898	74,733

* Note: Cumulative Adjustments for VISPO, Conservation and SAWS ASR

3.4 VISPO + Municipal Conservation + SAWS ASR with Trade-Off Option + Stage V (Layer #4)

In Layer #4 of Bottom-Up Program, CPM Stage V is added to the VISPO, Municipal Conservation, and SAWS ASR with Trade-Off components. Key elements of Stage V are triggering this emergency action off of J-17 water levels and applying an equal 44 percent reduction to permitted wells in both the San Antonio and Uvalde pools. Based on the Bottom-Up Program and the J-17 results of Layer #3, Stage V was activated for seven months, of which, four months were in 1956, as illustrated in Figure E-5.

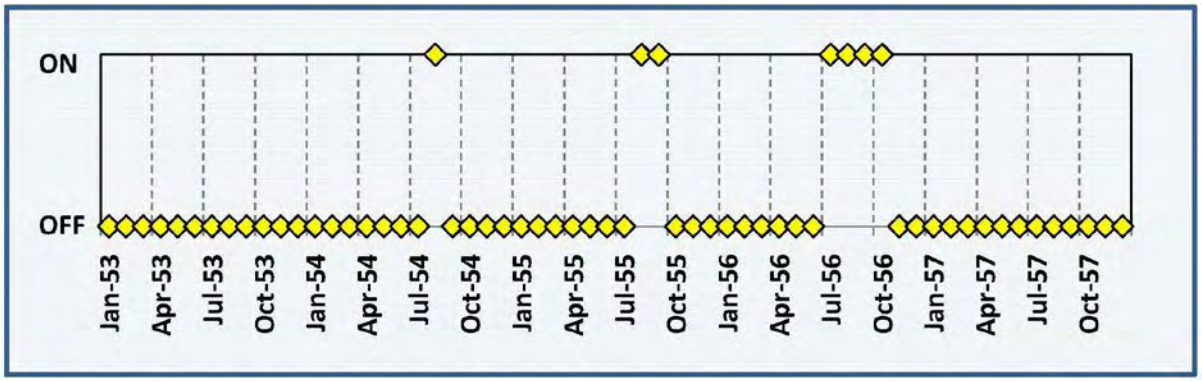


Figure E-5. Occurrences of Stage V

For the periods 1947-1957 and 1947-2000, cumulative net pumping reductions for VISPO, Municipal Conservation, SAWS ASR, and Stage V (Layer #4) are presented in Table E-4. This table shows that for the 1947-1957 period the average Layer #4 net pumping reductions were 70,140 acft/yr. For the 1947-2000 period, Layer #4 net pumping reductions averaged 75,033 acft/yr. As stated earlier, CPM is a strong controlling factor in the pumping reductions.

Table E-4.
Average Annual Pumping Adjustments for Layer #4*

Units: acft/year

	San Antonio Pool	Uvalde Pool	Total
Potential Reductions (IRP Face Value)	78,859	48,608	127,467
1947-1957	36,714	33,426	70,140
1947-2000	39,046	35,988	75,033

* Note: Cumulative Adjustments for VISPO, Conservation, SAWS ASR, and Stage V

4.0 Results

4.1 Springflow Hydrographs

Hydrographs from the MODFLOW model simulations are used to temporal display of the variations in magnitude of springflow over time. For comparison purposes, hydrographs are presented for the five scenarios (baseline and each of the four Bottom-Up Program layers). Study of the hydrographs provides qualitative information on the changes in springflow over time for each additional layer of the Bottom-Up Program.

The MODFLOW calculated springflows for the 1947-1960 period for Comal and San Marcos Springs are presented in Figure E-6 and E-7, respectively. Observations upon review of Figures E-6 and E-7 focusing on the drought of record include the following: (1) the modest improvement in springflow when the Municipal Conservation and Stage V layers are added; (2) very substantial improvement from the VISPO and SAWS ASR components for 1951-1957 at

Comal Springs and for 1955-1957 at San Marcos Springs and (3) substantial improvement in Comal Springs flow due to implementation of Stage V during the summer of 1956.. These hydrographs indicate that the Bottom-Up Program limited the minimum springflow at Comal and San Marcos Springs to about 25 and 50 cfs, respectively. A study of the recovery schedule from SAWS ASR (Figure E-3) shows that the capacity of the SAWS ASR water transmission facilities (pipelines and pumps) is the limiting factor in the level of springflow protection at Comal Springs. If the capacity of the water transmission system had been greater, water could have been recovered at a greater rate for SAWS ASR Trade-Off pumping, which would have provided more springflow at Comal Springs.

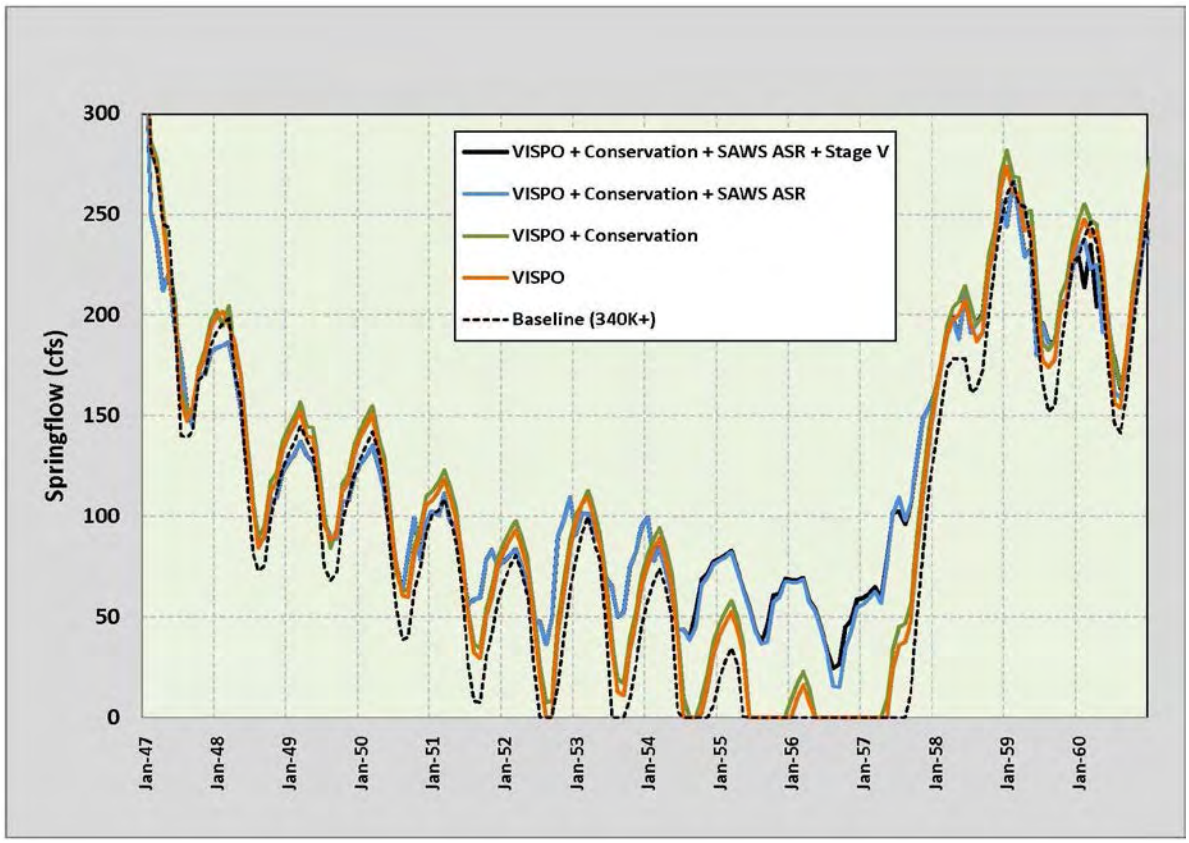


Figure E-6. Simulated Springflow at Comal Springs (1947-1960)

The MODFLOW calculated springflows for the entire 1947-2000 simulation for Comal and San Marcos Springs are presented in Figure E-8 and E-9, respectively. These hydrographs show that the Bottom-Up Program usually increases springflow by small amount in periods other

than the drought of record. Most of the increases are attributeable to adding VISPO and SAWS ASR alternatives, which lead to significantly less Edwards pumping.

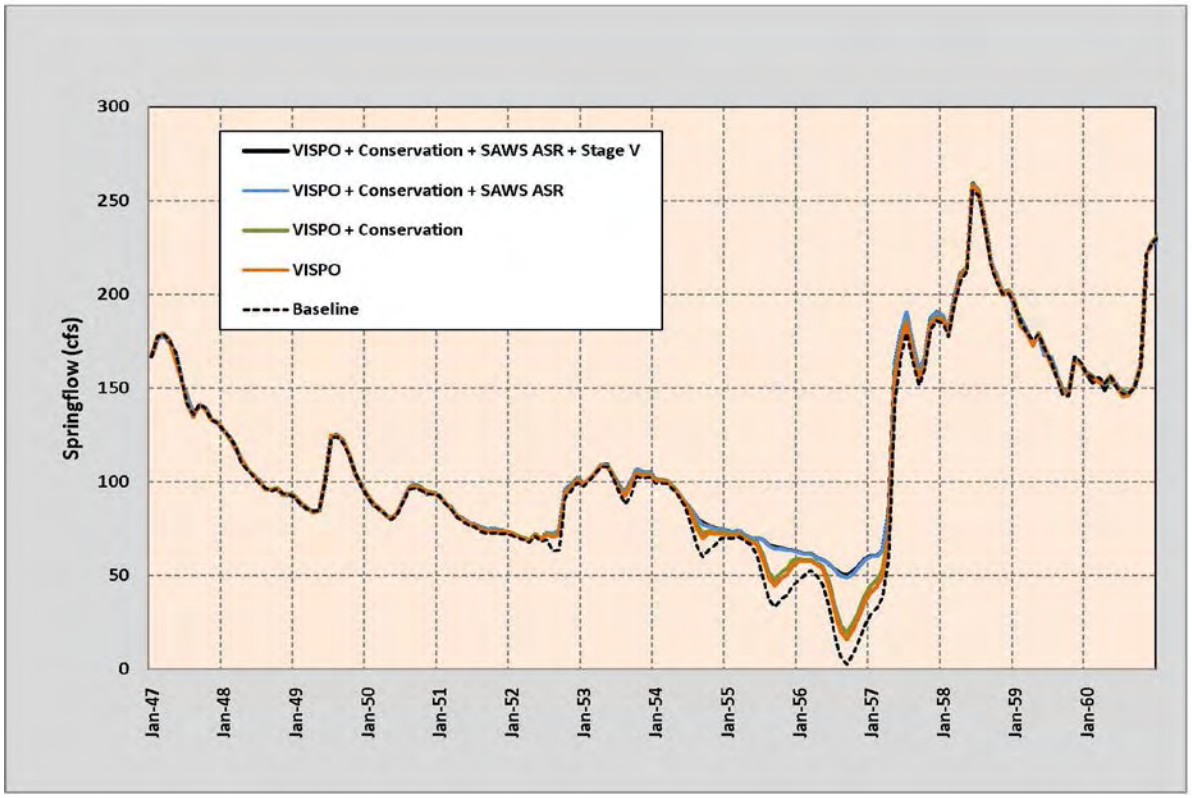


Figure E-7. Simulated Springflow at San Marcos Springs (1947-1960)

Further study of Figures E-8 and E-9 suggests that Comal Springs has a much more direct response to water management alternatives than San Marcos Springs. This is mostly attributable to: (1) a strong hydrogeologic connection between Comal Springs and the main body of the Edwards; and (2) discharge from San Marcos Springs being subject to discharge from Comal Springs and geologic faults located between Comal and San Marcos Springs that function as partial barriers to groundwater flow.

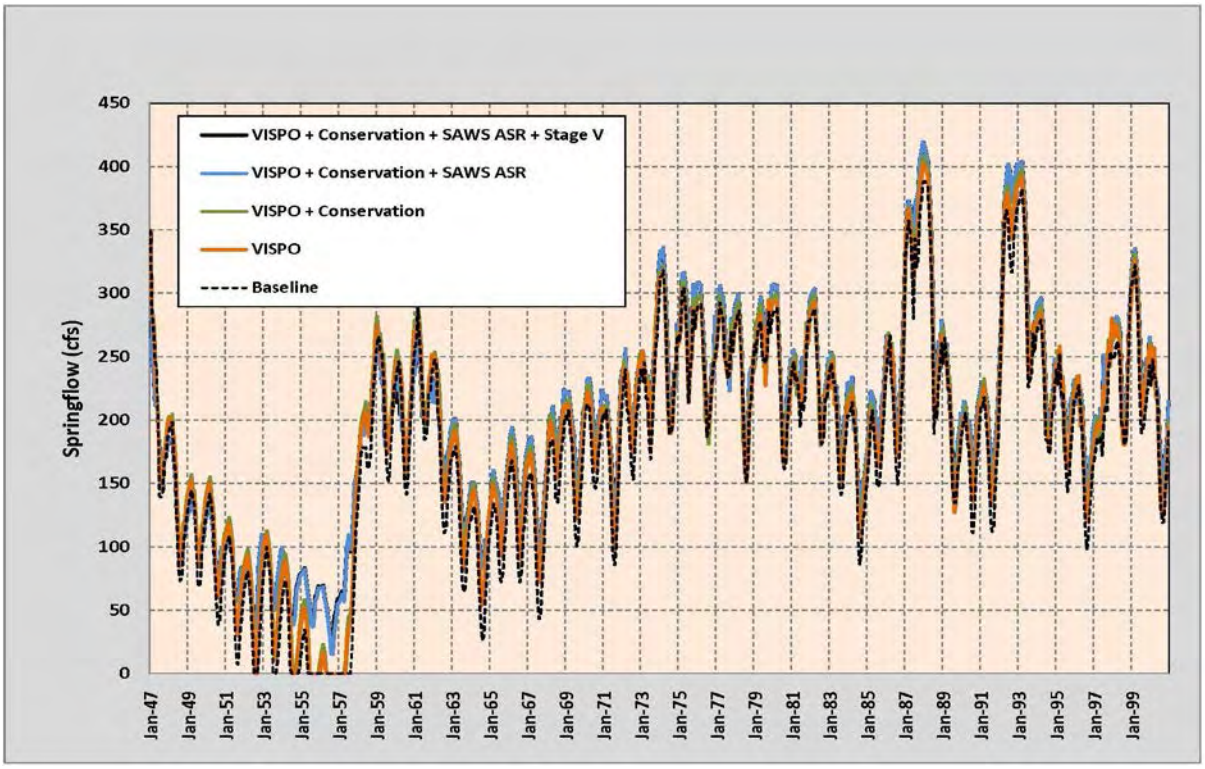


Figure E-8. Simulated Springflow at Comal Springs (1947-2000)

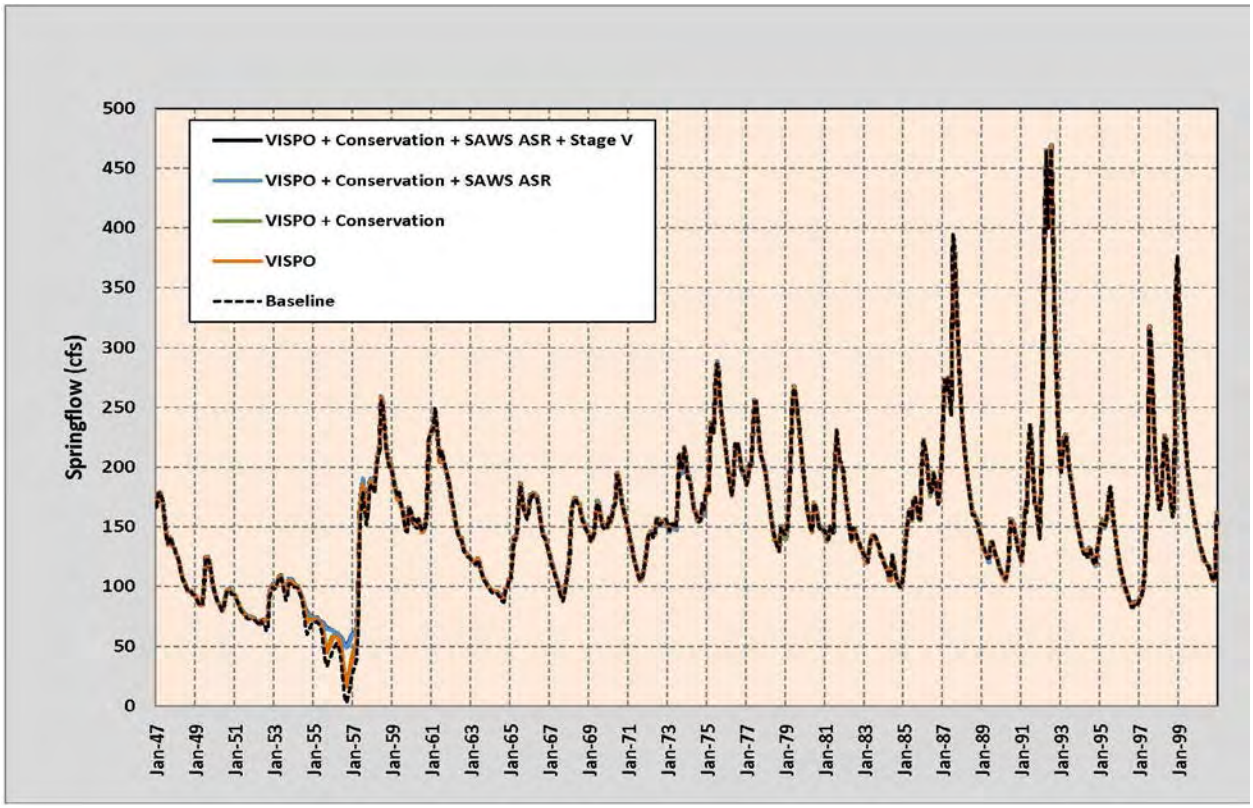


Figure E-9. Simulated Springflow at San Marcos Springs (1947-2000)

4.2 Frequency of Springflow below Thresholds

A measure of considerable importance in the protection of endangered species is the number of months that springflow at Comal and San Marcos Springs is below selected thresholds. Counts of the monthly occurrences for the selected thresholds of springflow are presented for Comal and San Marcos Springs in Table E-5 for the period 1947-2000. Review of these results shows very substantial improvement in springflow protection with VISPO and SAWS ASR. Critical thresholds are 30 cfs at Comal Springs and 52 cfs at San Marcos Springs. This table shows that there were no months of zero springflow and two months below the thresholds at Comal and San Marcos for these critical conditions. Finally, this analysis indicates that the extents of the periods of time below all the thresholds were reduced or stayed the same with the Bottom-Up Program.

Table E-5.
Number of Occurrences of Springflow Below Selected Thresholds (1947-2000)

Spring	Threshold (cfs)	Number of Months				
		Baseline	VISPO	VISPO + Conservation	VISPO + Conservation + SAWS ASR	VISPO + Conservation + SAWS ASR + Stage V
Comal	**0**	38	26	21	0	0
	30	54	36	34	2	2
	60	73	58	55	31	28
	90	111	87	83	76	76
	120	157	129	124	118	117
San Marcos	**0**	0	0	0	0	0
	52	20	14	12	3	2
	80	52	50	50	48	48
	100	121	118	115	115	115
	120	189	189	188	187	187

4.3 Frequency of CPM

Water users in the Edwards are interested in the amount of time that their permits will have CPM restrictions. These results for the period 1947-2000 are summarized for the San Antonio Pool on the basis of J-17 water levels for all EAA CPM stages for the Bottom-Up Program in Table E-6. These results show that the number of months with no CPM constraints generally increased for each Bottom-Up layer, which, obviously is an improvement over the baseline conditions. However, the amount of time in Stage I increased in an amount that generally offset the improvement for no CPM conditions. In the more severe Stage II to IV CPM restrictions, the number of months generally became less or stayed the same with each successive Bottom-Up layer. Stage V only applied to the last layer of the Bottom-Up Program.

Table E-6.
Number of Occurrences of CPM in San Antonio Pool (1947-2000)

Stage, as indicated by Comal Springs, except for Stage V	Number of Months				
	Baseline	VISPO	VISPO + Conservation	VISPO + Conservation + SAWS ASR	VISPO + Conservation + SAWS ASR + Stage V
None	205	223	228	237	237
I	71	82	91	107	109
II	151	153	149	142	140
III	99	88	86	72	72
IV	122	102	94	90	83
V	0	0	0	0	7

4.4 Springflow Statistics

A few key statistics of importance to biologists in evaluating the performance of springflow protection from the Bottom-Up Program are minimum springflow, minimum 6-month moving average springflow, and long-term average springflow. These statistics are presented for the period 1947-2000 in Table E-7 for Comal and San Marcos Springs. As shown in this summary, the minimum monthly average springflows for Comal and San Marcos Springs are 25 and 50 cfs, respectively, for the full Bottom-Up Program. For the minimum 6-month

moving average, the minimum monthly average springflows for Comal and San Marcos Springs are 37 and 53 cfs, respectively. The long-term average springflows were 200 cfs at Comal and 154 cfs for San Marcos.

Table E-7.
Springflow for Selected Statistics (1947-2000)

Spring	Statistic	Baseline (340K+)	VISPO	VISPO + Conservation	VISPO + Conservation + SAWS ASR	VISPO + Conservation + SAWS ASR + Stage V
Comal	Minimum Month	0	0	0	15	25
	Minimum 6-Month Moving Average	0	0	0	30	37
	Long-Term Average	178	188	192	200	200
San Marcos	Minimum Month	2	16	19	49	50
	Minimum 6-Month Moving Average	12	25	29	52	53
	Long-Term Average	153	153	154	154	154

5.0 Cost Estimates

As discussed earlier, the Bottom-Up Program is a key component of the Initial Adaptive Management Phase. Accordingly, the concept is to postpone engineering solutions to later phases and adopt management alternatives to the extent possible. With this concept, none of the selected alternatives in the Bottom-Up Program requires new facilities. Instead, the water management alternatives can be developed under existing EAA rules and with SAWS existing facilities. As a result, the cost basis for the water management alternatives were largely prepared by EARIP work groups. The presented cost estimates for the Bottom-Up Program do not include

administrative or management cost, which is assumed to be provided by the sponsoring stakeholders and without cost to the EARIP.

5.1 Assumptions and Definitions

The costs bases for the VISPO, Municipal Conservation, and SAWS ASR components of the Bottom-Up Program were provided by EARIP Work Groups and processed by HDR. Where Edwards irrigation IRPs are to be procured, the contractual arrangements are assumed to be leases or temporary contracts instead of purchases. A background summary for the cost of each program component follows:

- **VISPO:** The tentative working proposal for the VISPO Work Group is to offer holders of irrigation permits either a 5-year or 10-year option under which EARIP would pay a standby fee and an implementation fee. For a 5-year commitment, the standby fee ($50.00/ acft/yr) would escalate at a rate of 1.5 percent per year for 10 years in the program, and the implementation fee ($150.00/ acft/yr) would escalate at the rate of 3 percent per year. For the 10-year commitment, the standby fee would be $57.50/ acft/yr for the first five years and $70.20/acft/yr for the second five years; and, the implementation fee would be $172.50/ acft/yr for the first five years and $210.60/ acft/yr for the second five years. For purposes of this EARIP report, it is assumed that: (1) 70 percent of the leases are in the 5-year option and 30 percent are in the 10-year option, and (2) the annual fee per acft of water for the 1947-2000 period is the composite average fee for the first ten years for leases under 5-year option and the first 10 years for leases under the 10-year option. The long-term average annual cost is based on an annual calculation that considers the standby each year and the and whether or not the implementation fee as needed.
- **Municipal Conservation:** The Conservation Work Group provided the following guidelines:

  List of elements and their initial cost and annual pumping reductions:

  - High Efficiency Toilets: $12,000,000 (1,531 acft/yr)
  - High Efficiency Water Fixtures: $480,000 (1,286 acft/yr)
  - Lost Water (Reducing leaks or lost water in small municipal water systems): $3,750,000 (3,750 acft/yr)
  - Large Scale Retrofit (Supporting industries): $2,500,000 (2,500 acft/yr)
  - Landscape: $1,000,000. (1,000 acft/yr)

  Implementation of the 10-year option is assumed to occur evenly over 10 years.

  As envisioned by the Conservation Work Group, these are incentive programs so the costs shown are those potentially borne by the EARIP. Total costs to obtain water savings and pumping reductions may be substantially greater.
- **SAWS ASR with Trade-Off Option:** The concept is to obtain leases and options on 50,000 acft/yr of Initial Regular Permits (IRPs) on Edwards Aquifer irrigation and other

permits. The leases and options will be divided into thirds (tiers). The first third, approximating 16,667 acre-feet of permits, will be leased at all times. The middle third and final third of the leases would be implemented during moderate and severe drought conditions, respectively. The first third of the leases (continual) are assumed to cost $125/ acft/yr. For the second and third tiers, lease costs have two elements. One is a standby cost, which is assumed to be $40/ acft/yr, and would occur each year; and the other is an implementation cost of $150/ acft/yr, which would be paid only when the second and third tiers are implemented. The tentative working EARIP-SAWS agreement is that SAWS would: (1) waive costs equivalent to depreciation of a third of the $250,000,000 asset over 30 years on a straight line basis, and (2) be reimbursed $3,080,000 per year for water treatment, power, and other operations and maintenance expenses.

- **Stage V:** The EARIP did not develop guidelines on an appropriate method of estimating these costs. As general information, HDR has presented a range of water supply alternatives that may be considered to replace an equivalent of 27,400 acft/yr on an intermittent basis. The unit costs for these alternatives are from the 2011 South-Central Texas Regional Water Plan. These alternatives and the assumed unit cost include:
  - Irrigation water conservation ($160/acft/yr),
  - Municipal water conservation ($600/acft/yr),
  - Near-term water management strategies for SAWS ($1,300/acft/yr),
  - Long-term water management strategies for SAWS ($2,300/acft/yr), and
  - Drought management ($150/acft/yr to $15,000+/acft/yr).

One concept for implementing the SAWS water management strategies is for the EARIP or others to sponsor a new water supply for SAWS. In exchange, SAWS would temporarily transfer a prorated amount of their Edwards permits or leases to these sponsors (e.g., outlying municipalities).

5.2 Summary

A summary of the estimated cost, not including administrative and management costs, is provided in Table E-8 for layers 1-3 and Table E-9 for layer 4. For the first three layers, the total investment cost over 10 years is estimated to be $19,730,000. The greatest annual cost is for Edwards irrigation water leases, which totals $16,466,000 per year. The total annual cost is estimated to be $22,259,000. The most costly layers are the VISPO and SAWS ASR alternatives which cost about $10,000,000 each. It’s important to note that these two programs also have the greatest impact on springflow protection.

Table E-8.
Estimated Cost for Layers 1-3 of Bottom-Up Program

Program Component	Investment	Annual				Total
		Edwards Water Leases	Depreciation over 30-years	O&M (54-Yr Average)	Energy (54-Yr Average)	
Layer 1: VISPO (10-Year Option)	N/A	$10,216,000	N/A	N/A	N/A	$10,216,000
Layer 2: Municipal Conservation (10-Year Program)	$19,730,000	N/A	N/A	N/A	N/A	$1,973,000
Layer 3: SAWS ASR	N/A	$6,250,000	$2,778,000	$833,000	$209,000	$10,070,000

Table E-9.
Range of Estimated Cost for Layer 4 of Bottom-Up Program

Alternative (from 2011 Region L Water Plan)	Unit Cost (acft/yr)	Annual Cost
Irrigation Water Conservation	$140	$3,836,000
Municipal Water Conservation	$600	$16,440,000
Near-Term Water Management Strategies for SAWS	$1,300	$35,620,000
Long-Term Water Management Strategies for SAWS	$2,300	$63,020,000
Drought Management	$150 to $15,000+	$4,110,000 to $411,000,000+
Note: Annual cost is based on acquiring 27,400 acft/yr		

Appendix F
List of MODFLOW Runs in Development of Selected Springflow Protection Program

1.0 Introduction

During the course of development of the Bottom-Up Program, HDR and Todd Engineers formulated, prepared input files, conducted model simulations, and summarized results for numerous model runs. This process was directed by the Steering Committee and the Program Manager and continued until the Stakeholders informally agreed on a phased approach in implementing a Habitat Conservation Plan (HCP) and informally adopted the Bottom-Up Program for springflow protection.

Technical assumptions for the simulations were prepared by HDR. Almost all of the simulations in the evaluation of water management alternatives and programs were performed by Todd Engineers. They also conducted sensitivity tests to evaluate the performance of various levels of baseline pumping and pumping reductions. To efficiently do this work, Todd Engineers wrote and utilized several computer programs to prepare data sets for a MODFLOW simulation and to process the model results. HDR's simulations were limited to an evaluation of determining the performance of providing enhanced recharge for springflow protection by use of injection wells discharging directly into a conduit leading to Comal Springs or by use of surface recharge structures and features. This evaluation included the development of an episodic recharge schedule and rate to optimize springflow protection for a given amount of water available for recharge.

A listing of the significant simulations preformed by Todd Engineers is provided in Table F-1, and the ones performed by HDR are listed in Table F-2. As shown, Todd Engineers performed nearly 80 significant simulations, and HDR nearly 10 sensitivity tests.

Table F-1.
List of MODFLOW Simulations Performed by Todd Engineers

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
Program 1							
1	ASR_Wells	Pumped unused rights from new managed well field	Base	Unused_ne_ Bexar	Base	Program1	Prelim
2	ASR_Recharge	Recharge regime A in conduit location to maintain > 30cfs springflow at Comal , no pumping of unused rights	Conduit	Base	Base	Program1	Prelim
3	ASR_RechargeB	Recharge regime B in conduit location to maintain > 30cfs springflow at Comal , no pumping of unused rights	Conduit	Base	Base	Program1	Prelim
4	ASR_B	Pumping unused rights and recharge regime B in conduit location with managed pumping	Conduit	ASR_wells	Base	Program1	Iteration
5	ASR_C	Pumping unused rights and recharge regime C in conduit location (pumping occurs when recharge does not)	Conduit	ASR_wells_c	Base	Program1	Final
6	ASR_320K	Revise CPM pumping reductions so the minimum is 320K AFY. Same as ASR_all with new rules file	Conduit	ASR_wells	320K	Program1	Iteration

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
7	ASR_286K	Revise CPM pumping reductions so the minimum is 286K AFY. Same as ASR_all with new rules file	Conduit	ASR_wells	286K	Program1	Iteration
8	ASR_320K_D	Revise CPM pumping reductions so the minimum is 320K AFY. ASR recharge regime D	Conduit	ASR_wells_D	320K	Program1	Final
9	ASR_286K_E	Revise CPM pumping reductions so the minimum is 286K AFY. ASR recharge regime E	Conduit	ASR_wells_e	286K	Program1	Final
10	ASR_C_lease	Pumping unused rights and recharge regime C2 in conduit location (pumping occurs when recharge does not). Rights are leased	Conduit	ASR_wells_c_lease	Base	Program1	Final
11	ASR_320K_D2	Pumping unused rights and recharge regime D2 in conduit location (pumping occurs when recharge does not). Rights are leased	Conduit	ASR_wells_D_lease	320K	Program1	Final

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
12	ASR_286K_e2	Pumping unused rights and recharge regime e2 in conduit location (pumping occurs when recharge does not). Rights are leased	Conduit	ASR_wells_e_lease	286K	Program1	Iteration
13	ASR_286K_e3	Pumping unused rights and recharge regime e3 in conduit location (pumping occurs when recharge does not). Rights are leased	Conduit	ASR_wells_e2_lease	286K	Program1	Final
Program 2							
14	Type2	Recharging at Type 2 locations	Type 2s (LF,LS,LH,LV,SG,C,FRS)	Base	Base	Program2	Final
15	DYO	Implement DYO triggers on Type2	same Type2	DYO_well	Base	Program2	Final
16	Land	Add Land Stewardship	Type 2s + Dry Comal	DYO_well	Base	Program2	Final

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
17	SAWS_ASR	Simulated pumping reductions at the end of the drought.	Type 2s + Dry Comal + Offset pumping	DYO_well	Base	Program2	Final
Program 3							
18	Unused	Pumped unused rights from managed well field and recharge to LH and LV	zone 51,52	unused	Base	Output_credits_710	Prelim
19	Unused_Type2	Pumped unused rights from managed well field and recharge to LH and LV, Type 2 recharge from LF, LS, LH, LV	zones 49,50,51,52	unused	Base	Output_credits_710	Prelim
20	recovery150	Examining recharge recovery with a trigger of Comal springflow at 150cfs.	Type 2s (LF,LS,LH,LV), Recovery to LH, LV	Recovery_150.wel	Base	Program3	Final
21	recovery100	Examining recharge recovery with a trigger of Comal springflow at 100cfs.	Type 2s (LF,LS,LH,LV), Recovery to LH, LV	Recovery_100.wel	Base	Program3	Final

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
22	RR3	R&R trigger 100 cfs, Hondo/ Verde split adjusted to .75/.25	Type 2s (LF,LS,LH,LV), Recovery to LH, LV	Recovery_2_ 100.wel	Base	Program3	Final
23	RR4	R&R trigger 30 cfs, Hondo/ Verde split adjusted to .75/.25	Type 2s (LF,LS,LH,LV), Recovery to LH, LV	Recovery_2_ 30.wel	Base	Program3	Final
Trade Off Bexar							
24	TradeOff_B_ Base	Run creating new stages and pools without changing reductions to test implementation	Base	Base	TO_Base	Trade_Offs	Prelim
25	TradeOff_B1	More severe rules for Bexar County	Base	TO_Bexar	TO_Bexar	Trade_Offs	Iteration
26	TradeOff_B1 b	More severe rules for Bexar County. Iteration to ensure total water in storage is equviliant to the replacement water needed.	Base	TO_Bexar	TO_Bexar	Trade_Offs	Final

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
27	TradeOff_B2	More severe rules for Bexar County, improve on previous attempt	Base	TO_Bexar2	TO_Bexar 2	Trade_Offs	Iteration
28	TradeOff_B3	More severe rules for Bexar County, improve on previous attempt	Base	TO_Bexar3	TO_Bexar 3	Trade_Offs	Final
Trade Off Comal Hays							
29	TradeOff_C_Base	Run creating new stages and pools without changing reductions to test implementation	Base	Base	TO_Comal_Base	Trade_Offs	Prelim
30	TradeOff_C_Type2	Run applying type 2 recharge and rules changes to ensure correct implementation	Type 2s (LF,LS,LH,LV,SG,FRS)	Base	TO_Comal	Trade_Offs	Prelim
31	TradeOff_C_recovery	Final run including recharge, rules changes, and pumping recovery	Type 2s (LF,LS,LH,LV,SG,FRS)	TO_Comal	TO_Comal	Trade_Offs	Final
Bottom Up Oct 2010 - 1947-2000							
32	DYO	A reduction of pumping of 40,000 AFY in dry years. The dry year option is triggered in every year of the simulation.	Base	DYO	base	Final 1010	Final

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
33	Conservation	This builds on the DYO run. A reduction of pumping of 10,067 AFY distributed based on municipal pumping by county.	Base	DYO_Con	base	Final 1010	Final
34	SAWS_ASR	Builds on DYO and Conservation. Unused rights are used to fill the ASR and when "recharge" is not needed for the aquifer based on by the regime developed by HDR (BU2).	Recovery	ASR	base	Final 1010	Final
35	Stage V	Builds on all previous runs. Creates a new stage V triggered by J-17 for SA and U as discussed in the assumptions technical memorandum.	Recovery	ASR	StageV	Final 1010	Final
36	Stage Vb	Builds on Layer 3. Creates a new stage V triggered by J-17 for SA and U.					
Bottom Up Dec 2010 - 1947-2000							

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
37	DYO	A reduction of pumping of 40,000 AFY in dry years. The dry year option is triggered in every year of the simulation.	Base	DYO	base	Final 1210	Final
38	Conservation	This builds on the DYO run. A reduction of pumping of 10,067 AFY distributed based on municipal pumping by county.	Base	DYO_Con	base	Final 1210	Final
39	SAWS_ASR	Builds on DYO and Conservation. Unused rights are used to fill the ASR and when “recharge” is not needed for the aquifer based on by the regime developed by HDR (BU2).	Recovery	ASR	base	Final 1210	Final
40	Stage V	Builds on all previous runs. Creates a new stage V triggered by J-17 for SA and U as discussed in the assumptions technical memorandum.	Recovery	ASR	StageV	Final 1210	Final

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
41	DYO	Simulates the VISPO program with new totals and triggers	base	DYO	base	Final_811	Final
42	Water_Con	This builds on the DYO run. A reduction of pumping of 10,067 AFY distributed based on municipal pumping by county.	base	DYO_Con	base	Final_811	Final
43	ASR	Builds on DYO and Conservation. Includes new totals for IRPs in all counties and operates pumping reductions based on the tier system.	Recovery	ASR	base	Final_811	Prelim
44	Stage V J-17, J-27	Stage V with trigger at J-17 and J-27	Recovery	ASR	Stage_Va	Final_811	Prelim
45	Stage V J-17	Stage V with trigger at only J-17	Recovery	ASR	Stage_Vb	Final_811	Prelim
Bottom Up Phase II - 1947-2000							
46	Version 1	Recovery at only Naco	Version 1 recovery	ASR_811b	base	Final_811	Prelim
47	Version 1_stage V	Recovery at only Naco	Version 1 recovery	ASR_811b	StageV_comal	Final_811	Prelim
48	Version 2	Recovery at Naco and Maltsberger	Version 2 recovery	ASR_811c	base	Final_811	Prelim

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
49	Version 2_stage V	Recovery at Naco and Maltsberger	Version 2 recovery	ASR_811c	StageV_comal	Final_811	Prelim
50	Version 2a	Recovery at all four eastside locations	Version 2a recovery	ASR_811c	base	Final_811	Prelim
51	Version 2a_stage V	Recovery at all four eastside locations	Version 2a recovery	ASR_811c	StageV_comal	Final_811	Prelim
52	Version 3	New Recovery regime (east and west)	Version 3 recovery	ASR_911	base	Final_911	Prelim
53	Version 3_stage V	New recovery regime with stage V, Comal trigger	Version 3 recovery	ASR_911	StageV_comal	Final_911	Prelim
54	Version 4	New Recovery regime	Version 4 recovery	ASR_911	base	Final_911	Prelim
55	Version 4_stage V	New recovery regime with stage V, Comal trigger	Version 4 recovery	ASR_911	StageV_comal	Final_911	Prelim
54	Version 5	New Recovery regime	Version 5 recovery	ASR_911	base	Final_911	Final
55	Version 5_stage V	New recovery regime with stage V, Comal trigger	Version 5 recovery	ASR_911	StageV_comal	Final_911	Final
56	Version 6	New Recovery regime	Version 6 recovery	ASR_911	base	Final_911	Final
57	Version 6_stage V	New recovery regime with stage V, Comal trigger	Version 6 recovery	ASR_911	StageV_comal	Final_911	Final

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
Additional Runs							
58	HDR_LB	Enhanced Recharge from Lower blanco and San Macros pump over added per HDR's calculations	Zone 55,58	Base	Base	Output_040310	Other
59	GWSIM1	Enhanced Recharge Based on GWSIM simulations, Recharge from HDR Scenario1 40 cfs	Zone 59	Base	Base	Output_040310	Other
60	GWSIM2	Enhanced Recharge Based on GWSIM simulations, Recharge from HDR Scenario2 60 cfs	Zone 59	Base	Base	Output_040310	Other
61	GWSIM3	Enhanced Recharge Based on GWSIM simulations, Recharge from HDR Scenario3 100 cfs	Zone 59	Base	Base	Output_040310	Other
62	Recover - LF	Hypothetical pulse at each type 2	Zone 49	Base	Base	Output_recovery	Recovery
63	Recover - LS	Hypothetical pulse at each type 2	Zone 50	Base	Base	Output_recovery	Recovery
64	Recover - LH	Hypothetical pulse at each type 2	Zone 51	Base	Base	Output_recovery	Recovery
65	Recover - LV	Hypothetical pulse at each type 2	Zone 52	Base	Base	Output_recovery	Recovery

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
66	Recover - C	Hypothetical pulse at each type 2	Zone 54	Base	Base	Output_recovery	Recovery
67	454	Examines baseline if total pumping is reducted to 454K	base	Wel_454	base	454	Other
68	Stage V	Triggers CPM stage V for Uvalde from J-27 and San Antonio off J-17.	Base	Base	Stage V	Stage V	Other
69	Stage Vb	Triggers CPM Stage V for both Uvalde and San Antonio pools off J-17.	Base	Base	Stage Vb	Stage V	Other
70	ASR_Task 2a	Uses a comal springflow trigger of 5o cfs. If flow is above the trigger irrigation permits are pumped to ASR until max capacity of 200K is reached. When flow is under trigger, water is retrieved (at a rate of 5,600 AFM when available) from ASR for direct use at 4 SAWS pumping centers in lieu of pumping.	Framework 2a	ASR_2a	base	base	Other

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
71	ASR_Task 2b	Uses an episodic recharge regime developed by Larry. Irrigation rights are pumped as needed from **Artesia and Seale pump centers**, the pumping states are shown in the framework file also attached. Recharge is applied to the conduit upgradient from Comal.	Framework 2b	ASR_2b	base	base	Other
72	ASR_Task 2c	Uses a comal springflow trigger of 50 cfs. If flow is above the trigger irrigation permits are pumped to ASR until max capacity of 200K is reached. When flow is under trigger, water is retrieved (at a rate of 5,600 AFM when available) from ASR. Water is "recharged" to the Artesia/Seale pump centers, recovered at Naco pump center and injected in the conduit.	Framework 2c	ASR_2c	base	base	Other

Table F-1 (Concluded)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
73	Baseline	Baseline run to use as comparison for program runs	Base	Base	Base	Base	Baseline
74	Unused	Baseline run to use as comparison for program runs. Unused rights are retired.	Base	Unused_zero	Base	Base	Baseline
75	320K	Baseline run to use as comparison for program runs. The CPM floor in stage 4 is 320K.	Base	Base	320K	Base	Baseline
76	286K	Baseline run to use as comparison for program runs. The CPM floor in stage 4 is 286K.	Base	Base	286K	Base	Baseline
77	Unused_320K	Baseline run to use as comparison for program runs. Unused rights are retired and the CPM floor in stage 4 is 320K.	Base	Unused_zero	320K	Base	Baseline
78	Unused_287K	Baseline run to use as comparison for program runs. Unused rights are retired and the CPM floor in stage 4 is 286K.	Base	Unused_zero	286K	Base	Baseline

Table F-2.
List of MODFLOW Simulations Performed by HDR

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
Program: Sensitivity Test to Evaluate Performance of Enhanced Recharge Locations and Rates near Comal Springs							
1	Direct (Injection_Wells)_1	Test Springflow Benefit with Injection Wells in Edwards Conduit	Base with Recharge Schedule_1	Base	Base	Program1	Sensitivity Test
2	Direct (Injection_Wells)_2	Test Springflow Benefit with Injection Wells in Edwards Conduit	Base with Recharge Schedule_2	Base	Base	Program1	Sensitivity Test
3	Direct (Injection_Wells)_3	Test Springflow Benefit with Injection Wells in Edwards Conduit	Base with Recharge Schedule_3	Base	Base	Program1	Sensitivity Test
4	Direct (Injection_Wells)_4	Test Springflow Benefit with Injection Wells in Edwards Conduit	Base with Recharge Schedule_4	Base	Base	Program1	Sensitivity Test
5	Indirect (Recharge_Structure)_1	Test Springflow Benefit with Natural Recharge on Outcrop	Base with Recharge Schedule_1	Base	Base	Program1	Sensitivity Test
6	Indirect (Recharge_Structure)_2	Test Springflow Benefit with Surface Recharge on Outcrop	Base with Recharge Schedule_2	Base	Base	Program1	Sensitivity Test

Table F-2 (Concluded)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
Program: Sensitivity Test to Evaluate Performance of Enhanced Recharge Locations and Rates near Comal Springs							
7	Indirect (Recharge_Structure)_3	Test Springflow Benefit with Surface Recharge on Outcrop	Base with Recharge Schedule_3	Base	Base	Program1	Sensitivity Test
8	Indirect (Recharge_Structure)_4	Test Springflow Benefit with Surface Recharge on Outcrop	Base with Recharge Schedule_4	Base	Base	Program1	Sensitivity Test
9	Indirect (Recharge_Structure)_5	Test Springflow Benefit with Surface Recharge on Outcrop	Base with Recharge Schedule_5	Base	Base	Program1	Sensitivity Test

Appendix G
Evaluation of Quarries for Surface Storage Reservoirs

1.0 Introduction

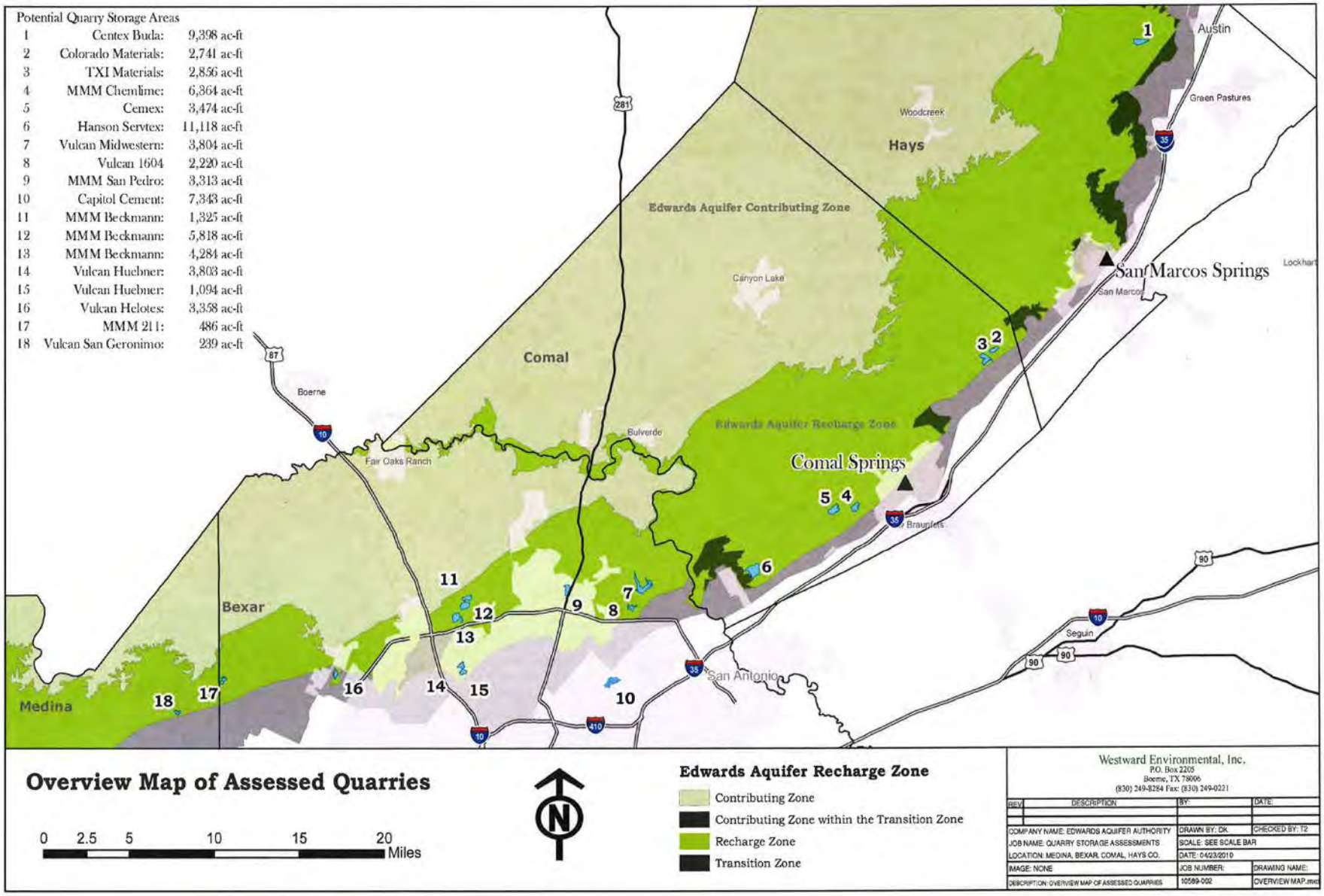
The following is a brief summary of a draft report by Westward Environmental, Inc. (WEI) titled ***Draft Quarry Evaluation Report*** and dated May 3, 2010. The full report is posted on the web at: http://earip.org/Reports/Draft%20Quarry%20Report.pdf

WEI was engaged by HDR and the Texas Agrilife Extension Service of the Texas A&M University System at the request of the EARIP Program Manager to develop technical information relating to quarries in Hays, Comal, Bexar, and eastern Medina Counties. This information is to assist in the engineering analysis and the decision making process regarding the potential use of quarries to store water, in the area of the Comal and San Marcos Springs for springflow protection.

Numerous quarries are located along the Balcones Escarpment between central Medina County and Travis County. In the draft report, these quarries are divided into three groups: those within ten miles of Comal or San Marcos Springs, those beyond ten miles, but within Bexar County, and all others. Key areas of mining activity (mined/excavated areas) were identified using publicity available aerial photography and topographic data. The excavated volumes of these areas were analyzed and calculated.

Analyses show approximately 35,952 acft of excavated quarry volume within ten stream miles, 36,083 acft of additional excavated quarry volume beyond ten miles within Bexar County, and 750 acft in eastern Medina/western Bexar Counties. It is noted that embankment construction and measures to control leakage would be necessary to effectively use these excavated volumes for water storage. The locations of and potential storage capacities associated with these quarries are shown in Figure F-1. WEI's review of the mining status of these quarries revealed that they are still in some stage of active mining activity and that none of the quarries reviewed within our target area are abandoned/exhausted.

Materials such as limestone fines and clay are present at several of the quarry sites or on adjacent properties. These materials present a possible source for liner, structural fill, or embankment construction. The six sites within ten miles of Comal or San Marcos Springs are also adjacent to Union Pacific rail lines, several gas pipelines, electrical transmission lines, and surface road right of ways which could serve as a potential corridors for water transmission lines in the direction of the springs or to recharge sites near the springs. Maps and exhibits identifying these areas are presented in the draft report.



F-1. Location of Large Quarries near Comal and San Marcos Springs

APPENDIX L:

HALFF ASSOCIATES, INC., "INITIAL STUDY ON THE RECREATIONAL IMPACTS TO PROTECTED SPECIES AND HABITATS IN THE COMAL AND SAN MARCOS SPRINGS ECOSYSTEM," NOVEMBER 3, 2010

Edwards Aquifer Recovery Implementation Program

Initial Study on the Recreational Impacts to Protected Species and Habitats in the Comal and San Marcos Springs Ecosystems

HALFF

November 3, 2010

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Appendix B: New Braunfels Stakeholder Interview Responses

Appendix C: San Marcos Stakeholder Interview Responses

Appendix D: USGS Water-Quality Assessment of the Comal Springs Riverine System, NewBraunfels, Texas, 1993-94

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Appendix F: Response to TWDB Comments

Acknowledgements

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Nathan Pence, CNB River Manager
Stacy Laird-Dicke, CNB Director of Parks
Chad Donegan, CNB Golf Course Manager
Judy Young, Visitors and Convention Bureau
Michael Meek, Chamber of Commerce
Suzanne Herblin, Wurstfest / Landa Falls
Jason Hunter, WurstFest. / Landa Falls
Cecil Eager, Gruene Mansion Inn
Darren Hill, Schlitterbahn Water Parks

City of San Marcos (CSM)
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Susan Narvais, Mayor CSM
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Glen Hanley, Texas State University Golf Manager
Tom Goynes, San Marcos River Retreat
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River Systems Institute, Texas State University
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EXECUTIVE SUMMARY

This report is an initial study and compilation of existing data and research that illustrates the impacts of water-based recreational activities on protected species and habitats in the Comal and San Marcos Springs ecosystems for the Edwards Aquifer Recovery Implementation Program (EARIP). The EARIP limited the project area to those portions of the Comal and San Marcos Springs that are within the city limits of New Braunfels and San Marcos.

This study is a summary of existing data that was made available to Halff Associates by the Edwards Aquifer Recovery Implementation Program, the cities of New Braunfels and San Marcos, Texas Commission on Environmental Quality, U.S. Fish and Wildlife Service and the River Systems Institute of Texas State University. During the course of the study, existing data from various sources was reviewed and evaluated in an effort to identify and locate water-based recreational activities within the limits of the project area. Halff Associates worked to quantify and map the numbers of users, times of use, types of users and the areas they frequent, numbers and locations of endangered species, the locations and limits of their habitats. Halff also conducted review of existing ordinances that pertain to recreation and recreation development on and around the springs. Interviews with various stakeholders were conducted. Water quality data on protected species and their habitats was mapped. A review of existing scientific studies regarding recreational impacts on protected species and economic data from existing studies that was pertinent to the project area was reviewed. The sources of all this data include scientific studies, consultant studies, public agency records and stakeholder interviews.

Existing ordinances from the cities of New Braunfels and San Marcos that relate to water-based recreational activities and development within the limits of the project were reviewed. This section of the report summarizes what those specific ordinances are. Of particular note is the restricted (recreation) use by respective city ordinance on the upper reaches of both the Comal Springs (Mill Run Channel and upstream) and San Marcos Springs (Spring Lake) systems. Also included in this summary are ordinances that pertain to development or potential recreation development adjacent the rivers.

Geographical Information Systems software was utilized to map locations of water-based recreational activities, locations of water quality sampling stations and locations of listed species. While waters of the Comal and San Marcos springs systems are considered State property, access to and from the banks is restricted by land use/ownership; this information is also provided in the mapping data.

Interviews with stakeholders included members of city staff, chambers of commerce, recreation and tourist based business owners/managers, representatives of user groups and members of city council. A questionnaire prepared by Halff Associates, with the assistance of the EARIP was provided to stakeholders in advance of the interviews, to give interviewees the opportunity to elaborate on the questions and requested data.

Scientific studies relative to the impacts of recreational activities on endangered species and their habitats were sought but few were found. Documents and studies included in the reviews were habitat conservation plans, information pertaining to flood control and raw data from an ongoing doctoral study. There were also studies that were cited and referred to by some of the data providers, but several of these were not accessible for review.

Economic information pertaining to recreational activities within each of the cities is very limited. There is no published data for San Marcos, although Halff provides extrapolated figures based on survey data provided by the Texas State University doctoral candidate and the information provided by the one and only tube vendor in this city for one particular year. Two studies for the New Braunfels area on tourism and hospitality were made available, and information on river based recreational activities was extrapolated from data included in both of the studies as there is no specific data on recreation in either study.

The **recreational impacts** on these river systems are cultural, social, economic, and most importantly, physical. The rivers are iconic elements within each of the two cities. With a large portion of the river banks fronting public parks, they are the center of community events and prime socializing spaces. As populations increase in Central Texas, so does the popularity of recreating in these rivers and as such, there were reports of physical degradation of adjacent parks and banks, but quantitative data to identify the extent of the degradation is minimal at best. The physical impact of litter and erosion is evident in the public parks and there are no real controls for capacity other than parking restrictions.

Conclusion

Further study is needed in the pursuit of specific and quantitative correlations between recreational uses and listed species. Most of the important information in this document is anecdotal and perceived, and some of the factual information is peripheral and could definitely be used to support more specific research. In summary, the information that Halff has explored within the body of this report provides a good starting point from which further study could be pursued.

I. DATA COLLECTION

Sources of information for this report were derived from a list of activities and facilities provided by the EARIP, the cities of New Braunfels and San Marcos, their chambers of commerce, stakeholders referred to by the EARIP, the Texas Commission on Environmental Quality, Texas Department of Parks and Wildlife, United States Fish and Wildlife Services and sources of literature provided by the River Systems Institute and the EARIP. Information regarding types of recreation vendors, activities, types of users, times of use, numbers of users, regulations of use, economic information, water quality, and species locations were sought and GIS mapping was developed to illustrate locations of various attributes. The GIS mapping will also provide a base from which further study can be documented. The information provided within this document is known to be limited as some information sources that were referred to are not available.

A. New Braunfels

Recreation activities on the Comal River include: swimming, wading, lounging/picnicking, snorkeling, scuba diving, tubing, fishing, paddle boating, swift water rescue, and rope/tree jumping (though it is not lawful). The most common activities are tubing, swimming, wading and lounging, and fishing. Paddle boating and fishing are the only activities permitted in Landa Lake, closer to the springs although there is very small area in Landa Park that permits wading and there is a spring fed public swimming pool that is dammed off from the Comal River and dates to the 1930's within Landa Park. Most activity in the water is concentrated at the stretch from Landa Falls / Wurstfest grounds downstream to the Union Avenue exit commonly known as the last public exit. Upstream of Landa Lake is Texas Water Recreation District No. 1, which is a legislated area designated for restricted use by adjacent property owners. Wooden docks and stacked canoes were observed along this water front.

Members from the Halff team gathered information and data about recreational activities and events from city staff, members of the convention and visitors bureau/chamber of commerce, recreational outfitters and various users of the springs.

Tubing is the predominant recreational activity in the river. The City has an agreement with the tubing outfitters that limits the number of tubers on the river at any one time. There are significant number of tubers that do not rent tubes however, but choose instead to provide their own tube to enjoy the river. The costs of tube rentals range between $10-$15 per person, and the rental fee typically includes a shuttle ride from the tube outfitter to the river drop-off and

pick-up points. $1.25 of each tube rental is a river management fee that goes directly to the City of New Braunfels.

The following list of water-based recreational outfitters illustrates the variety of recreational activities available along the Comal River. Tube rental outfitters located along the banks of Guadalupe River were excluded from the list even though they are located within the city limits. It is also note worthy to advise that year 2010 was a bit of an anomaly because of the severe flooding experienced in early June; as a result, many outfitters were not accessible for participation.

Table 1

Type of Vendor	Company	Address	Phone	Hours of operation
Tube Rental	Rock'n R River Rides	1405 Gruene Road New Braunfels, TX 78130	830-629-9999	No information available
Tube Rental	Texas Tubes	250 Meusebach St. New Braunfels, Texas	830-626-9900	March 13 – May 1 11a.m. to 7 p.m. May 2 – Sept. 10 9 a.m. to 8 p.m. Sept. 11 – Sept 30 11 a.m. to 7 p.m. October 1 and later Weather permitting
Tube Rental	Corner Tubes	120 South Liberty Avenue New Brauanfels, TX	830-626-6687	No information available
Tube Rental	Felger Tube Rental	161 South Liberty Avenue New Braunfels, TX	830-625-4003	No information available
Tube Rental	Landa Falls/Wurstfest	178 Landa Park Drive New Branfels, TX	830-627-1440	May-June 10 a.m. – 5 p.m. July 10 a.m. – 8 p.m.
Paddel Boat Rental	City of New Braunfels Landa Park Paddle Boats	Landa Park Boathouse	830-221-4350	March 22 to 26 Noon – 7 p.m. Weekends only Apr – Memorial Day Noon – 7 p.m. Daily Memorial Day – Aug 22 Noon – 7 p.m. Weekends only Aug 28 – Labor Day Noon – 7 p.m.
Campground	Landa RV Park and Campground	565 North Market Street New Braunfels, TX	830-625-1211	Year round
Other	S chlitterbahn Waterpark Resourt	381 East Austin Street New Braunfels, TX 78130 And 305 West Austin Street New Braunfels, TX 78130	830-625-2351 830-608-8520	Various hours throughout the year

Other activities that occur in the Comal River but do not generally require rental equipment or professional guidance include wading, swimming / snorkeling, fishing, swift water rescue training, rope/tree jumping, and lounging / picnicking.

In addition, there are numerous locations where river users can purchase tubes, and ad hoc tube outfitters are present along the river intermittently during the summer months.

B. San Marcos

Information gathered from interviews with stakeholders revealed that recreation activities on the San Marcos River include swimming, wading, lounging/picnicking, boat touring, snorkeling, scuba diving, tubing, fishing, rope swinging/jumping, boating (kayak and canoe), white water kayak training, dog playing. The most common activities are tubing, swimming, wading and lounging/picnicking. Spring Lake, where the springs originate, is restricted to research use and guided boat tours either by kayak or glass bottom boat. Cost for glass bottom boat tours range between $6-$9; kayak tours are by appointment and are available through an the Aquarena Nature Center, operated by Texas State University. Scuba diving on this lake is permitted research purposes only. The prime areas of activity along the San Marcos River are between Sewell Park and Rio Vista Falls Park falls.

Most of this stretch is adjacent public park property and access to the water is only limited by vegetation on the banks. As the demand for river activity grows, there is compelling physical evidence of trampled vegetation, bank damage and bank erosion caused by visitors to the River in their efforts to access the water.

Information gathered regarding recreational activities and the events that surround them is from city staff, members of the convention and visitors bureau/chamber of commerce, recreational outfitters, various users, and researchers.

The following list of water-based recreational outfitters illustrates the variety of recreational activities available along the San Marcos River.

Table 2				
Type of Vendor	**Company**	**Address**	**Phone**	**Hours of operation**
Tube Rental	Lion's club Tube Rentals	170 Bobcat Trail San Marcos, TX	512-396-0342	Mid May – Sept 11 a.m. to 4 p.m. Last shuttle 7 p.m.
Kayak and Canoe Rental	TG Kayaks and Canoes	402 Pecan Park Drive San Marcos, TX	512-353-3946	
Kayak Instruction	White Water kayak instruction	Power Olympics Outdoor Center 602 N. Interstate 35 San Marcos, TX		
Other	Aquarena Nature Center	601 University Drive San Marcos, TX	245-7570	

Other activities that occur in the San Marcos River but do not generally require rental equipment or professional guidance include wading, swimming / snorkeling, fishing, swift water rescue training, rope/tree jumping, lounging / picnicking, scuba diving and dog play.

II. EXISTING ORDINANCES

Existing ordinances were collected from the cities of New Braunfels and San Marcos with the assistance of planning staff from each city. The majority of the ordinances in place in each city deal with development restrictions along the rivers, while there are a few ordinances that address particular behaviors or activities that typically occur. New Braunfels has a higher number of ordinances pertaining to recreation activities on the river than San Marcos does.

A. City of New Braunfels

Land use and zoning districts alongside the Comal River within the city of New Braunfels identifies areas of open space, commercial/resort land use districts, as well as low density residential. Each of these land uses and zones permit recreation activity of varying degrees. Ordinances related to development of recreation facilities within the floodplain as well as ordinances that relate directly to activities on the water are summarized in the following text.

Most notable and of specific relevance to river-based activities (not specific to Comal) are the following ordinances:

Table 3

Ordinances Specific to Recreational Activity on the Rivers	New Braunfels	San Marcos
Prohibition of Alcohol @ riverside parks	X	
Means to Restrict Beverage Consumption on the River (cooler size & limit)	X	
Prohibition of Glass in parks and rivers	X	X
Prohibition of Styrofoam	X	
Prohibition of dangerous jumping	X	X
Prohibition of Litter in the river	X	
Prohibition of Wastewater in rivers		X
Restrictions on Recreation in parts of the spring rivers	X	X
Minimum size of open containers on the river	X	
Noise restrictions at parks	X	X
Restrictions on types of floating devices	X	
River tax collected on Water-based Recreation Equipment	X	
Restricted methods of fishing and bait type	X	X
Fishing bait must be artificial	X	
Unlawful to release any type of aquatic organism into waters of a city park		X
Unlawful to wash bodies/animals, personal belongings in the river		X
Park curfews	12am - 6am	11pm - 6am
No overnight camping in riverside parks unless otherwise designated	X	X
Restrictions on use of motorized vehicles within riverside parks	X	X
Unlawful to damage/destroy vegetation @ parks	X	X
Regulations on Water Rereational Service Shuttles	X	X
Unlawful to disturb wildlife in city parks		X

The following ordinances are focused on the control of recreational activities and providers within the city of New Braunfels.

(NB) Section 23-50(f) – Entering rivers by jumping or dangerous acts

It is a violation of this code to enter any river, lake stream or waterway by jumping, diving or doing any other dangerous act on or off any publicly owned bridge, street, highway, appurtenance, publicly owned land or public right of way unless for reason of rescuing someone from drowning.
It is also a violation to jump dive or perform any dangerous acts on or off of trees, platforms, high banks, dams or other walkways to enter streams, rivers or waterways.

(NB) Sec. 50-57. - Prohibited accumulations; litter; weeds; graffiti; duty of property owner, occupant.

(Code 1961, § 8-34; Ord. No. 98-22, § II, 8-10-98; Ord. No. 2006-22, § 1, 3-13-06)

Owners and supervisors of real property occupied or not are not lawfully permit to allow filth, carrion, weeds, rubbish, junk, trash, waste products, brush and refuse, graffiti of any kind to remain on the property.
Deposit of any such matter into or along any drain, gutter, alley, sidewalk, street or right of way, vacant lot (private or public)
Weeds and Unsightly vegetation greater than 12 inches height within 150 feet of any right of way, alley or utility easement, building or structure is not permitted and Owners of real property shall maintain or remove such.
Graffiti is not permitted on real property and shall be removed within 15 days of notice from health official.

(NB) Section 58-33 Same – Duties and responsibilities (of the floodplain administrator)

(Code 1961)

To review permit applications to determine whether proposed building sites including mobile homes will be safe from flooding
To review permits for proposed development to assure all necessary permits have been obtained from federal, state or local government agencies.
To notify the state water commission and adjacent communities prior to any alteration or relocation of a watercourse and submit copies of such to FEMA
Assure the flood carrying capacity within the altered or relocated portion of any watercourse is maintained
To interpret the exact location of the boundaries of the flood plain in areas of special flood hazards where interpretation is needed
When regulatory floodway has not been designated, the administrator must require no new construction, substantial improvements, or other development be permitted unless it can be demonstrated that the cumulative effect of the

proposed development when combined with all other existing and anticipated development will not increase the water surface elevation of the base flood more than one foot at any point within the community

(NB) Section 58-34 Permit procedures

(Code 1961, ss 5-31, Ord. No. 98-29, ss I)

Dev Permits must describe extent of alteration or relocation of any watercourse or natural drainage as result of development

(NB) Section 58-36 Provision for flood hazard reduction

In areas of special flood hazard, structures must be adequately anchored to prevent flotation, collapse or lateral movement

Construction methods and practices must minimize flood damage and of materials resistant to flood damage

Water supply systems as well as sanitary sewage systems shall be designed to minimize or eliminate infiltration of floodwaters

Recreation vehicle parks must develop a plan for evacuating residents

All recreation vehicles must not be permitted to have uninflated tires or any condition that would impede, delay or hinder immediate evacuation

With respect to floodways, encroachments are prohibited: including fill, excavation , ew construction, substantial improvements unless certification by a profession engineer or architect is provided to demonstrate encroachments do not increase in flood levels

(NB)Section 74-1. - Park rangers and river project manager authorized to issue citations.

(Ord. No. 2004-24, § I, 4-12-04)

For the violation of any of the city ordinances under Chapter 86 "Parks and Recreation", Chapter 126 "Traffic and Vehicles", Chapter 6 "Animals" and section 82-9 and section 82-10 of Chapter 82 "Offenses and Miscellaneous Provisions."

(NB) Section 82-10. - Noise prohibitions, public rights-of-way and public property, exceptions; penalty.

(Ord. No. 2003-34, § I, 5-12-03; Ord. No. 2006-53, § I, 6-26-06)

It is unlawful to operate any radio, tape recorder, cassette player, CD player, DVD player or MP3 player or any other sound reproducing device any louder than audibility at 50 feet or more while located on public property, exceptions are for athletic and city authorized events

(NB) Section 82-12. - Volume drinking devices prohibited

(Ord. No. 2006-54, § I, 6-26-06)

(a)*Definitions.* For the purpose of this section, the following definitions shall apply:

Volume drinking devices means an object used, intended for use or designed for use in artificially increasing the speed with which, and/or amount of, alcohol is ingested into the human body by carrying the liquid from a higher location into the mouth by force of gravity or mechanical means, including but not limited to funnels, tubes and hoses. The term includes a beer bong.

It is an offense to use or possess with intent of use in a public place

(NB) Section 82-13. - Amplified sound devices prohibitions on the Comal and It is unlawful to operate or permit to be operated any amplified sound device or equipment between the hours of 10pm-8am. Violations may result in fines ranging Guadalupe Rivers.

from $100-$500.

(NB) Section 86-1 – Overnight camping prohibited; hours parks closed; penalty

No tents for camping and no overnight camping is permitted within parks.

No overnight parking of vehicles, portable buildings, camping units of any type are permitted.

No person, vehicle or equipment or activity is permitted between the hours of 12am and 6 am with exception of grant by the city.

(NB) Section 86-4 – Additional rule and regulations for control of parks and recreation ares and facilities

(Code 1961, ss 14A-6; Ord. No. 2003-51, ss I(2.))

With the exception of city and city authorized equipment, it is unlawful to launch any type of boat, canoe, water vehicle or flotation device from the banks of Land Park Lake.

It is unlawful to deposit /throw/drop/place loose paper, cans, bottles, sacks, boxes, cloths, waste materials, rubbish alongside any body of water within city limits.

It is unlawful to drive any motor vehicle on any trail/footpath/footbridge spanning a creek or stream with the exception of golf carts or maintenance vehicles

It is unlawful to remove, destroy or damage any vegetation within parks and recreation areas.

It is unlawful to wade or swim in any water body within the Landa Park Golf Course to retrieve golf balls or for any other purpose.

(NB) Section 86-6 Swimming or wading prohibited in Landa park Lake; exception

(Code 1961, ss 14A-5)

It is an offense to enter, wade, swim or engage in any aquatic activity in any area of Landa Park Lake with exception of area posted 'wading area'; exception is law enforcement and public safety agencies operating water craft

(NB) Section 86-7. - Operation of vehicles in parks

(Code 1961, § 14A-7; Ord. No. 98-7, § I, 2-9-98; Ord. No. 01-18, § I, 3-12-01; Ord. No. 01-63, § I, 12-10-01; Ord. No. 2003-51, § I(3.), 8-11-03; Ord. No. 2004-25, § I, 4-12-04; Ord. No. 2008-41, § 1, 6-9-08)

Landa Park: operation of motor vehicles on designated portions of Landa Park Drive prohibited by law: 7am-8pm, Saturdays, Sundays and legal holidays from Easter weekend through Labor Day

Hinman Island: operation of motor vehicles of any kind prohibited by lawn on that portion of Hinman Island Drive from its west side intersection with Liberty Avenue in a westerly direction to its east side intersection with Elizabeth Avenue 7am – 8pm Saturdays, Sundays and legal holidays from Easter weekend through Labor Day when the barricades on Hinman Island Drive are closed..

Parking fees in Prince Solms Park East. There shall be a parking fee applicable 9am-6pm Saturdays, Sundays and holidays from Easter weekend through Memorial Day weekend and on weekdays and weekends from Memorial Day weekend through Labor Day, unless exempt by city manager.

Fees are designated for the restoration and improvement of Prince Solms Park East

No through commercial truck traffic except Light trucks including any truck with a manufacturer's rated carrying capacity not to exceed 2,000 pounds and including those trucks commonly known as pickup trucks, panel delivery trucks, vans and carryall trucks shall be excluded from the provisions of this section. Recreational vehicles and passenger buses shall be excluded from the provisions of this subsection.

Any truck which has a destination point, for commercial purposes, within Landa Park or Hinman Island Park shall be permitted to proceed by the shortest route through such parks to its destination, and shall exit by the same route.

Maximum weight limits for bridges in Landa Park:

(1) Bridge on Landa Park Drive at the Comal River and Landa Railroad Train Depot, TxDOT location number 15-046-8403-15-004, shall have a maximum safe load limit of 12,500 pounds, axle or tandem;

(2) Bridge in Landa Park at the main spring flow from Panther Canyon area nearest the wading pool, TxDOT location number 15-046-8403-15-003, shall have a maximum safe load limit of 24,000 pounds tandem;

(3) Arched bridge on Landa Park Drive at the Comal River Springs closest to California Street, TxDOT location number 15-046-8403-15-002, shall have a maximum safe load limit of 24,000 pounds tandem.

(NB) Section 86-8 Glass containers prohibited in park areas and on rivers, lakes and streams

(Ordinance No. 2005-62)

It is a misdemeanor offense to be carrying, using and/or disposing of glass beverage containers in all city parks adjacent rivers, lakes and streams

Cross reference—Waterways, ch. 142.

(NB) Section 86-10. - Prohibition of alcoholic beverages in city parks and city-owned property

(Ord. No. 2007-12, § 1, 2-12-07; Ord. No. 2008-11, § 1, 1-28-08)

(a)It shall be unlawful for anyone to consume liquor or any alcoholic beverage, or possess an open container of intoxicating liquor or alcoholic beverage within the boundaries of the following public parks or city-owned property within the city limits:

(1)Prince Solms Park; (2)Hinman Island Park; (3)Cypress Bend Park; (4)The City-owned tuber exit on the Comal River that borders Lincoln Street and Union Avenue. (5)River Acres Park; (6)H.E.B. Soccer Park; (7)Jesse Garcia Park; (8)Ernest Eikel Field; (9)Haymarket Park; (10)Torrey Park; (11)Kraft Park; (12)Northridge Park; (13)Dry Comal Trails; (14)Solms Park; and (15)Fredericksburg Sports Complex.

(b)It shall be unlawful for anyone to consume intoxicating liquor or any alcoholic beverage, or possess an open container of intoxicating liquor or alcoholic beverage in all designated parking areas or within 25 feet, either side of any roadway, within the boundaries of the following public parks or city-owned property within the city limits:

(1)Landa Park;

(2)Camp Comal.

City permitted functions are exempt. Fine $500

(NB) Section 86-11. - Noise restrictions in city parks

(Code 1961, § 14A-10.1; Ord. No. 2006-53, § II, 6-26-06)

Unlawful between the hours of 10:00 p.m. and 8:00 a.m.:

(1) Operating of any radio receiving set, tape player, cassette tape player, compact disc player, DVD player, MP3 player, musical instrument, television, phonograph, drum or other machine or device for the production or reproduction of sound.

(2)Operating or permitting to be operated any loudspeaker or sound-amplifying equipment.

It shall be unlawful and considered a misdemeanor offense for any person to play musical instruments or provide live music any time within the boundaries of all city parks within the city limit. City park events exempt.

Violations may result in fines $100-$500

(NB) Section 86-13 – Prohibition of use of foam, polypropylene, expanded polypropylene and polystyrene in certain public waters

(Ord. No. 94-36, ss I)

It is unlawful to use, carry, possess or dispose of any of above referenced on or in the public waters of the portions of Guadalupe River, Lake Dunlap and Comal River with exception of

Foam for boat flotation devices when enclosed within the structural framework of the boat or are fully encapsulated by a water based acrylic coating

Foam minnow buckets which meet or exceed a 2 lb density

Foam dock supports fully encapsulated in a water based latex coating

(NB) Section 86-14 – Coolers that are allowed on rivers, lakes and streams

Cooler size is limited to maximum 16 quarts, must be able to be securely fastened as to prevent contents from falling out cannot be Styrofoam.

Only one cooler per person is permitted on Guadalupe and Comal Rivers.

No containers constructed of Styrofoam or glass are permitted on or in the public waters of Guadalupe and Comal Rivers.

It is unlawful to dispose of any container into the waters or banks of the Guadalupe or Comal River unless it is an authorized and placed trash receptacle.

No open containers with capacity of 5 oz or less permitted on Guadalupe, Comal Rivers and Lake Dunlap.

(NB) Section 86-15 – Use of life jackets on rivers

Young children and individuals who cannot swim or are poor swimmers are recommended to wear life jackets on the Comal River.

Outfitters shall provide information to customers concerning recommendations and requirements for life jackets

(NB) Section 86-14 – Coolers that are allowed on rivers, lakes and streams

Coolers: not to exceed 16 quarts, must be secured by zipper, Velcro snap, mechanical latch or bungee cord to prevent contents from falling out cannot be Styrofoam

Only one cooler per person is permitted on Guadalupe and Comal Rivers

No containers constructed of Styrofoam or glass are permitted on or in the public waters of Guadalupe and Comal Rivers

It is unlawful to dispose of any container into the waters or banks of the Guadalupe or Comal river unless it is an authorized and placed trash receptacle

No open containers with capacity of 5 oz or less permitted on Guadalupe, Comal Rivers and Lake Dunlap

(NB) Section 86-16 – Rivers, flotation devices, Ord. No. 2007-20, ss II

It is unlawful to float the Guadalupe or Comal Rivers except by canoe, kayak, boat or raft (including inflatable vessels), not exceeding 18' length.

Sat, Sun and holidays: Persons floating on such vessels are not permitted to exit 'last tubers' exit adjacent to Garden St. and Union Ave. between May 1 and October 1.

Rafts (non-inflatable structures used to transport 2 or more) are not permitted on the Comal River.

On the Comal River, inflatable devices are limited to 2 person capacity and cannot be greater than 5' diameter (or have any length of the vessel greater than 5').

(NB) Section 86-100 Requirements for rental of water-oriented recreational equipment

(Ord. No. 01-22. ss II)

There shall be a written record of (name, DOB, address) all those renting water-oriented equipment

(NB) Section 86-101 – Wristband; public exits, City Tube Chute, Prince Solms Park, Hinman Island Park.

(Ord. No. 01-22, ssII)

All persons on these city premises in possession of water oriented rented equipment or using the public exits on the Comal or Guadalupe rivers between Apr 1 and Oct 1 shall wear a city approved wristband

(NB) Section 86-117. - Public river exits

(Ord. No. 01-32, § II, 5-14-01; Ord. No. 2008-29, § III, 4-14-08)

Each water oriented recreation equipment rental customer is required to remit $1.25 river management fee to the city for us of any public river exit unless this fee has already been included as a shuttle passenger fee; this river management fee is valid only for the date that it is collected.

(NB) Section 86-118 – Water recreation shuttles

(Ord. No. 01-32, § III, 5-14-01; Ord. No. 2008-29, § IV, 4-14-08)

Water recreation shuttle permit holders collect and remit to the city $1.25 river management fee for each shuttle passenger transported to the city, unless the fee has already been collected as part of the water oriented recreation equipment rental; this fee is valid only for the date it is collected.

(NB) Section 86-119 – Fee payment; reports

(Ord. No. 01-32, § IV, 5-14-01; Ord. No. 2008-29, § V, 4-14-08)

River management fees are required to be recorded and reported to the city monthly between April 1st and November 1st of each year. Reports are to include, numerical counts for each day, total counts for the month and a calculation of fees based on $1.25 per person. This revenue is directly allocated to the city management of the river.

(NB) Section 86-120 – Penalty

River management fees are required to be submitted to the city within 15 days of the following calendar month; the penalty for failure to comply is a suspension of the water recreation shuttle permit and use of the public river exits.

(NB) Sec. 126-334. - Trailers, time limit

(Code 1961, § 23-140)

Trailers or semitrailers may not be parked or left standing on a public street for one continuous period of more than 30 minutes without authority from the chief of police

(NB) Sec. 126-346. - Stopping, standing or parking prohibited in specified places

(Code 1961, § 23-127; Ord. No. 93-15, §§ 1, 2, 4-12-93; Ord. No. 94-9, § I, 2-28-94; Ord. No. 94-15, § I, 4-25-94; Ord. No. 94-34, § I, 8-22-94; Ord. No. 96-22, § I, 4-8-96; Ord. No. 97-40, § I, 11-24-97; Ord. No. 98-19, § I, 7-27-98; Ord. No. 98-28, § I, 10-26-98; Ord. No. 99-10, § I, 2-22-99; Ord. No. 99-27, § I, 4-26-99; Ord. No. 99-40, § 6-28-99; Ord. No. 99-45, § I, 7-12-99; Ord. No. 99-68, § I, 10-25-99; Ord. No. 00-09, § I, 2-28-00; Ord. No. 2000-44, § I, 11-13-00; Ord. No 2000-54, § I, 11-13-00; Ord. No. 01-25, § I, 4-9-01; Ord. No. 2001-39, § I, 8-13-01; Ord. No. 2001-62, § I, 12-10-01; Ord. No. 2002-13, § 1, 4-8-02; Ord. No. 2002-47, § I, 12-9-02; Ord. No. 2003-37, § I, 5-27-03; Ord. No. 2003-69, § I, 10-13-03; Ord. No. 2004-18, § I, 3-8-04; Ord. No. 2004-36, § I, 5-10-04; Ord. No. 2004-41, § I, 6-14-04; Ord. No. 2005-51, § I, 6-13-05; Ord. No. 2005-83, § I, 11-28-05; Ord. No. 2005-84, § I, 11-28-05; Ord. No. 2006-04, § I, 1-23-06; Ord. No. 2006-19, § I, 2-27-06; Ord. No. 2006-27, § I, 4-10-06; Ord. No. 2006-39, § I, 5-8-06; Ord. No. 2007-40, § I, 5-29-07; Ord. No. 2008-14, § I, 1-28-08; Ord. No. 2008-25, § I, 3-24-08; Ord. No. 2008-72, § I, 11-10-08; Ord. No. 2008-75, § I, 12-8-08; Ord. No. 2009-06, § I, 2-9-09; Ord. No. 2009-42, § I, 7-27-09)

Pedestrians shall not stand nor stop in vehicular areas that will put them in conflict with other traffic.

There is no parking permitted on many of the streets and intersections near and surrounding public access points to the river: streets surrounding Landa Park, Hinman Island, Prince Solms Park and the public tuber exits at Garden Street and Union Avenue. Some locations are restrictive only from 8am to 8pm and from May 1st to September 15th. Other locations are restrictive between 7am and 8pm weekends and holidays from Easter weekend through to Labor Day weekend.

(NB) Section 126-368. - Fifteen-minute parking on Lincoln Street

(Code 1961, § 23-136.1; Ord. No. 2000-46, § I, 11-27-00; Ord. No. 01-25, § III, 4-9-01; Ord. No. 2001-39, § II, 8-13-01; Ord. No. 2003-32, § I, 5-12-03; Ord. No. 2004-39, § I, 6-14-04; Ord. No. 2006-92, § I, 9-25-06; Ord. No. 2009-05, § I, 2-9-09; Ord. No. 2009-42, § I, 7-27-09)

No parking is permitted on the southeast curb of Lincoln Street at Union Ave. for a distance of 710 feet west.

No parking for more than 15 minutes is permitted on the north side of Lincoln from 600 feet west of Union for a distance of 100 feet between 8am and 8pm weekends and holidays from Memorial Day through Labor Day

On certain parts of Liebsher Drive, parking is restricted to water recreation shuttle vehicles (by permit) from 7am – 8pm April 1st to October 31st; these areas are loading zones for such permitted vehicles and are restricted to 15 minutes.

A 15 minutes loading zone is designated for water recreation shuttles on parts of Lincoln Street near Union Avenue, and on Union Avenue near Lincoln Street.

There is no parking on Common Street near Liberty Avenue other than for water recreation shuttles for the purposes of loading and unloading.

Same for Liberty Avenue near the near W. South Street.

(NB) Part II

Chapter 138 – Vehicles for Hire

Article VI – Water Recreation Shuttle Services

Commercial shuttle operators used for water recreation require an annual permit from the city. The number of seats permitted for the Comal River is limited to 1,205 annually, whereas it is unlimited for the Guadalupe River.

By Ordinance, shuttle entry and exit points for the Comal River are restricted to city property: Shuttle Zone at Prince Solms Park Garden Street and Union Avenue tubing exits

(NB) Section 138-2 – Annual permit required

(Ord. No. 01-10, § I, 2-12-01)

An operating permit from the city authorizing transport of passengers for compensation from a point within the city is required.

(NB) Section 138-3 – Transferability of operating permit

(Ord. No. 01-10, § I, 2-12-01)

Operating permits are not transferrable unless approved in writing by the city manager or his designee. Transfers may be made to different operators after all ordinance requirements are met and a fee of $75 collected by the city secretary for administering permit records.

(NB) Section 138-4. - Application for operating permit

(Ord. No. 01-10, § I, 2-12-01)

Applications for a taxicab permit are filed with the city secretary and must be filed before December of each calendar year with the following information: owner(s), address, telephone, make, hp, vehicle identification number, seating capacity, license number of every vehicle to be used for service, evidence of insurance, names, addresses, dates of birth and DL#'s of each driver operating vehicles for the company, schedule of rates, statement that no felony convictions or other offense involving moral turpitude exist which adversely affects the applicant's ability to provide safe and reliable passenger transportation, history of any revocation or suspension of like permits. A fee of $75 plus $10 for each vehicle is collected.

(NB) Section 138-5. - Issuance of permit

(Ord. No. 01-10, § I, 2-12-01)

Upon written proof of insurance and determination all documents for application are met, a permit is issued for period of January 1 to December 31

(NB) Section 138-167 - permit

(Code 1961, ss 25-71; Ord. No. 01-17, ss I, Ord. No. 2005-12, ss I, Ord. No. 2005-30, ss1, Ord. No. 2008-35, ss II)

Guadalupe and Comal River permits are required for operating water recreation vehicles

Limited shuttle zones for Guadalupe River

Guadalupe River Shuttle seats are annually unlimited

Limit of 1,205 Shuttle seats permitted annually for Comal River

(NB) Section 138-170 – shuttle entry/exit points

(Code 1961, ss 25-74; Ord. No. 01-22, ss IX; Ord. No. 01-32, ss VI; Ord. No. 2005-12, ss I; Ord. No. 2005-30, ss I; Ord. No. 2008-29, ss VII)

Comal River entry and exit points on **city property:**

Shuttle zone at Prince Solms Park

Union Street tubing exit

Guadalupe River exit point on **city property:**

Public river exit at Cypress Bend Park

(NB) Part II Chapter 142 – Waterways

(NB) Section 142-2 – powers of city concerning water bodies; responsibilities of property owners

(Code 1961, ss4-4, Ord. No. 01-24,ss I)

the city shall have the power to alter or improve any water body within its limits; no owner of property fronting any river within city limits shall alter any

body of water without first obtaining and permit and without the approval of the city engineer.

(NB) Section 142-3 – Comal River; Guadalupe River

(Code 1961, ss4-2,4-2.1(a),(b))

Rafts, boats or floats are not permitted beyond speed limit of 5 mph on any portion of the Comal River and on the Guadalupe River: between Textile Mill Dam and where the G River meets the city limits (excludes law enforcement and public safety agencies)

Horsepower of motor; exception

On Comal River: no motors rated in excess of 10 hp

This does not apply to any existing franchise, concession, lease or license to operate any boat, float or raft on the Comal.

(NB) Section 142-4 – Methods of fishing

(Code 1961,ss4-3)

Fishing is lawful only by pole & line, casting rod and reel, artificial bait, trotline or set line; seines may be permitted in accordance with state laws or parks and wildlife commission regulations

(NB) Section 142-5Control of aquatic activities on Mill Race (Comal Channel)

(Code 1961,ss 4-5)

It is an offense to enter or engage in any aquatic activity between Landa Park Lake and the confluence with the Comal River (dry Comal Crk)

It is unlawful to launch in water vessel or flotation device on any portion of the same

This does not apply to law enforcement and public safety agencies

(NB) Section 144-5.12 Bowling alleys, dance halls, shooting galleries, shooting ranges, skating rinks, commercial or public tuber entrance or take out facilities, and similar commercial recreation buildings or activities

(Ord. No. 2006-99, ss 1 (exh. A))

No commercial or public tuber entrance or take out facility shall be developed without a special use permit

B. City of San Marcos

Recreation activity on the San Marcos River predominantly occurs along city owned parkland, however, there is also privately owned property where recreation is permitted within their zoning so long as development of recreation within the floodplain is in accordance with the municipal code. These development ordinances, and those that relate directly to activities on and in the water aim to protect the waterways (biological diversity, natural and traditional character) and water quality are reported. All these related ordinances found for the City of San Marcos are reported.

Ordinances that pertain specifically to recreation activities include:

- ordinances pertaining to parks adjacent the San Marcos River: curfew, hunting, fishing, camping, disruptive conduct, restriction of motorized vehicles on trails, possession of alcohol, horseback riding restrictions
-

Ordinances that pertain specifically to activities of the river include:

- prohibition of glass
- Release of any organisms into the waters
- Washing of bodies, pets and personal items are prohibited
- Restriction of activities in Spring Lake
- Prohibition of speargun use
- Jumping into the river from bridges is prohibited
- Restrictions regarding operation of river shuttles: including parking allowances and franchise application detailing routes, stops, seating capacity, parking allowances, documentation of revenue

<u>(SM) Chapter 58 Public Facilities, Parks and Recreation</u>
<u>Article 3 Water Activities</u>

<u>(SM) Section 58.029 Night curfew in city parks</u>
11pm – 6am

<u>(SM) Section 58.030 Disruptive conduct</u>
It is unlawful to remove, destroy, deface, tamper with or disturb any artifact, or cultural feature to take, remove, disturb any rock, soil, gem mineral except by permit.
It is unlawful to mutilate, injure, destroy, pick, cut or remove and any plant life except by permit

(SM) Section 58.032 Motor vehicles

It is unlawful to drive a motor vehicle in a city park area that is not an improved roadway or park in area not designate for such

No motors on trails or bike paths

Abandoning, storing or leaving a vehicle, boat, trailer or other personal property beyond park facility hours if not permitted

(SM) Section 58.033 Possession of alcoholic beverages in certain parks

It is unlawful to possess any alcoholic beverage within 500' of a softball or baseball field, within a children's park, within a fenced area surrounding a city swimming pool

(SM) Section 58.034 Glass beverage containers are prohibited

In any city park

In or on the waters of the San Marcos River

(SM) Section 58.037 Hunting, fishing and camping in city parks

It is unlawful to hunt, harm, harass, disturb trap, confine, catch, possess or remove wildlife from or in city parks

To release any fish, bait-fish, plant or other aquatic organism into the waters of a city park

Fish, grapple or catch and release in an area where fishing is prohibited by sign

No fires unless designated otherwise

No wood gathering

No camping unless otherwise designated

No washing of bodies, clothing, pets or other personal belongings in drinking fountains, pools, sprinklers, reservoirs, lake, river or any other water body in a park

No depositing wastewater, sewage or effluent from sinks, toilets or other plumbing fixtures onto grounds or waters of a city park

(SM) Section 58.040 animals

No riding, driving, leading or saddling of horses without a permit in a city park unless designated a horseback riding trail

(SM) Section 58.067 Using public waters of Spring Lake

Restrict uses to:

Sightseeing, excursion boats, archaeological and scientific projects

(SM) Section 58.068 Possessing of or shooting spearguns in San Marcos River
It is unlawful to possess or shoot a speargun while in or upon the San Marcos River

(SM) Section 58.069 Activities on bridges crossing San Marcos River
It is unlawful to jump or dive into San Marcos River from any bridge crossing the river

(SM) Section 58.072 Bridge construction over river; prohibited entry ; warning signs
During periods of construction over the San Marcos River, city manager may prohibit entry of persons within or along the San Marcos River into the areas, unless contracted to work in the area

(SM) Chapter 90
Article 5 River Shuttles
Division 1. Generally

(SM) Section 90.3903 Restrictions to operation
Written approval of routes and stops, dates and times from city manager ('s office)

(SM) Section 90.310 Franchise required and application
Application to include seating capacity, maps detailing routes, dates of operation, parking allowances for customers, statement of gross revenues generated from river related activities for the previous year, a comprehensive description of type and nature of business

(SM) Section 90.313 Fees
Annual franchise fee valid May 1 – Apr 30

(SM) Chapter 5 – Environmental Regulations
(SM) Section 5.1.1.2 Erosion Control Standards
Preserve natural drainage patterns whenever possible
Limit loss of pervious character of soil
Utilize open surface drainage through grass lined swales
Located stormwater runoff to avoid sinkholes, fractures, faults
Channelizing stormwater permitted by Engineering Director
Dissipate point discharges in sheet flow
Minimize erosion impacts of runoff and control contaminants with sediment control devices

Vegetate detention ponds
Provide internal rock berm baffles in ponds
Trap floating matter in ponds
Provide maintenance access to ponds

(SM) Section 5.1.1.3 Runoff Attenuation
Utilize strategies for energy dissipation, sediment and pollutant traps
Detention required to maintain runoff rates at pre-development levels

(SM) Section 5.1.1.4 Wastewater collection and Disposal
Not permitted in water quality corridors: septic tanks, holding tanks, evapotranspiration units, cesspools or other sewage disposal systems

(SM) Section 5.1.1.5 Impervious Cover Limitations
A percentage is permitted and varies with grade/slope of hillside

(SM) Section 5.1.1.6 Street and Drainage Improvements
Must be designed to 25 year frequency rainfall
Drainage improvement costs at sole responsibility of property owner
Drainage improvements serving multiple developments shall be dedicated to the public
(in an easement that contains all storm water flows to the limits of the 100 year floodplain; drainage improvements serving streets or other public property may dedicated in a public street ROW rather than a drainage easement); Easements must be 25'5" in width for open drainage systems or 15' width for enclosed
Maintenance of drainage easement corresponds with ownership

(SM) Section 5.1.1.7 BMP Improvements Maintenance Criteria
Holder of an approved watershed protection plan is required to maintain any required permanent BMP's after construction; submit an annual maintenance report to Engineering Director

(SM) Section 5.1.1.8 Continuing Responsibilities
Passes on with any transfer of property

(SM) Div.2 Stream and River Corridor Water Quality Standards

(SM) Section 5.1.2.1 Purpose, Applicability and Exceptions
To protect water quality and prevent flood damage, applies to SMRC and Edwards Aquifer recharge zone, exception is a drainage basin of less than 120 acres upstream from development

(SM) Section 5.1.2.2 Water Quality Zones

FEMA mapped waterway & for each stream, river or waterway in SMRC and Edwards Aquifer Recharge zone: 50' extending out from each side of CL of minor waterway, 100' extending out on each side of the CL of intermediate waterway or 100 yr flooplain resulting from full developed conditions in the watershed
Required when a plat is required for development

(SM) Section 5.1.2.3 Buffer zones

= 100' width measured from the outer boundary of the water quality zone, buffer and WQZ not to exceed width of 100 yr floodplain

(SM) Section 5.1.2.4 Impervious Cover Limitations

Not permitted in a water quality zone
Permitted within a buffer zone, dependent on gradients
Exceptions permitted where access (vehicular) across waterway is limited

(SM) Section 5.1.2.5 Clustering and Development Transfers

Clustering of residential density and impervious cover allowed in accordance with Table 5.1.16.1, when approved under a cluster development plan

(SM) Section 5.1.2.6 Performance Standards in Water Quality and Buffer Zones

Shall be stabilized with 70% vegetation/ground cover; areas disturbed shall be restored
Sheet flow point discharges
No fertilizers nor pesticides permitted within water quality zones
Limitations on excavation and fill (see Article 4, Div. 2 Chapt 5)

(SM) Art 3: Development Related to the San Marcos River Corridor
Div. 1: General Provisions

(SM) Section 5.3.1.1

(a)(6) corridor is facing potential for intense development
(10) city Mgr has directed staff to conduct a study of characteristics of the corridor, adverse impact of development activities and how to mitigate
(b) (1) prevent stripping of native vegetation
(2) prevent soil erosion and sedimentation
(3) prevent increase in stormwater runoff
(4) prevent or reduce pollution concentrations
(5) protect biological integrity of SMR habitat
(6) preserve natural and traditional character of the land and waterway

Map of areas located at City Clerk's Office
(d) (1) additional requirements of this article shall not apply to SF detached residence on a properly platted subdivision lot that has been properly platted before the effective date of the ordinance

(SM) Div.2 Development Standards

(SM) Section 5.3.2.1 Ecological Preservation
Restoration of disturbed areas containing native plants shall be approved by Engineering Director.
Stabilization of eroding creek banks is permitted to protect threatened property, as approved by federal and state agencies and the Engineering Director.
Excavating or filling permitted as necessary for structural engineering for a building or structure.

(SM) Section 5.3.2.2 Water Quality Standards
Impervious cover not permitted except for trails for walking, running and non-motorized biking or for access to another public road (within distance limitations of other crossings)
Disposal of contaminants must be approved by Engineering Director and in accordance with the Contaminant Removal Guidelines of the City
Input and release from water quality basins shall utilize grass lined swales and /or overland dispersion measures.

(SM) Section 5.3.2.3 Overland Flow and Natural Drainage
Limit to prevent erosion and attenuate impact of contaminants transported by flow
Open surface drainage via grass lined swales preferred (leave in undeveloped or natural state for runoff to occur); use of streets as central drainage network is prohibited
Storm Sewers
Enclosed and impervious channels by permission of Engineering Director

(SM) Section 5.3.2.4 Velocity Attenuation and Surface Drainage Channels
Channelization of San Marcos and Blanco Rivers and any tributary of the SMR within the SMRC is prohibited

(SM) Section 5.3.2.5 Creation of Impervious Cover
Permitted outside water quality zone, % varies with various slopes

III. GIS DATABASE PREPARATION

Section 1. Data Collection

Recreation use data provided during stakeholder interviews, as described in Section IV, was collected and mapped for the San Marcos River in San Marcos, Texas and the Comal River in New Braunfels, Texas. The San Marcos River study area extends from Spring Lake downstream to the San Marcos City Limit. The Comal River Study area extends from Landa Park to the confluence with the Guadalupe River.

The following data sets were obtained for use in delineation of recreation uses on the Comal River and the San Marcos River. Halff coordinated with the Capital Area Council of Governments (CAPCOG), the City of San Marcos, the City of New Braunfels, Texas Water Development Board (TWDB), Texas Commission on Environmental Quality (TCEQ), and the United States Geological Survey (USGS) to gather available data . The following is a summary of data obtained for the purpose of executing this study effort.

- CAPCOG Aerial Imagery, 0.5 meter resolution, February 2008
- National Hydrography Dataset (NHD) Streams and water bodies, USGS
- San Marcos City Parks, City of San Marcos
- TNRIS Stratmap (TWDB) Parks, Roads, and City Limits
- TCEQ Clean Rivers Water Quality Stations

The Comal County Regional Habitat Conservation Plan Environmental Impact Statement (Draft) was also referenced to delineate areas of potential wildlife habitat of protected species within the study area.

In addition to the basemap data collected as described above, Halff Associates conducted two days of stakeholder meetings to collect recreation use information as discussed in Section I, IV, V, and VI. Recreational activities identified in these meetings are listed in Table 4.

Table 4
Reported Recreation Activity
Swimming
Picnicking
Paddle Boats
Swift Water Rescue Training
Tubing
Fishing
Wading
Rope Swing
Lounging
Playing
RV Campground
Snorkeling
SCUBA
Kayak
Canoe

A limited amount of temporal use data was provided during stakeholder interviews, as described in Section IV. The temporal use data that was collected was presented in terms of intensity, not numerical values. Based upon the data gathered during stakeholder interviews, temporal use data was grouped into four categories of intensity: high, medium, low, and unknown to best describe the intensity of use occurring at the recreation area. Based on the limited data available at this time, no temporal patterns of use intensity were indentified. However, the GIS geodatabase attribute table was prepared such that any future data may be added to the database and analyzed. Entrance and exit locations were also identified and delineated from interviews and surveys. Locations shown are those described by stakeholders during interviews and do not necessarily represent all points of access. Critical habitat areas for the species, as discussed in Section VI, have also been delineated. Tubing, kayak, canoe, and paddleboat vendors were identified from interviews, surveys, and internet data searches. Preparation of the data is discussed in Section 2.

Section 2. GIS Database Preparation

Recreational areas were delineated using ArcGIS version 9.3.1.
A file geodatabase feature class was set up with the attribute fields listed in Table 5.

Table 5		
Attributes – Recreation Area		
Field Name	**Data Type**	**Description**
OBJECTID	Object ID	Unique id
SHAPE	Geometry	Type of feature (Polygon, point, etc.)
LOCATION_ID	Long Integer	Identifier for entries using common SHAPE.
ACTIVITY	Text	Recreation activity reported for the area
INTENSITY	Text	Intensity of recreation activity reported for area
ENTRY_EXIT	Text	Identifies if area is reported as a specific entry/exit area.
NOTE	Text	Additional notes if applicable
SHAPE_Length	Double	Perimeter length of area (feet)
SHAPE_Area	Double	Area of recreation area (square feet)
Public_or_Private	Text	Identifies if area is reportedc as public or private access.

Metadata for the Recreation_Area feature is summarized below:
File Geodatabase: EARIP_Recreation.gdb
Feature Dataset: EARIP_Recreation
Feature: Recreation_Area

-+Coordinate System: NAD 1983 State Plane Texas South Central 4204
Projection: Lambert Conformal Conical
Geographic Coordinate System: GCS North American 1983
Horizontal Datum: North American 1983
The recreation areas were delineated for each type of use reported. The reported recreation areas can be queried and symbolized by activity. Areas reported as specific entry and exit areas are identified in the ENTRY_EXIT field. Additional fields were also included to identify the intensity of use and if the area is for public or private use. These attributes can be updated if information becomes available.

Section 3. Associated Exhibits

The attached exhibits illustrate recreation areas and areas of potential wildlife habitat of protected species. Table 6 summarizes these exhibits. They are grouped by city and further arranged by type of area.

Table 6		
Exhibit Index		
Exhibit #	**Title**	**Description**
New Braunfels Recreation Areas		
NB.1	Tubing	Identifies areas where tubing occurs in the Comal River.
NB.2	Paddle Boats	Identifies areas where paddle boats are used in the Comal River.
NB.3	Picnic Areas, RV Campground	Identifies areas along the banks of the Comal River where picnic areas and RV Campgrounds occur.
NB.4	Swift Water Rescue Training	Identifies the area where swift water rescue training occurs in the Comal River.
NB.5	Swimming	Identifies areas in the Comal River where swimming occurs.

Table 6 continued

NB.6	Tube, Paddle Boat, Kayak, Canoe Rentals	Illustrates the locations of rentals categorized by tube rental and paddle boat, kayak, and canoe rentals near the Comal River in the City of New Braunfels.
NB.7	Fishing	Identifies areas of fishing along the banks and in the Comal River
NB.8	Wading, Lounging, Playing, Rope Swing	Identifies areas where wading occur in the Comal River and the locations of lounging, playing, and rope swing use occur along the banks.
NB.9	All Uses	Summarizes all of the identified recreation uses along and in the Comal River, all entry/exit areas, and the storm water quality stations.
New Braunfels Potential Wildlife Habitat Areas		
NB.10	Comal Springs Dryopid Beetle, Peck's Cave Amphipod	Illustrates areas of potential wildlife habitat.
NB.11	Comal Springs Riffle Beetle	Illustrates areas of potential wildlife habitat.
NB.12	Fountain Darter	Illustrates areas of potential wildlife habitat.

San Marcos Recreation Areas		
Exhibit #	**Title**	**Description**
SM.1	Dog Parks Tubing	Identifies areas where tubing occurs in the San Marcos River.
SM.2	Fishing	Identifies areas of fishing along the banks and in the San Marcos River.
SM.3	Kayaking, Canoeing	Identifies areas where kayaking and canoeing occur in the San Marcos River.
SM.4	Picnic Area	Identifies areas along the banks of the San Marcos River where picnicking occurs.

Table 6 continued

SM.5	Swimming	Identifies areas in the San Marcos River where swimming occurs.
SM.6	Tube, Kayak, Canoe Rental Locations	Illustrates the locations of rentals categorized by tube rental and kayak and canoe rentals near the San Marcos River in the City of San Marcos.
SM.7	Tubing Dog Parks	Illustrates three locations where dogs are allowed.
SM.8	Wading, Lounging	Identifies areas where wading occur in the San Marcos River and the location of lounging along the banks.
SM.9	All Uses	Summarizes all of the identified recreation uses along and in the San Marcos River, all entry/exit areas, and the storm water quality stations.
San Marcos Potential Wildlife Habitat Areas		
SM.10	Fountain Darter	Illustrates areas of potential wildlife habitat.
SM.11	San Marcos Gambusia	Illustrates areas of potential wildlife habitat.
SM.12	San Marcos Salamander, Texas Blind Salamander, Comal Springs Riffle Beetle	Illustrates areas of potential wildlife habitat.
SM.13	Texas Wild-rice	Illustrates areas of potential wildlife habitat.

IV. STAKEHOLDER INTERVIEWS

Stakeholder interviews were conducted June 29th and 30th 2010. The lists of interviewees were provided by EARIP representatives and city staff in both cities. A questionnaire was provided to all individuals in advance of the interviews. Stakeholders from San Marcos and New Braunfels were comprised of city representatives, river committee members, active river users and commercial operators.

Twenty two (22) stakeholders from San Marcos were sent questionnaires and invited to be interviewed. Eleven responded, and ten (10) attended the interview and answered the questionnaire. One(1) submitted the questionnaire but did not attend the interview.

Thirteen (13) stakeholders from New Braunfels were invited to be interviewed and sent a questionnaire. Nine (9) responded and seven (7) attended the interview and answered the questionnaire. Two (2) submitted the questionnaire but did not attend the interview.

Interviews were conducted by two members of the Halff team and interviewees were scheduled individually or as part of group of not more than three (3) at 30 minute intervals. Questionnaires and maps were made available at the interviews and participants were given the option to respond to the questionnaire during the interview or provide them via email following our dates. The list of questions not only aimed to obtain information directly regarding recreation activity but also peripherally and indirectly to identify potential impacts recreation activities have on the cities, be they economic, operational or physical. Not all individuals provided an answer to every question and answers provided may be based on the perceptioins of the stakeholder and not necessarily factual data. (See Appendices B and C for specific responses)

Responses common to both cities include:

- Peak use occurs between Memorial Day weekend and Labor Day
- During this period, weekends and holiday long weekends have the highest use numbers
- occur between 11am and 4 pm
- The most highly used areas of these springs are along city owned parks that run adjacent the rivers.
- During high use periods, parking is an issue for both these cities
- and the current rate of use of these rivers is having a degrading effect on these surrounding parks
- Litter is a constant maintenance issue

- Despite the crowds and trash, these rivers are highly valued for the economic opportunities, and social as well as health benefits they provide to their respective communities.

A. New Braunfels

Stakeholders from New Braunfels hold their rivers in high regard for the quality of life they provide and as an economic resource. Based on a 2009 economic study commissioned by the City of New Braunfels, tourism contributed $469.7 million in revenue for the area.

There is no definitive study or tracking methodology in place to determine how many people use the river as a recreational resource as it is an open source of recreation without fee. While one respondent perceived between 3000-5000 people per typical weekend during the peak season used the river, another thought there might be three times this many.

Prime activities are tubing and picnicking in the peak season. Hinman Island and the Tube Chute at Prince Solms Park seem to draw the most crowds as they are considered both launch and exit points, but also the surrounding parks offer plenty of free space for picnickers.

Although there is a perception that the parks are overcrowded and the amount of users are negatively impacting the condition of the parks, there is also the feeling that there is a reasonable amount of control on number of (tube) users on the river, as it is monitored by the river manager and commercial (tube) outfitters, who have learned to work together to prevent congestion on the river. The river manager has the authority to prohibit use of the river if he feels there is such numbers to cause safety concerns.

The use of water recreation shuttles is common in New Braunfels. Stakeholders estimated that 50-70% of all tubers use this service. Shuttles provide service to satellite parking lots as well as tuber pick up and drop off points along the river. In the off season, the river is used for swift water rescue training by fire departments from all over Central Texas and beyond.

New Braunfels has ordinances in place to minimize the amount of trash, reduce potential for misconduct on the river as well as protect the users of the river, but some offer that though these are admirable, people find a way around every rule and that there is inadequate enforcement to enforce the rules that exist. The issue of alcohol consumption is an ongoing contentious issue. Alcohol is not permitted to be consumed in public parks, however, once in the water,

standing or floating, consumption cannot be regulated as the river is within the State's jurisdiction. The consumption of alcohol is often enjoyed with recreation on the river; however, many stakeholders commented that they felt it also contributed to altercations and unfavorable public behavior.

Although not ranked by priority, the following table illustrates number of respondents who identified specific issues.

Table 7	
New Braunfels Comal Springs River Stakeholder Perceived Issues	**of 8 respondents:**
Trash / Litter	6
River is Overregulated	4
Behavior	4
Adequate Enforcement (Non-issue)	4
Alcohol	3
Wear on the Landscape / Deterioration of Environment	2
Crowding	1

New Braunfels Stakeholder Interview Responses
June 30, 2010

1. What are the peak times of recreation use: days, seasons, months, holidays, hours?

- *Memorial Day – Labor Day*
- *Weekends / Long weekends, more Saturday than Sunday*
- *Afternoon hours (11am-4pm)*

a) How many people are using the river at these times?

- *Comal: 3,000-5,000 (per typ. Peak season weekend)*
- *Uknown because there is no entry fee*
- *Estimate: 187,000/yr on both rivers over approx. 110 days = approx 1700 people/day*

b) What areas of the river see the highest amount of use?

- *@ Tube Chute*
- *Hinman Island to Last Tubers Exit (@ Union)*

2. Should there be restrictions on times of use or hours of use?

- *Yes, to daylight hours only, as safety factor*

3. Does use have any correlation with water flow or river levels?

- *No, Comal springs brings constant flow*
- *Perception of flooding events around central Texas reduces #'s*

4. Can recreational activities on the river continue at current levels of activity?

- *Mixed response, see below*

a) Why or why not?

- *Yes because recreational outfitters are active about controlling their rate of users*
- *Yes, because habitats are surviving and thriving*
- *No because parks where people access are free and are over-capacity now*

5. If arriving at the river by vehicle, where do people park (private lots, owned by recreation outfitters or other private lots? Street? Public park?).

- *City: Public parks, public owned lots, streets*
- *Private businesses (satellite lots)*

a) Do the majority of recreational users use commercial shuttle buses and are those desirable?

- *50% -70% of tubers use shuttle*

b) How many people (or what percentage of people) arrive at river tubing/raft launch locations by private vehicle versus shuttle bus?

- *60% private*
- *40% shuttle*

c) **Is one method of arrival preferable over the other?**
    - *Shuttle is preferred*

6. **Do most users access / launch from public/city owned property or private property?**
    - *Public:City Parks*

    a) **Please list all known points of access and launching.**
        - *Hinman Island*
        - *Tubers Chute (Prince Solms)*
        - *Wurst Fest (Landa Falls)*
        - *Texas Tubes*
        - *Resort properties on the Comal*

7. **Do most users exit the river at public/city owned property or private property?**
    - *70% exit on public*

    a) **Please list all known points of exit.**
        - *Last tubers/public exit (@Union)*
        - *Garden St.*
        - *Resort Properties*
        - *Rock'n R*

8. **What recreational activities other than tubing, rafting and fishing occur along the river?**
    - *Rope swinging*
    - *Camping*
    - *scuba*
    - *Wading/water play /water lounging/ drinking/sunbathing*
    - *grilling/picnicking*
    - *swimming*
    - *fire dept. swift water rescue training*
    - *nefarious activity*

9. **What specific locations are most frequented by these other users?**
    - *Tube Chute*
    - *Hinman Island*
    - *Landa Park*
    - *Wurstfest*

10. **What are the positive aspects of recreation on the river?**
    - *Economic: tourism $, Jobs for young people*
    - *Education about the river*
    - *Outdoor enjoyment: mental, physical health*

11. What are the negative aspects of recreation on the river?

- *Trash*
- *Negative behavior (3-5% of users cause trouble, of which half are local)*
- *Wear on the landscape*

12. How important are river-based recreational activities to the local economy?

- *Extremely as it is the 'brand' of New Braunfels; impacts everything, not just water related activities*

a) What are its contributions: i.e. sales tax, property taxes, other taxes/fees, spin-off businesses (related revenue sources for the city)?

- *Employment & wages*
- *City & other local taxes from hospitality industry*

b) How much does recreation activity contribute to the local economy? (in $ or % of city revenue)

- *$12 million annually in tax revenue (response closely approximated what was reported by Impact Data Source, 2009)*
- *$469.7 million in 2009 (response closely approximated what was reported by Impact Data Source, 2009)*

13. What is your perception of the level of enforcement on the river? Too much, not enough? Why?

- *Good, sometimes excessive*

14. Is the amount of regulation with regards to activities on the river acceptable? Should there be more? Or less?

- *Less*

a) Are there certain things that should be regulated that aren't currently?

- *Alcohol on the river*
- *Access points aren't managed/controlled*
- *Pop up tents and crowding at access points*

b) Are there certain things that are currently regulated that shouldn't be?

- *No other than: number of coolers per tube and size of ice cooler*

15. What is your perception of the level of maintenance? Too much, not enough? Why?

- *Ok, Acceptable*

16. Are there operational issues with regards to emergency flood situations?

- *None*

Additional Notes:

- *Tubers: 50% rent, 50% bring their own*
- *The amount of negative behavior associated with river activity is within normal range of any 'open source, no price point activity'; placing a $ value on the activity would make a difference*
- *NBU has a wastewater facility that has flooded 3x in the last 12 years: contamination downhill, especially @ Lake Dunlap*
- *A study done in 2008(interviewee did not specify) showed overall positive economic impact of recreation but not as great as thought (see page 63: average daily expenditure per individual)*
- *Regulating alcohol is an ongoing contentious issue*

B. San Marcos

The San Marcos River, as compared to the Comal, has a greater variety of uses in specific zones of the river. Spring Lake, near the San Marcos springs is an area with restricted recreation activities: sightseeing (glass bottom boats), and scuba diving and snorkeling for the purposes of research.. Down river has much greater activity with tubing and swimming as the primary day use activities and canoeing and kayaking as the night time activities. It is informally agreed upon that the kayak / canoe community uses the river during night time hours, in addition to the off-season.

It is unknown as to how many total users there are of the San Marcos River at any given time. Data from year 2000 reported 500,000 people visit the river each year (Greater San Marcos Economic Development Council 2000); it is also reported that there is approximately 2500 kayaks per year that travel the river and that the only tube rental outfitter in town reported to have rented out 29,829 tubes in the year 2005, which estimated to account only for about 50-60% of tubers. These numbers do not account for all others that swim, snorkel, dive, picnic, wade, play, lounge or bring their dogs.

The city has restrictions on hours of use (nighttime curfew: 11pm-6am) for their parks, however, kayakers and canoeists are tolerated during these hours. When asked if there should be restrictions on hours of use of the river, most of those that responded said no while one responded that the hours should be restricted to 6pm when the less desirable users seem to arrive.

Recreation seekers in San Marcos typically arrive by private vehicle and though there is a shuttle in place to transport those who rent tubes back upstream, most people tubing will use the park trails (walk) to return upriver, which is unlike those tubing the Comal River in New Braunfels. It is important to note also that the tube trip in San Marcos is approximately 45 minutes as compared to 2 to 2-1/2 hours on the Comal River in New Braunfels.

Aside from the already stated positive and negative aspects of recreation on the San Marcos River, there is perceived gang activity, social disorder, degradation of the river banks and bed.

It is undetermined as to how much recreation on the river contributes to the local economy but it is an attraction to visitors whose primary focus may not necessarily be recreation on the river. Regardless, visitors contribute to the local economy via patronizing local retail and hospitality services and businesses.

Although the level of law enforcement didn't seem to be an issue, it was reported that there is only one park ranger on staff and part time staff is added

to patrol the parks during peak times. With the growing population and popularity of the river, more law enforcement is welcomed.

San Marcos does not have restrictions regarding litter (food/beverage packaging) type, cooler size, or alcohol consumption in their parks though it was reported that some individuals felt alcohol should be banned and that there should be stricter rules regarding litter including prohibiting Styrofoam containers. In general, it was expressed that maintenance-wise, it was challenging to keep up with the amount of trash generated at these park sites. There is perception that the growing popularity of the river is degrading the surrounding parks and that there is conflicted sentiment about the lack of dredging of the river bed, to remove the wild rice, as once was the practice, with some users perceiving the water not as clean as it once was.

Although not ranked by priority, the following table illustrates number of respondents who identified specific issues.

Table 8

San Marcos Springs River Stakeholder Perceived Issues	of 11 respondents:
Trash / Litter	10
Traffic / Parking	9
Crowding	7
Alcohol	6
Behavior	4
Noise	4
Wear on the Landscape / Deterioration of Environment	3
Dog Feces	3
Information Lacking regarding Natural River & Ecosystem	3
Not Enough Enforcement	3

San Marcos Stakeholder Interview Responses

June 29, 2010

1. **What are the peak times of recreation use: days, seasons, months, holidays, hours?**
   - *Memorial Day to Labor Day*
   - *Weekends/Long weekends*
   - *11am-4pm*
   - **a) How many people are using the river at these times?**
     - *Approx 2500 kayaks/ year*
     - *May-Sept 2005: tube rentals: 29,829 (estimate to represent only about 50% of tube users)*
     - *Data from 2000 (Greater San Marcos Economic Development Council): 500,000 visitors/yr*
   - **b) What areas of the river see the highest amount of use?**
     - *University & City parks on the river*

2. **Should there be restrictions on times of use or hours of use?**
   - *No*

3. **Does use have any correlation with water flow or river levels?**
   - *No, because the spring is a constant flow*

4. **Can recreational activities on the river continue at current levels of activity?**
   - *No*
   - *Increasing levels each year but somewhat capped by having on 1 tube rental outfitter*
   - **a) Why or why not?**
     - *No due to degradation to water quality and parks*
     - *Yes, if it is possible to create a culture of respect and stewardship for the river*

5. **If arriving at the river by vehicle, where do people park (private lots, owned by recreation outfitters or other private lots? Street? Public park?).**
   - *There is current exploration on utilizing a shuttle to/from remote (private) parking lots*
   - *Public: streets, parks, city owned lots*
   - *Private: illegally on TSU campus*
   - **a) Do the majority of recreational users use commercial shuttle buses and are those desirable?**
     - *Most people walk the park trails for tubing*
     - *Most arrive to/nr river by private vehicle*
   - **b) How many people (or what percentage of people) arrive at river tubing/raft launch locations by private vehicle versus shuttle bus?**
     - *Most arrive at river via private vehicle*
   - **c) Is one method of arrival preferable over the other?**
     - *Non motor is preferable*

6. **Do most users access / launch from public/city owned property or private property?**
   - *City Park (90%)*
   a) **Please list all known points of access and launching.**
      - *City Park*
      - *Sewell Park*
      - *Dog Park (San Marcos Plaza)*
      - *All City parks along the river*
      - *Rio Vista*
      - *Immediately south of I-35 (kayaks)*
      - *Stokes Park*
      - *Nr. Water treatment plant/ Animal Shelter Rd.*
      - *Ramon Lucio (ball) Park (dogs)*
      - *Children's Park*

7. **Do most users exit the river at public/city owned property or private property?**
   a) **Please list all known points of exit.**
      - *Rio vista*
      - *Beyond City Limits*

8. **What recreational activities other than tubing, rafting and fishing occur along the river?**
   - *Swimming*
   - *Wading, water lounging (lawn chairs in the water)*
   - *barbecuing/ picnicking*
   - *canoeing, kayaking dog swimming*
   - *Ducky Derby (no longer)*
   - *special olympics (kayak) practice*
   - *junior (kayak) olympics trials (both at Rio Vista*
   - *canoe racing*
   - *tours on glass bottom boats at Spring Lake*
   - *scuba @ Spring Lake*
   - *Power Olympic outdoor kayak courses*

9. **What specific locations are most frequented by these other users?**
   - *Swimming at the Spring Lake Dam (all over but this is the ideal location because of clarity of the water)*
   - *dog swimming at Dog Park (San Marcos Plaza)*
   - *Wading at all park locations: City Park, Sewell Park, Rio Vista Park*
   - *Kayak instruction at Rio Vista Falls*
   - *Canoes at City Park*
   - *All city and university parks*

10. **What are the positive aspects of recreation on the river?**
    - *Economic benefits: liquor sales, restaurants, employment, tourism*
    - *Wellness, health, quality of life*

11. **What are the negative aspects of recreation on the river?**
    - *Environmental degradation: pollution, litter, erosion*
    - *Parking issues/ traffic congestion*
    - *Water safety issues*
    - *Crowding issues*

12. **How important are river-based recreational activities to the local economy?**
    - *Hard to determine exactly*
    - *Important but does not drive the economy*

    a) **What are its contributions: i.e. sales tax, property taxes, other taxes/fees, spin-off businesses (related revenue sources for the city)?**
        - *Tourism & entertainment businesses*

    b) **How much does recreation activity contribute to the local economy? (in $ or % of city revenue)**
        - *Lions Club tube rentals returns between $110k-$125k/yr to local charities*
        - *Unknown. Check with Michael Ravel & Richard Earl of TSU geography department for studies*

13. **What is your perception of the level of enforcement on the river? Too much, not enough? Why?**
    - *Enforcement is not an issue, but more is better*

14. **Is the amount of regulation with regards to activities on the river acceptable? Should there be more? Or less?**
    - *Need regulation to protect wild rice and prevent overcrowding issues*

    a) **Are there certain things that should be regulated that aren't currently?**
        - *More stringent litter laws including restrictions on food and beverage containers (glass & Styrofoam)*
        - *Ban or limit alcohol from the river (4x)*
        - *Crowding issues & river access points to disperse crowds*

    b) **Are there certain things that are currently regulated that shouldn't be?**
        - *No*

15. **What is your perception of the level of maintenance? Too much, not enough? Why?**
    - *With regards to litter: there is never enough trash maintenance*
    - *Sentiment that the river should be dredged annually as in previous years*

16. **Are there operational issues with regards to emergency flood situations?**
    - *Well prepared: dams control many of the severe floods*

OTHER COMMENTS

- *Much degradation over last 8 years*
- *People feel conflicted over the alcohol consumption on the river/parks*
- *The revenue from the river helps maintain the river*
- *Though the city parks are closed after dark, canoeists and kayakers operate during this time and the city is tolerant of canoeists and kayakers moving through the parks at this time; there seems to be a general understanding that daytime (summer) is for tubers and all else times are best for canoeists and kayakers*
- *There is only 1 tube vendor for San Marcos: Lions Club; they run the shuttle*
- *Richard Earl, Geography Dept. at Texas State has studies regarding number of users and revenue generated from river activities*

OTHER CONTRIBUTORS TO THE ECONOMY:

- *Outlet malls: 25-30% sales tax revenue (over 11 million visitors /yr, 3rd highest visitor attraction inTexas)*
- *University Conference Center*
- *River in general is a draw; people attend TSU because of the setting, people move here because of the setting*

OPERATIONAL ISSUES

- *Not enough restrooms & drinking fountains to support the peak capacities*
- *Need to disseminate information about the river as a natural entity so users can more fully understand what the experience of tubing on the river will be*
- *The Lions Club contributes between $110k-$120k/year to local charities*
- *There is abuse of the Domestic Water Rights in that certain land owners have been drawing water to stock their ponds for uses other than agriculture (TCEQ permits 200 acre/ft / year)*
- *Cummings Dam at the confluence of the Blanco has had a possible effect on Fountain Darter population as it stagnated a 3 mi. length and the population has shown decline (Tom Goynes article)*
- *San Marcos's water supply is 73-74% surface drawn, city has made effort to minimize their draw on the aquifer*

V. WATER QUALITY DATA

Water quality in the San Marcos and Comal Rivers is a measurable parameter that is being monitored on a regular basis by the TCEQ Clean Rivers Program. The data obtained through monthly sampling at specific locations can be a useful tool to assess the current health of the protected species in the two river systems, and possibly draw correlations between the frequency/type of recreation that contribute to measurable changes in water quality, and how these changes could affect protected species.

Initially for this study, it was proposed that aquatic specialists would review existing water quality data trends and indentify potential spatial and temporal correlations between water quality data, recreational use, and protected species habitat. However through recreational research for this study, it was realized that there is not a comprehensive monitoring program to count the number of recreational users, or reliable user counts readily available. Data for protected species was limited and thus this initial recreational study was limited to only providing the available historical water quality data in the GIS geodatabase to build a framework for future analysis. No correlations were made during this process due to lack of data for recreation and limited data for protected species.

GIS analysts obtained data from the TCEQ Water Data Management & Analysis, Water Quality Planning division. This information is considered to be the most recognized, comprehensive scientific data for this area that is readily available in GIS format. The TCEQ surface water quality monitoring program coordinates the monitoring and assessment of surface water resources and oversees the statewide network of monitoring sites. The Texas Clean Rivers Program (CRP) is a state fee–funded program for water quality monitoring, assessment, and public outreach. The CRP is a collaboration of 15 partner agencies and the TCEQ. The TCEQ monitors the quality of surface water to evaluate physical, chemical, and biological characteristics of aquatic systems. Water quality is monitored in relation to human health concerns, ecological condition, and designated uses. (TCEQ website, 2010)

During this study, additional water quality data sources were identified. These studies are either in progress or have just recently been published. For example, the contracted study between TCEQ and Guadalupe-Blanco River Authority (2009 and 2010) to collect water quality samples is a newer ongoing study. The results of this study are scheduled to be incorporated into the future published TCEQ Clean Rivers Program.

Tables 9 and 10 list the TCEQ Clean Rivers Program monitoring stations within the study area identified on map exhibits A-1 to A-25. The Comal River section of the study area consists of 18 surface water monitoring sites. The San Marcos River section consists of 8 surface water quality monitoring sites. Of these 26 sampling locations, monitoring data presented in the GIS geodatabase spans various months over a nineteen year period from 1990 to 2009.

Table 9	
TCEQ Clean Rivers Program Monitoring Stations: Comal River	
15412	COMAL RIVER AT MULBERRY AVE UPSTREAM OF LANDA PARK
13510	COMAL RIVER AT ISLAND AT END OF BOONEVILLE AVENUE IN LANDA ESTATES IN NEW BRAUNFELS
12574	COMAL SPRINGS AT FOOTBRIDGE NEAR GAZEBO IN LANDA PARK IN NEW BRAUNFELS
18525	PANTHER CANYON IMMEDIATELY UPSTREAM OF LANDA PARK DR NEAR COMAL SPRINGS IN NEW BRAUNFELS TX
15413	COMAL RIVER AT LANDA LAKE IMMEDIATELY WEST OF LANDA PARK IN NEW BRAUNFELS .25 KM DIRECTLY EAST OF CALIFORNIA RD
12572	COMAL SPRINGS AT CALIFORNIA BLVD IN NEW BRAUNFELS
12573	COMAL SPRINGS DOWNSTREAM PANTHER CANYON IN NEW BRAUNFELS
15204	COMAL RIVER/LANDA LAKE AT BOATHOUSE IN LANDA PARK
12654	COMAL RIVER AT MINIATURE TRAIN DEPOT IN LANDA PARK IN NEW BRAUNFELS
15082	COMAL RIVER AT LANDA PARK AREA 16 2.45 MI UPSTREAM FROM CONFLUENCE WITH GUADALUPE RIVER IN NEW BRAUNFELS
15146	COMAL RIVER AT HINMAN ISLAND 2.1 MI UPSTREAM OF CONFLUENCE WITH GUADALUPE RIVER
14933	DRY COMAL CREEK AT SEGUIN ST NEW BRAUNFELS
12570	DRY COMAL CREEK AT MISSOURI-KANSAS-TEXAS RAILROAD CROSSING IN NEW BRAUNFELS
12652	COMAL RIVER DOWNSTREAM STEINKE FALLS BETWEEN CONCRETE STAIRWAYS BEHIND COTTAGE NO. 13 IN NEW BRAUNFELS
15401	COMAL RIVER IMMEDIATELY SOUTH OF UNION BLVD 0.2 KM UPSTREAM OF THE GUADALUPE RIVER IN NEW BRAUNFELS
12651	COMAL RIVER NEAR GUADA COMA/UNION BLVD|COMAL RIVER 50 M UPSTREAM OF END OF GUADA COMA DR WEST/UNION BLVD BRIDGE IN NEW BRAUNFELS
12657	GUADALUPE RIVER 1.1 MI UPSTREAM FROM COMAL RIVER IN NEW BRAUNFELS
12656	GUADALUPE RIVER AT THE BEGINNING OF CYPRESS BEND PARK IN NEW BRAUNFELS

Table 10	
TCEQ Clean Rivers Program Monitoring Stations: San Marcos River	
15496	SPRING LAKE AT AQUARENA SPRINGS BRIDGE IN SAN MARCOS
15497	SPRING LAKE AT DAM .10 MI UPSTREAM FROM LOOP 82 IN SAN MARCOS
15498	UPPER SAN MARCOS RIVER AT CONFLUENCE OF SESSOM CREEK AT LOOP 82 IN SAN MARCOS
15499	UPPER SAN MARCOS RIVER AT CONFLUENCE OF PURGATORY CREEK AT CITY PARK .10 MI DOWNSTREAM OF SH 12 IN SAN MARCOS
15500	UPPER SAN MARCOS RIVER AT RIO VISTA PARK FOOTBRIDGE .20 MI DOWNSTREAM OF SH 12 IN SAN MARCOS
12672	UPPER SAN MARCOS RIVER IMMEDIATELY UPSTREAM OF IH 35 BRIDGE AT SAN MARCOS
14153	SAN MARCOS/A.E. WOODS TPWD FISH HATCHERY DISCHARGE POINT TO SAN MARCOS RIVER
12671	UPPER SAN MARCOS RIVER 0.7 MILE DOWNSTREAM FROM IH 35

Future investigations can utilize the GIS geodatabase created during this study, and update it with the most current readily available data from the TCEQ Clean Rivers Program. Once numerical recreation use data becomes available, it can be compared to the water quality data to ascertain any correlations between the frequency and intensity of recreational use and water quality. Then layering any protected species mapping data may allow analysis of any potential relationship between species sustainability or proliferation and recreation use. Two recognizable studies conducted by the USGS in the 1990's can be used as a model for future studies (See Appendix D). The GIS geodatabase of TCEQ data includes the parameters that the

USGS used: pH, temperature, dissolved oxygen, major ions, nutrients, trace elements, selected organic compounds, and stream flow. A list of all of the parameters monitored by TCEQ are illustrated in Table 11.

TABLE 11. **TCEQ WATER QUALITY SAMPLING PARAMETERS**
00060 FLOW, STREAM, MEAN DAILY (CUBIC FEET PER SEC)
00061 FLOW STREAM, INSTANTANEOUS (CUBIC FEET PER SEC)
00078 TRANSPARENCY, SECCHI DISC (METERS)
00090 OXIDATION REDUCTION POTENTIAL (MILLIVOLTS)
00094 SPECIFIC CONDUCTANCE,FIELD (UMHOS/CM @ 25C)
00095 SPECIFIC CONDUCTANCE,LAB (UMHOS/CM @ 25C)
00300 OXYGEN, DISSOLVED (MG/L)
00301 OXYGEN, DISSOLVED (PERCENT OF SATURATION)
00400 PH (STANDARD UNITS)
00403 PH (STANDARD UNITS) LAB
00410 ALKALINITY, TOTAL (MG/L AS CACO3)
00480 SALINITY - PARTS PER THOUSAND
00530 RESIDUE, TOTAL NONFILTRABLE (MG/L)
00535 RESIDUE, VOLATILE NONFILTRABLE (MG/L)
00593 NO2 PLUS NO3-N, TOTAL, WHATMAN GF/F FILT (MG/L)
00608 NITROGEN, AMMONIA, DISSOLVED (MG/L AS N)
00610 NITROGEN, AMMONIA, TOTAL (MG/L AS N)
00613 NITRITE, DISSOLVED (MG/L AS N)
00615 NITRITE NITROGEN, TOTAL (MG/L AS N)
00620 NITRATE NITROGEN, TOTAL (MG/L AS N)
00623 NITROGEN, KJELDAHL, DISSOLVED (MG/L AS N)
00625 NITROGEN, KJELDAHL, TOTAL (MG/L AS N)

TABLE 11. TCEQ WATER QUALITY SAMPLING PARAMETERS
00630 NITRITE PLUS NITRATE, TOTAL 1 DET. (MG/L AS N)
00631 NITRITE PLUS NITRATE, DISS 1 DET. (MG/L AS N)
00665 PHOSPHORUS, TOTAL, WET METHOD (MG/L AS P)
00666 PHOSPHORUS, DISSOLVED (MG/L AS P)
00671 ORTHOPHOSPHATE PHOSPHORUS,DISS,MG/L,FLDFILT<15MIN
00680 CARBON, TOTAL ORGANIC, NPOC (TOC), MG/L
00681 CARBON, DISSOLVED ORGANIC, DNPC (DOC), MG/L
00689 CARBON, SUSPENDED ORGANIC - POC (MG/L)
00900 HARDNESS, TOTAL (MG/L AS CACO3)
00915 CALCIUM, DISSOLVED (MG/L AS CA)
00925 MAGNESIUM, DISSOLVED (MG/L AS MG)
00930 SODIUM, DISSOLVED (MG/L AS NA)
00935 POTASSIUM, DISSOLVED (MG/L AS K)
00940 CHLORIDE (MG/L AS CL)
00945 SULFATE (MG/L AS SO4)
00950 FLUORIDE, DISSOLVED (MG/L AS F)
00955 SILICA, DISSOLVED (MG/L AS SIO2)
01000 ARSENIC, DISSOLVED (UG/L AS AS)
01005 BARIUM, DISSOLVED (UG/L AS BA)
01010 BERYLLIUM, DISSOLVED (UG/L AS BE)
01025 CADMIUM, DISSOLVED (UG/L AS CD)
01030 CHROMIUM, DISSOLVED (UG/L AS CR)
01035 COBALT, DISSOLVED (UG/L AS CO)
01040 COPPER, DISSOLVED (UG/L AS CU)

TABLE 11. TCEQ WATER QUALITY SAMPLING PARAMETERS
01046 IRON, DISSOLVED (UG/L)
01049 LEAD, DISSOLVED (UG/L AS PB)
01056 MANGANESE, DISSOLVED (UG/L AS MN)
01060 MOLYBDENUM, DISSOLVED (UG/L AS MO)
01065 NICKEL, DISSOLVED (UG/L AS NI)
01075 SILVER, DISSOLVED (UG/L AS AG)
01090 ZINC, DISSOLVED (UG/L AS ZN)
01095 ANTIMONY, DISSOLVED (UG/L AS SB)
01106 ALUMINUM, DISSOLVED (UG/L AS AL)
01145 SELENIUM, DISSOLVED (UG/L AS SE)
01351 FLOW:1=No Flow,2=Low,3=Normal,4=Flood,5=High,6=Dry
22703 URANIUM, NATURAL, DISSOLVED
31616 FECAL COLIFORM,MEMBR FILTER,M-FC BROTH, #/100ML
31648 E. COLI, MTEC, MF, #/100 ML
31673 FECAL STREPTOCOCCI, MBR FILT,KF AGAR,35C,48HR
31699 E. COLI, COLILERT, IDEXX METHOD, MPN/100ML
32211 CHLOROPHYLL-A UG/L SPECTROPHOTOMETRIC ACID. METH
32218 PHEOPHYTIN-A UG/L SPECTROPHOTOMETRIC ACID. METH.
32764 7,12-DIMETHYLBENZ(A)ANTHRACENE, SED, DRY WT
32772 DIBENZ(AJ)ACRIDINE, SEDIMENT, DRY WT, UG/KG
32778 M,P-CRESOL, SEDIMENT, DRY WT, UG/KG
34203 ACENAPHTHYLENE, DRY WT, BOTTOM (UG/KG)
34208 ACENAPHTHENE, DRY WT, BOTTOM (UG/KG)
34223 ANTHRACENE DRY WTBOTUG/KG

TABLE 11. TCEQ WATER QUALITY SAMPLING PARAMETERS
34233 BENZO(B)FLUORANTHENE,SEDIMENTS, DRY WT,UG/KG
34245 BENZO(K)FLUORANTHENE DRY WTBOT UG/KG
34250 BENZO-A-PYRENE DRY WTBOTUG/KG
34276 BIS (2-CHLOROETHYL) ETHER DRY WTBOTUG/KG
34281 BIS (2-CHLOROETHOXY) METHANE DRY WTBOTUG/KG
34286 BIS (2-CHLOROISOPROPYL) ETHER DRY WTBOTUG/KG
34295 N-BUTYL BENZYL PHTHALATE, SEDIMENTS,DRY WT,UG/K
34323 CHRYSENE DRY WTBOTUG/KG
34339 DIETHYL PHTHALATE DRY WTBOTUG/KG
34344 DIMETHYL PHTHALATE DRY WTBOTUG/KG
34349 1,2-DIPHENYLHYDRAZINE, DRY WT, BOTTOM (UG/KG)
34379 FLUORANTHENE DRY WTBOTUG/KG
34384 FLUORENE DRY WTBOTUG/KG
34389 HEXACHLOROCYCLOPENTADIENE DRY WTBOTUG/KG
34399 HEXACHLOROETHANE DRY WTBOTUG/KG
34406 INDENO (1,2,3-CD) PYRENE DRY WTBOTUG/KG
34411 ISOPHORONE DRY WTBOTUG/KG
34431 N-NITROSODI-N-PROPYLAMINE DRY WTBOTUG/KG
34436 N-NITROSODIPHENYLAMINE DRY WTBOTUG/KG
34441 N-NITROSODIMETHYLAMINE DRY WTBOTUG/KG
34445 NAPHTHALENE DRY WTBOTUG/KG
34450 NITROBENZENE DRY WTBOTUG/KG
34455 PARACHLOROMETA CRESOL DRY WTBOTUG/KG
34464 PHENANTHRENE DRY WTBOTUG/KG

TABLE 11. TCEQ WATER QUALITY SAMPLING PARAMETERS
34472 PYRENE DRY WTBOTUG/KG
34524 BENZO(GHI)PERYLENE1,12-BENZOPERYLENDRYWTBOTUG/KG
34529 BENZO(A)ANTHRACENE1,2-BENZANTHRACENDRYWTBOTUG/KG
34539 1,2-DICHLOROBENZENE DRY WT, BOTTOM (UG/KG)
34554 1,2,4-TRICHLOROBENZENE DRY WTBOTUG/KG
34559 1,2,5,6-DIBENZANTHRACENE DRY WTBOTUG/KG
34569 1,3-DICHLOROBENZENE, DRY WT, BOTTOM (UG/KG)
34574 1,4-DICHLOROBENZENE, DRY WT, BOTTOM (UG/KG)
34589 2-CHLOROPHENOL, DRY WT, BOTTOM (UG/KG)
34594 2-NITROPHENOL DRY WTBOTUG/KG
34599 DI-N-OCTYL PHTHALATE DRY WTBOTUG/KG
34604 2,4-DICHLOROPHENOL DRY WT, BOTTOM (UG/KG)
34609 2,4-DIMETHYLPHENOL DRY WT, BOTTOM (UG/KG)
34614 2,4-DINITROTOLUENE DRY WT, BOTTOM (UG/KG)
34619 2,4-DINITROPHENOL DRY WT, BOTTOM (UG/KG)
34624 2,4,6-TRICHLOROPHENOL ,DRY WT, BOTTOM (UG/KG)
34629 2,6-DINITROTOLUENE DRY WT, BOTTOM (UG/KG)
34634 3,3'-DICHLOROBENZIDINE, DRY WT BOTTOM (UG/KG)
34639 4-BROMOPHENYL PHENYL ETHER, DRY WT, BOT (UG/KG)
34644 4-CHLOROPHENYL PHENYL ETHER, DRY WT, BOT (UG/KG)
34649 4-NITROPHENOL ,DRY WT, BOTTOM (UG/KG)
34660 DNOC (4,6-DINITRO-ORTHO-CRESOL) DRY WTBOTUG/KG
34695 PHENOL(C6H5OH)-SINGLE COMPOUND DRY WTUG/KG
34721 2,3,4,6-TETRACHLOROPHENOL SEDIMENT, DRYWT(UG/KG)

TABLE 11. TCEQ WATER QUALITY SAMPLING PARAMETERS
39036 ALKALINITY, FILTERED SAMPLE AS CACO3 MG/L
39061 PCP (PENTACHLOROPHENOL) IN BOT DEPOS DRY UG/KG
39102 BIS(2-ETHYLHEXYL) PHTHALATE SED, DRY WT,UG/KG
39112 DI-N-BUTYL PHTHALATE, SEDIMENTS,DRY WT,UG/KG
39118 PENTACHLOROBENZENE IN SEDIMENT UG/KG
39121 BENZIDINE IN BOTTOM DEPOS (UG/KG DRY SOLIDS)
39191 TOTAL CHLORONAPTHALENE (1AND 2) IN SED, UG/KG
39631 ATRAZINE IN BOTTOM DEPOS (UG/KG DRY SOLIDS)
39701 HEXACHLOROBENZENE IN BOT DEPOS (UG/KG DRY SOLIDS
39705 HEXACHLOROBUTADIENE BOT. DEPOS. (UG/KG DRY WT)
70300 RESIDUE,TOTAL FILTRABLE (DRIED AT 180C) (MG/L)
70507 ORTHOPHOSPHATE PHOSPHORUS,DISS,MG/L,FILTER >15MIN
72053 DAYS SINCE PRECIPITATION EVENT (DAYS)
73031 PRONAMIDE IN SEDIMENT, DRY WEIGHT (UG/KG)
73116 P-DIMETHYLAMINOAZOBENZENE, SED, DRY WT, UG/KG
73117 PHENACETIN IN SEDIMENT, DRY WEIGHT (UG/KG)
73118 ETHYLMETHANSULFONATE IN SEDIMENT, DRY WT (UG/KG)
73119 METHYLMETHANESULFONATE IN SEDIMENT, DRY WT (UG/K
73122 2,6-DICHLOROPHENOL IN SEDIMENT, DRY WT (UG/KG)
73124 2-NAPHTHYLAMINE IN SEDIMENT, DRY WEIGHT (UG/KG)
73125 4-AMINOBIPHENYL, SEDIMENT, DRY WT (UG/KG)
73129 N-NITROSOPIPERIDINE IN SEDIMENT, DRY WT (UG/KG)
73143 1-NAPHTHYLAMINE IN SEDIMENT, DRY WT (UG/KG)
73156 3-METHYLCHLORANTHRENE, SEDIMENT, DRY WT(UG/KG)

TABLE 11. TCEQ WATER QUALITY SAMPLING PARAMETERS
73158 2-METHYLPYRIDINE IN SEDIMENT, DRY WEIGHT (UG/KG)
73159 N-NITROSO-DI-N-BUTYLAMINE, DRY WT,SEDIMENT (UG/K
74069 STREAM FLOW ESTIMATE (CFS)
75212 BENZYL ALCOHOL IN SEDIMENT, DRY WEIGHT (UG/KG)
75315 BENZOIC ACID IN SEDIMENT, DRY WEIGHT (UG/KG)
75647 DIBENZOFURAN, SEDIMENT, DRY WT (UG/KG)
78299 2-NITROANILINE IN SEDIMENT, DRY WEIGHT (UG/KG)
78401 2,4,5-TRICHLOROPHENOL IN SEDIMENT,DRY WT (UG/KG)
78543 CARBAZOLE IN SEDIMENT, DRY WEIGHT (UG/KG)
78755 ACETOPHENONE, SEDIMENT, DRY WT (UG/KG)
78866 ANILINE IN SEDIMENT, DRY WEIGHT (UG/KG)
78867 4-CHLOROANILINE, SEDIMENT, DRY WT (UG/KG)
78868 2-METHYLNAPTHALENE IN SEDIMENT, DRY WEIGHT (UG/K
78869 3-NITROANILINE, SEDIMENT, DRY WEIGHT (UG/KG)
78870 4-NITROANILINE, SEDIMENT, DRY WT (UG/KG)
78872 2-METHYLPHENOL(O-CRESOL) SEDIMENT DRY WT. (UG/KG
80154 SUSP. SEDIMENT CONCENTRATION-EVAP AT 110C (MG/L)
80256 SEDIMENT PRTCL.SIZE CLASS >2.0MM GRAVEL %DRY WT
81373 SOLIDS IN SEDIMENT, PERCENT BY WEIGHT (DRY)
81808 PENTACHLORONITROBENZENE IN SEDIMENT, DRYWT (UG/K
81818 SEVIN IN SEDIMENT DRY WEIGHT (UG/KG)
81951 TOTAL ORGANIC CARBON,NPOC(TOC), SED DRY WT,MG/KG
82003 MOISTURE CONTENT IN SEDIMENT (%)
82008 SEDIMENT PRTL.SIZE CLASS.0039-.0625 SILT %DRY W

TABLE 11. TCEQ WATER QUALITY SAMPLING PARAMETERS
82009 SEDIMENT PRCTL.SIZE CLASS <.0039 CLAY %DRY WT
82079 TURBIDITY,LAB NEPHELOMETRIC TURBIDITY UNITS, NTU
88811 CRESOL IN SEDIMENT, DRY WEIGHT, (UG/KG)
88817 N-NITROSODIETHYLAMINE, SED DRY WT (UG/KG)
88823 PYRIDINE SEDIMENT DRY WEIGHT (UG/KG)
88826 1,2,4,5-TETRACHLOROBENZENE SEDIMENT DRY WT (UG/K
89835 FLOW MTH 1=GAGE 2=ELEC 3=MECH 4=WEIR/FLU 5=DOPPL
89991 SEDIMENT PRCTL.SIZE CLASS,SAND .0625-2MM %DRYWT

In addition to data collection, the TCEQ assesses water quality throughout the state. Formerly called the "Texas Water Quality Inventory and 303(d) List," the Integrated Report evaluates the quality of surface waters in Texas, and provides resource managers with a tool for making informed decisions when directing agency programs. The Texas Integrated Report describes the status of Texas' natural waters based on historical data. It identifies water bodies that are not meeting standards set for their use on the 303(d) list. The Texas Integrated Report satisfies the requirements of federal Clean Water Act Sections 305(b) and 303(d). The TCEQ produces a new report every two years in even-numbered years, as required by law. The 303(d) List must be approved by the EPA before it is final. The TCEQ monitoring program also reports the status of water quality in the biennial Texas Water Quality Inventory and 303(d) List of Impaired Waters. The Texas Water Quality Inventory and 303(d) List reports the information on Texas' surface waters, including concerns for public health, fitness for use by aquatic species and other wildlife, and specific pollutants and their possible sources (TCEQ website, 2010).

Table 12 lists the stream segments within the study area. According to the 2008 Texas Water Quality Inventory and 303(d) List of Impaired Waters, no segments (1811, 1812, and 1814) within the study area were considered impaired. See Appendix D for the results of this analysis.

TABLE 12 2008 TEXAS WATER QUALITY INVENTORY STREAM SEGMENTS IN STUDY AREA	
1811 – Comal River	From the confluence with the Guadalupe River in Comal County to Klingemann Street in New Braunfels in Comal County (4 miles)
1811A – Dry Comal Creek Unclassified (Not assessed in 2008)	From the confluence of the Comal River in New Braunfels in Comal County to the upstream perennial portion of the stream southwest of New Braunfels in Comal County (30 miles)
1814 – Upper San Marcos River	From a point 1.0 km (0.6 miles) upstream of the confluence of the Blanco River in Hays County to a point 0.7 km (0.4 miles) upstream of Loop 82 in San Marcos in Hays County (5 miles)

VI. PERTINENT SCIENTIFIC STUDIES

Sources for the following studies come from the City of San Marcos, the City of New Braunfels, and River Systems Institute. Halff is aware there are relevant studies beyond what has been summarized in this document, however those relevant studies were either not accessible or not made available at the time of this report. It would likely be of benefit for the EARIP to take into consideration the results of those complementary studies.

The studies reviewed include habitat conservation plans, academic theses, articles and books and provide insight into the management of rivers for the sake of habitat and/or the physical and chemical affects on rivers from human activity, including recreation. Of greatest relevance is the current on-going study of Texas State University student Jenna Winters; although methodologies were not specifically revealed, her data on the San Marcos River is the most site specific and significant of information gathered.

A. Pertinent Studies

Doctoral Study of San Marcos River between Sewell Park and Rio Vista falls by Jenna Winters, unpublished data from 2007-2009

Geographical points of study of San Marco River from upstream to downstream order:
Last bridge
Just before City Park
Just after City Park
Hopkins St. Bridge
Bicentennial Park
Beginning of Rio Vista Park
Dam at Rio vista Park

Turbidity:

- Measurements of turbidity were taken at 6' from each bank and center of current channel
- Correlation was found between number of people and turbidity levels.
- Levels of turbidity in San Marcos River between Sept and April: mostly recorded at 2.00 NTUs and under, rarely more than 3.00 NTUs. Spikes in turbidity during this time correlated with rainfall events. Turbidity increased with summer months. The correlation was found to be consistently 0.72 in both 2008 and 2009.

- Years when flow of the river was low, turbidity was higher and vice versa.

Peak days were summer season (Memorial Day weekend – Labor Day) Saturdays and Sundays, with greater amount of people on Saturdays. Holiday Mondays showed higher numbers as well and in general, Thursdays and Fridays averaged greater numbers than Tuesdays and Wednesdays. In one counting survey performed during a July 4 weekend taken between 12pm and 2pm, 1756 people (swimming or tubing) and 6 dogs were counted to be in the river. On June 5, 2009 (a Friday), a count was documented at 706 people and 4 dogs. In her 2008 survey of 717 people, the following information was revealed:

- Reported primary activity of visitors to the San Marcos River:
- 33% swim
- 28% socialize
- 16% tube
- 6% boat
- 2% fish
- Mean age of user: 34
- 53% were from San Marcos area
- 76% were from the Austin- San Antonio IH 35 corridor
- 98% were Texas residents
- 98% reported they would return
- 87% were repeat visitors
- Average duration of stay at the river: 4 hours
- This duration does not vary with weekend or weekday days
- 50% brought their own tubes

For that particular visit:

- 75% spent less than $25
- 13% spent between $25-$50
- 6% spent between $50-$75
- 7% spent >$100
- 6% were overnight guests
- 24% advised that fuel prices would affect their decision to visit

Awareness of listed species in the San Marcos River:

- 59% advised they were aware
- 27% advised they learned this from school programs

- 18% advised they learned this from friends
- 13% advised they learned this from signage
- 67% of Caucasians were aware
- 44% of Hispanics were aware

Cleanliness of the River:

- 29% perceived the water as very clean
- 50% perceived the water is mostly clean

Perception of crowding

- 82% reported to have no issues with levels of crowd
- 94% reported to not feel crowded or only slightly crowded

Ethnicity
Percentage of Hispanic and Caucasian visitors proportionately mirrored the San Marcos city demographic

USFWS, *Summary of 2009 sampling efforts related to Edwards Aquifer Authority Variable Flow Study under USFWS permit number TE037155-0,* 2009
Methods and findings of federally listed species in specific locations of the Comal and San Marcos Rivers were explained.
This report provides current and specific information of where and in what kinds of densities each of the Fountain Darters, San Marcos Salamander, Texas Wild Rice, Comal Spring Riffle Beetle was found, along with other fish and crustaceans, arachnids and insects. Information regarding current flow, time of year and water quality was also provided, as well as findings from previous years for comparison.
This report is useful in ascertaining information about population fluctuations and habitat conditions and may provide clues as to where recreation use could be altered to accommodate for these habitats.

Owens, Chetta S., John D. Madsen, R. Michael Smart and Michael Stewart
Dispersal of Native and Nonnative Aquatic Plant Species in the San Marcos River, Texas
Five sites were sampled 5 times each on a quarterly schedule reflecting seasonal trends for introduced and native vegetation types. The article focuses on the proliferation of hyrdrilla and East Indian hygrophila and their effects on the native listed species Texas Wild Rice. References to other sources noted times and season of recreation use and the finding that recreation negatively impacts

Texas wild rice, additionally that recreation users disturb, tear and uproot native species allowing more aggressive nonnative species to proliferate.

Bussemey, Michelle, *Analysis of Landscape Change of the Rio Vista Dam in San Marcos, Texas*. MS Thesis, Texas State University, San Marcos, Texas, 2007

Repeat photography documents the changes of the river and adjacent banks at the location of the current day Rio Vista Dam dating back from 1917. A cultural and physical history is documented and concludes the landscape changes which include opening this part of the river to the community (for recreation use) and the reconstruction of the dam and construction of step pools has resulted in congestion, increased turbidity and trash in and around the river. The author also warns the alterations in the dams and the introduction of pools will also result in sediment bars and ultimately could alter the channel and the flow of the river.

City of San Marcos <u>Habitat Conservation Plan</u> (Draft – not yet implemented)

This report outlines options in strategies in which to protect and minimize disturbance and limit take (to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct) of federally listed aquatic species found in the San Marcos River during the course of maintenance and construction projects and activities for the next twenty (20) years. Those species include the fountain darter, the Comal Springs riffle beetle, the San Marcos salamander and Texas wild-rice.

Requirements under the take permit, known as a Section 10(a)(1)(B) permit, issued by US Fisheries and Wildlife Service (USFWS) include biological data, impact assessments, geographical area, activities of listed species within the project area, provisions to monitor, minimize, and mitigate impacts and procedures to deal with unforeseen circumstances.

This report aims to support a comprehensive watershed management plan for the San Marcos River within the city limits which includes the city's Recreation Master Plan as well as the Environmental Protection Agency Phase II Storm Water Management Program.

The projects and activities that apply to this study are those surrounding the San Marcos River corridor between the springs at Spring Lake and Rio Vista Falls.

This draft publication describes the physical attributes of the affected area, including hydrology, climate, water quality, existing land use, vegetation and wildlife including the listed species. The draft publication also makes an assessment of threats which include sedimentation, increased pollution, increased nutrient levels, expanding population of non-natives and recreational activity, on which this report focuses.

River recreation activities cited include scuba, swimming, tubing, canoeing/kayaking, fishing, wading, dog playing, snorkeling and boat touring. Recreation causes disturbance to the river bottom and vegetation, streamside issues include erosion, litter and pollution, while fishing specifically can introduce non-native bait species.

Maintenance is performed to maintain a clear corridor for water recreation; this includes clearing vegetation from the central 5 meters of the current channel to a depth of 12". The city will manage a strategically timed incremental removal of high growth and non-native vegetative species while replacing with low growth native species, in addition to sediment removal.

The proximity of Texas State University golf course incurs strict regulations by USFWS on use of fertilizers and pesticides, as well as watering regimes.

In addition to outlining on-going maintenance activities within the area, this draft publication also lists future projects by Texas State University, including construction of a new hike/bike trail and an expanded academic curriculum of water activities (at Spring Lake) by Texas State University. City projects include bank stabilization projects and provision of controlled river access points taking care to remediate with native rock and riparian vegetation.

Edwards Aquifer Authority. 'Comprehensive and Critical Period Monitoring Program to Evaluate the Effects of Variable Flow on Biological Resources in the Comal Springs/River Aquatic Ecosystem Final 2009 Annual Report' . BIO-WEST Inc. March 2010

This report was made known to the Halff team late in the process of producing this report and was thus not thoroughly reviewed. Relevant information found in this document includes monitoring efforts by the Master Naturalist volunteers who collected data on river users (numbers, types/activities) and water quality (pH, carbon dioxide) on a weekly basis in the years 2006 through 2009. Five (5) sites were visited regularly at roughly the same time for the same duration at each of the five locations. Tubing was found to be the dominant recreation activity, with emphasis between May and September of each year and 2009 showed a higher number of users at four of the five locations over 2007 and 2008. With regards to water quality, pH levels were shown to be consistently lower nearer the springs than downstream and carbon dioxide concentrations showed higher levels nearer the springs and less downstream.

Edwards Aquifer Authority. 'Comprehensive and Critical Period Monitoring Program to Evaluate the Effects of Variable Flow on Biological Resources in the San Marcos Springs/River Aquatic Ecosystem Final 2009 Annual Report' . BIO-WEST Inc. March 2010

This report was made known to the Halff team late in the process of producing this report and was thus not thoroughly reviewed. This document summarizes the methodology and findings of two comprehensive monitoring events and three critical period low-flow events. These samplings examined water chemistry, current flow, water levels, water temperature, aquatic vegetation and changes in channel morphology. This type of detailed investigation found correlations between the establishment of Texas wild rice with water levels and current flow and subsequently, recreation use as a result of water levels and their impact on the establishment of Texas wild rice. The report cites mechanical disturbance on river banks and bottom and fragmentation of wild rice stands from recreationists. Quantitative data comes from mapping of wild rice stands and measurement of current flows, water levels, and changes in channel morphology. Observed recreation use (areas and activities) correlated with accessibility of the river and water depths. Similarly, fountain darter found locations correlated with stands of aquatic vegetation and was thus also found to be affected by recreationists.

Edwards Aquifer Area Expert Science Subcommittee for the Edwards Aquifer Recovery Implementation Program. 'Analysis of Species Requirements in Relation to Spring Discharge Rates and Associated Withdrawal Reductions and Stages for Critical Period Management of the Edwards Aquifer'. Report to Steering Committee for the Edwards Aquifer Implementation Program. December 28, 2009. This report was made known to the Halff team late in the process of producing this report and was thus not thoroughly reviewed. Quantitative documentation of water flow and physical changes to vegetation and stream channel were provided for the three (3) years of this study. Information regarding population size and locations of the various species at various times of the year were also provided and qualitative observations were made regarding the context of each sampling period, including human (recreation) activity. The report provides information on which and how listed species are affected by flow rates and the various factors flow rates affect (that ultimately affect the habitat for listed species): turbidity (sunlight), scouring effects (establishment of Texas wild rice and opportunities for more aggressive (competitive) non-native aquatic vegetation), sedimentation, recreation (opportunites for greater human contact with banks and river bottoms, accessibility of shallow depth stream areas). The report clearly indicates recreation has a direct and indirect effect on fountain darters and a direct effect on Texas wild rice but cites such factors as sedimentation, turbidity, presence of exotic species are also variables in their populations. Populations of the Texas blind salamander and listed beetle species are noted to be physically found closer to or within the spring sources and are thus much less affected by recreation but more so by water table depth (draw), water flow rates (draw and drought) and water quality (pollution within recharge zones). The San Marcos blind salamander riverbed habitat was found to be

impacted near Spring Lake Dam by siltation (allowing extensive vegetation growth) and (accessibility of water) recreation during low discharge years of 2006 and 2009. The report makes conclusions about minimum flow rates for species survival.

Bradsby, D.D. 1994. *A Recreational Use Survey of the San Marcos River.* MS Thesis, Southwest Texas State University, San Marcos, Tx 82pp.
This study was not accessible but was referred to by several sources.

Breslin, S.L. 1997. *The impact of recreation on Texas wild rice*. MS Thesis, Southwest Texas State University, San Marcos, Tx. 69pp.
This study was not accessible but was referred to by several sources. One reference found stated Texas wild rice is found only in the upper 2.5 km of the San Marcos River. Recreation visibly causes considerable damage to Texas wild rice stands with highest occurrence during peak recreational months in the hours between 2-3pm.

Earl, Richard A. and Wood, Charles R. 'Upstream Changes and Downstream Effects of the San Marcos River of Central Texas'. The Texas Journal of Science February 2002
The San Marcos River is recognized as a unique resource; it is attracting a growing population to the city as well as Texas State University. It is documented to have the potential to produce a floodflow of 247 square kilometers. The flood of May 15, 1970 which resulted in a discharge of 76,600 cubic feet per second was the impetus for the formation of the Upper San Marcos Watershed Reclamation and Flood Control District. Another flood on June 13, 1981 prompted the funding for a series of five (5) control dams upstream San Marcos River, the last of which was completed in 1991. These dams have a combined capacity of 23 million cubic meters (19,000acre feet) and consequently reduced the uncontrolled drainage area from 247 square km to 47 square km. Although effective in controlling flood damage (as evidenced by larger than 100 year flood event of October 1998, which produced a peak discharge of what would have been a 25 year event), the construction of the dams have resulted in decreased scouring action (reduced flow), and consequently, increased sedimentation of the river, by as much as 0.5 meters depth in the main channel. The changes have caused issue with the increases in exotic riparian and aquatic vegetation, and thereby affecting the natural habitats of the four (fountain darter, texas wild rice, san marcos salamander, comal springs riffle beetle)US Fish and Wildlife Services aquatic species. While flooding control measures are effective, they have brought on a new set of management issues. The Texas Parks and Wildlife Department and the City of San Marcos Parks and Recreation Department since 1990 have been closely monitoring the river for critical habitat and for protection of the river as an aesthetic and tourism resource.

Comal County, Texas and Comal County Commissioners Court. <u>Comal County Regional Habitat Conservation Plan</u>. April 2010

The rate of growth in Comal County has induced a desire for a strategy in which to ensure the protection and preservation of open space for the benefit of the County's citizens, to conserve the County's endangered species and to help landowners comply with Endangered Species Act (ESA)compliance efficiently and cost effectively. Participation in the County's process by landowners is voluntary, although compliance with the Endangered Species Act is not.

A Habitat Conservation Plan (HCP) by Comal County would help establish a 30 year regional permit that would allow authorization under the ESA for land development activities that could affect the 'take' (to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct) of federally listed or endangered wildlife species listed under the ESA. This type of regional plan specifies the conservation measures that would be implemented in exchange for a US Fisheries and Wildlife Service section 10(a)(1)(B) permit.
The Regional HCP addresses habitats for the golden cheeked warbler and the black capped vireo. (Federally) Listed species not addressed in this HCP are aquatic species associated with Edwards Aquifer: the fountain darter, Peck's cave amphipod, Comal Springs riffle beetle, and the Comal Springs dryopid beetle.

Comal County, Texas and Comal County Commissioners Court. <u>Comal County Regional Habitat Conservation Plan Environmental Impact Statement</u>. April 2010

This report describes the potential impacts of the 'take' permit described in the Comal County Regional Habitat Conservation Plan (RHCP) of April 2010. Although the aforementioned plan addresses only the take of the golden cheeked warbler and the black capped vireo, this environmental impact statement describes the affect on habitats of other species as a result of land development; the report provides three (3) scenarios for Comal County: no regional permit (alternative A), regional permit granted (alternative B), reduced take regional permit (alternative C, does not cover habitats of the black capped vireo). Each scenario is described in terms of the direct, indirect and cumulative effects of take and mitigation as proposed by the RHCP.
The proposed action, as the favored scenario is referred to, is alternative B: to obtain a regional permit that would allow Comal County to process and monitor land development in terms of take and to ensure that the RHCP is adhered to in terms of mitigating environments and allocating habitat in perpetuity for the survival of the golden cheeked warbler and the black capped vireo.
A regional permit would require a commitment of resources, including revenue, to monitor and support the RHCP. This direction is described as most strategic in that it

is projected to least hinder the pace of economic growth in the area while also yielding the greatest potential for preservation.

A detailed analysis of various topics is part of this environmental impact assessment: water resources, vegetation, general wildlife, covered species, socioeconomic resources. Of the covered species, the listed species of interest in our river recreation study are identified as other protected species (other = those negligibly or minor affected by land (woodland) development as outlined in the RHCP): San Marcos salamander (Eurycea nana), Texas blind salamander (Typhlomolge rathbuni), Fountain Darter (Etheostoma fonticola), San Marcos gambusia (Gambusia georgei), Comal Springs Dryopid Beetle (Stygoparnus comalensis), Comal Springs Riffle Beetle (heterelmis comalensis), Texas wild-rice (Zizania texana). It should also be noted that The San Marcos salamander, Texas blind salamander, San Marcos gambusia and Texas wild rice are not evident in Comal County.

The consequential impacts from land development that may affect our species of interest would be any affects to the Edwards Aquifer (development will not be permitted to draw from this aquifer) such as any draw/reduction in flow and any sedimentation or toxic deposits in surface waters as a result of development and the reduction of pervious ground (unfiltered recharge). Changes in water levels, temperature and toxicity would be the largest threat, but because there are strict regulations on aquifer withdrawal, water quality control and development over the Edwards Aquifer recharge zone, and with the development of the Edwards Aquifer Recovery Implementation Program (EARIP), our three species of interest in Comal County (Comal Springs Riffle beetle, Comal Springs dryopid beetle and the fountain darter) would be minor to negligible. It is also stated that developing programs such as the EARIP, of which this study is a part, could be beneficial to such species. The primary focus of this RHCP is the take of black capped vireo and golden cheeked warbler habitat, which is woodland and is thus theoretically unlikely to affect the habitats of our species of interest.

The following ongoing or planned authorities, rules and regulations are expected to minimize the impacts on water resources and aquatic species:

- Edwards Aquifer Authority Rules
- Texas Pollutant Discharge Elimination System regulations
- Environmental Protection Agency and Army Corps of Engineers wetlands program
- Texas Commission on Environmental Quality total maximum daily load program
- Groundwater pumping regulation of the Edwards Aquifer Authority
- Texas House Bill 1763: requiring groups of Groundwater Districts to plan for the desired future condition of the groundwater resources in their Groundwater Management Area

- Texas Senate Bill 3: process leading to establishment of minimum environmental flow standards for each river basin in the state
- Water quality regulations of the city of San Antonio
- Edwards Aquifer Recovery Implementation Program
- Creation of a groundwater district over parts of the Trinity Aquifer occurring over Comal County

This environmental impact statement states the maintenance of water levels within the Edwards Aquifer area as established and regulated by the Edwards Aquifer Authority is the strongest measure in protecting the aquatic listed species so much so that it concludes that the RHCP measures proposed would minimally reduce cumulative adverse impacts on such species.
The report lastly discusses the possibility of climate change and other unavoidable adverse impacts and that they would be offset by the preservation of larger blocks of unfragmented habitat.

B. Related Studies:

Bowles, David E,. and Arsuffi , Thomas L. ***Karst aquatic ecosystems of the Edwards Plateau region of central Texas, USA: A consideration of their importance, threats to their existence, and efforts for their conservation.*** **28 Jun 2006 (on-line publication), from Aquatic Conservation: Marine and Freshwater Ecosystems: Special Issue: Endangered Aquatic Habitats - A Symposium of the Entromological Society of America December 1992 Volume 3, Issue 4, pages 317-329, December 1993 John Wiley & Sons, Ltd 1993**
This article identifies the endangered species within the Edwards Aquifer, along with the endemic and unique aquatic biota of the Edwards Plateau. It identifies specific threats from expanding human population including overpumping of aquifers, agricultural practices, pollution, development, recreational activities, introductions of exotic species and changes in regional and global climatic patterns and means for protection and remediation.
This article is most relevant to our focus of study by means of its discussion of water conservation, development of alternative water sources and land management and stewardship programmes.

Newsome, David. Moore, Susan A.. Dowling, Ross Kingston. <u>Natural Area Tourism, ecology, impacts and management.</u> Channel View Publications, 2002.
A book that looks at the evolution of natural area tourism, creation of national parks, preservations areas globally and the means by which

environmental consciousness is leading us to find more comprehensive means of planning and managing the impacts of environmental tourism in such a way that not only heightens the experience of the tourist but also benefits the environment simultaneously. The book has many examples of monitoring and surveying techniques used globally to measure various physical and social aspects to first establish a baseline of use and secondly, direction in which to maximize benefits to both users and the environment. Of particular interest in this document related to our study of the San Marcos and Comal systems are the physical variables that are measured with regards to soil compaction and bank stabilization/erosion. It also lists some effects that have not been discussed previously: noise levels, changes in nutrient availability and distribution caused by disturbing river bottoms as well as disturbance of mating rituals and deposited eggs of various species. This book is a wealth of examples of how and what could be sampled to help monitor the effects of recreation for further study.

***GCAGS Transactions* Volume 48 (1998)**

Barton Creek watershed and springs located under the Glen Rose Formation : found differences in chemistry of shallow ground water between urban and rural settings, including nutrient levels, pH, temperatures, nitrates, ammoia, Kjeldahl nitrogen, specific conductance and total dissolved solids and potential sources of increased nitrogen levels.

Edwards Aquifer Authority. 'Variable Flow Study: Seven Years of Monitoring & Applied Research' . BIO-WEST Inc. August 2007.

This report was made known to the Halff team late in the process of producing this report and was thus not thoroughly reviewed. Over the course of seven years, multiple studies by various academic and government agencies have helped contribute to the findings of variable flows on aquatic habitat with a focus on the federal list of endangered species, the population dynamics and their habitat conditions. Water flow (rates), water quality, water levels, temperature, chemistry, aquatic vegetation, stream morphology were all studied with a focus on the effects on the biological communities. One of the major findings is the importance of aquatic vegetation to the biological community whose changes are measurable and relevant with spring discharge/current flow. The findings include an expanded range of habitat for the Comal Spring riffle beetle, stable populations for the San Marcos and Comal Springs salamanders as well as the fountain darter (but found to correlate with establishment of aquatic vegetation) and that the greatest threats to these species include recreation as well as sedimentation, introduction of exotic species and

aquatic vegetation mats. As so much of water quality is a factor for biological species, such is the importance of aquatic vegetation and Texas wild rice which are most greatly impacted by recreation activities. The document cites direct impacts from recreation on Texas wild rice stands indirectly affect the habitat availability and quality for fountain darters. The study found stable populations in the beetles, salamander species of the endangered species list.

Gramann, James H. ***Toward a behavioral theory of crowding in outdoor recreation: An evaluation and synthesis of research***

This document provides research on physical density versus psychological crowding in outdoor recreation.

Kuss, FR | Graefe, AR ***Effects of recreation trampling on natural area vegetation.***

Journal of Leisure Research [J. LEISURE RES.]. Vol. 17, no. 3, pp. 165-183. 1985.

The injurious effects of recreational use on vegetation of natural areas is influenced by not only plant responses to the direct mechanical effects of trampling, but also by stress factors internal to the ecosystem as well as changes in the physical, chemical and, biological nature of the soil medium. These effects are reviewed by tracing the dimensions of impact through selected stages in the life cycle of vascular plants beginning with seed germination and seedling establishment, growth functions after establishment, vigor and biomass production, flowering, seed production, and finally recolonization of impacted areas.

Sabine River Authority of Texas, Orange, Tx, Sabine River Authority, ***Recreation Use and Needs Assessment Study Plan, Revised Study Plan Toledo Bend Relicensing Project FERC Project No. 2305.*****State of Louisiana, Many, LA, July 2009**

By use of surveys and site analyses, the study explains a methodology for assessing the recreation facilities around the Toledo Bend Reservoir, the demand and factors to look at for carrying capacity. This study may be useful in providing a list of variables in which to help determine limits on the various recreation activities that currently exist on our rivers of study and for any future land (recreation: camping, sports fields, amphitheaters, picnic sites, trails and the like) developments adjacent.

Smith, Kellen A. ***Providing the best of both worlds: balancing conservation and recreation in a system of protected areas in Texas.***

MS thesis, Louisiana State University and Agricultural and Mechanical College, August 2007

Texas Parks and Wildlife Department is charged with the task of providing conservation while offering recreational activities. Using the salient points of the Rio Summit of 1992 on Environment and Biodiversity as a guide, the questions of (a) whether the designated wildlife management areas (WMAs) are successful at providing enough area to adequately represent the various ecoregions of Texas (b) what do visitation rates tell us about what these WMAs offer and (c) do these WMAs adequately fulfill the desires of Texans regarding protection of wildlife and providing outdoor recreation. A list of societal, park management, and individual benefits and goals are presented as well as the variables that limit or attract visitors: proximity to urban areas/highly populated areas, size of WMA, clustering of WMAs, types of recreation activities (consumptive and non-consumptive), existence and number of endangered or threatened species.

Though the San Marcos and Comal River systems are not WMAs, it could be asked if they should be treated or managed as such considering their locations in highly populated areas, the benefits they provide and the number of federally listed species within these ecosystems.

VII. ECONOMIC INFORMATION

A. New Braunfels

'The Impact of Tourism in Comal County', TXP, Inc. December 2007
This study looks at growth between years 2001 through 2006 in the county in terms of employment, population, single family building permits, and sales tax as indicators of the local economy. The graphs presented in the report express an accelerated growth with time. The report notes that tourism has grown at a slower pace than the local economy and cites probable causes such as 9-11, unusual weather patterns, and loss of shopping outlets.

Under the Bureau of Economic Anaylsis of the U.S. Department of Commerce, 'tourism' is not a a distinct industry classification and therefore the numbers in this report are extrapolated from tourist related activity such as restaurant/bar sales and amusement and recreation sales.

Using ratios and adjustments in accordance with statistics of growth in factors like employment, population and building permits, it is estimated the full direct economic impact of tourism for Comal County in year 2002 was $143.6 million, and by year 2006 had grown to $224.9 million.

For the year 2006, sales taxes from tourism generated approximately $5 million for the City of New Braunfels and Comal County, of which river recreation accounted for approximately 20 percent.

2006 River Tourism Calculation:
A survey of 1,046 tubers using the Comal and the Guadalupe entry and exit points at various times in the summer of 2007 yielded the following results:

52 repsondents resided in Comal County
48 respondents reported that tubing was not their primary reason for their visit to the area
approximately 486 were day trip visitors
Approximately 460 were overnight visitors
The average dollar expenditure of a day trip visitor was $27
The average dollar expenditure of an overnight visitor was $187.64

River tourism spending and calculated numbers were based on the following: In 2006, the City of New Braunfels reported more than 208,000 tubers who paid

the tube fee, of which it is estimated (based on the 2007 survey of percentages of out-of-towners and locals) that there were approximately 199,122 tubers who were not local (overnight guests). TXP estimated a blended average daily expenditure to be $113, yielding direct river tourism at $22.5 million for 2006. The full economic impact of river tourism was calculated based on direct spending, indirect spending (such as the additional costs of cleaning supplies for a hotel operator) and the increase in the overall local economy due to the added income by all the above, known as an induced effect. The results of river tourism are expressed in the report as output (equivalent to all sales directly related to recreation users)= $34.3 million, value-added (describes net revenue by reported firms)= $19.2 million, earnings (amount paid out to employees)=$8.3 million and employment = 387 jobs. This output amount represents 12.5% of Comal Country's total travel and tourism economic impact for 2006.

In terms of tax revenue, it is based on revenue from categories with a defined tax rate, such as lodging and the additional tax of indirect services and goods, and the spending of local workers who benefit from the need of additional services due to tourism.

For 2006 in Comal County, it was estimated that river recreation users contributed $630,270 to lodging taxes and $230,435 to sales taxes, totaling $860,705.

While the study recognizes the attraction of the rivers and lakes are the driving force behind tourism in Comal County, it also notes that other aspects of tourism have great potential and that all growth will be synergistically beneficial to Comal County as a whole.

Greater New Braunfels Economic Development Foundation, prepared by Impact Data Source.
'The Economic Impact of New Braunfels' Hospitality Industry 2009'
This report is derived from information available from the City of New Braunfels sales tax collections for the year 2009, and US government data sources, including US Census Bureau's Business and Industry Economic Census and NAICS (North American Industry Classification System) standard ratios. It is important to note that taxable sales do not represent the total economic output for the hospitality industry since not all economic output is taxed by the city; this then is adjusted for by analyzing the various tax types (hotel occupancy, mixed beverage). Direct and indirect economic output in terms of employment and earnings is calculated based on census and NAICS ratios.

Based on the information above, the hospitality industry yielded $469.6 million (direct and indirect sales, induced spending) in 2009. This amount includes various taxes (sales, hotel occupancy , beverage) totaling $12.8 million to the city of New Braunfels alone, with a total of $16 million to all local taxing authorities. $12.8 million represents 19% of the city's total revenue and almost 22% of all sales tax revenue for the city.

$469.7 million is the total hospitality economic output in New Braunfels which represents almost 20% of the total economic activity in New Braunfels. Of that dollar amount:

48% can be attributed to direct economic impacts
52% to indirect or spin off economic impacts
by subcategory:
65% restaurants/ eating establishments
19% entertainment
15% lodging
1% transportation

$70.3 million was paid in wages to those 5,181 people working directly in the hospitality industry and $51.5 million was paid to those 1,798 people working in indirect jobs that support the hospitality industry. The number of jobs represents 27% of the employment in New Braunfels.

Similar to hospitality representing approximately 20% of the economic output of New Braunfels, job earnings represented 19% of the total earnings in New Braunfels.

In addition to providing jobs and revenue to the city, the hospitality industry has a philanthropic component and is reported to have contributed more $722,000 in cash donations, scholarships and in-kind charitable donations in 2009.

<u>Growth</u>
The growth in economic output by the hospitality industry showed a steady increase over the years 2005 through 2009, with an annual growth rate of more than 6%.
The growth in workers' earnings grew 37% in the same period of time and employment grew by 32%

Visitors

The report states over 200,000 people participated in water recreation in the Comal and Guadalupe Rivers in 2009, yielding over $300,000 in river management fees to the City of New Braunfels.

The civic and convention center expanded in 2007-2008. In 2008, approximately 65,000 people attended more than 380 meetings, celebrations, performances, conferences and trade shows, yielding a $232,000 in revenue in their fiscal year with projected revenue of $350,000 for the 2009-2010 fiscal year.

Lodging in the city increased by 4 hotels in 2009, contributing $2.2 million in hotel occupancy taxes. In addition to this economic contribution, construction jobs were created and local sales taxes were increased; cost of construction projects was estimated at more than $21 million. Hotel rooms in the city in 2009 increased to 2,400 rooms.

Wurstfest is a fall event that pays homage to the city's German heritage; it had over 100,000 visitors and yielded over $3 million in 2009. Other events are scheduled at the same time to maximize the draw of visitors to shop, stay and dine.

B. San Marcos

Total number of visitors to San Marcos annually is estimated to be 10 million and is derived from traffic counts from the outlet malls; it is not a scientifically based number but is commonly quoted.

Information from the unpublished dissertation of Texas State University Ph. D candidate Jenna Winters, a 2008 survey of 717 visitors to the San Marcos River was conducted; the following spending was reported:

75% spent less than $25
13% spent between $25-$50
6% spent between $50-$75
7% spent >$100

Based on her survey, 16% of visitors were tubing and that approximately 50% of these tubers rented their tubes. From San Marcos Lions Club Tube Rentals numbers of year 2005 (approximately 30,000), we extrapolate the total number of visitors to the river to be in the realm of 375,000 people.

Based on the percentages of dollars spent, we also extrapolate the revenue from river visitors to be in the order of $12.9 million. (This amount does not account for any change in number of tube users between 2005 and 2008)
So although we estimate 375,000, the Greater San Marcos Economic Development Council in year 2000 estimated 500,000 annually visit the San Marcos River for water based recreation and civic activities adjacent to its banks (Earl & Wood art. 'Upstream Changes and Downstream Effects of the San Marcos River of Central Texas, February 2002).

There is no documentation on the number of river visitors during the period from Memorial weekend to Labor Day, nor is there any data available for revenue generated by tourist activity during that same period.

As of July 15, 2010 , The total number of booked/contracted and actual (Jan-July) events for 2010 was 780 events (this includes groups from 3 to 3,000) for an estimated total attendance of 70,393. The average attendance number per event is 90 persons. 84 conferences have been booked between May 2010 and December 2010 with 14,470 rooms dedicated. . (quotation: Ramirez, San Marcos Convention and Visitor Bureau, July, 2010).

Approximately 2,500 canoes and kayaks (TeGrotenhuis, TG canoes and kayaks, June 2010) are rented out annually and almost 30,000 tubes were rented out in the year 2005 (Fairchild, Lions Club). It is estimated from survey information (Winters, TSU, July 2008 data) that tube rentals represent only about 50% of tubers on the river. No other data was provided and there is no data on total number of boats on the river annually;

VIII. RECREATIONAL IMPACTS & FURTHER STUDY

A. New Braunfels

From stakeholder interviews, public parks are the predominant locations for access to the Comal River. Landa Park, as expressed by one interviewee, is felt to be at or beyond capacity as evidenced by the compaction and erosion along the banks of Landa Lake from foot traffic as well as from deterioration of vegetation caused by the foot traffic. The sentiment of general wear on the landscape was reported by a majority of the interviewees. Litter and negative behavior were also cited by stakeholders as on going issues due to recreation. In the more active recreation areas of the river, access is concentrated in various locations such as at Landa Falls, and downstream at various points along Hinman Island and Prince Solms Park and the public exit at Union Avenue. The river banks along these parks have mostly been reconstructed so erosion of the banks are not as much an issue in these areas, however, the limited availability of picnicking makes them most vulnerable to both the behavioral and litter issues, as well as overcrowding, which impedes access and egress to the river and continues to damage the vegetation and increases erosion.

In spite of these social issues, stakeholders held the value of the river in high regard, citing environmental stewardship, economics and mental and physical rejuvenation as benefits.

Quantitative information from weekly monitoring activities of the Texas Master Naturalist volunteers between 2006 and 2009 inclusive (Bio-West for Edwards Aquifer Authority, March 2010a) provide insight into optimum habitat variables for the listed species. This report provides a good basis from which to observe how recreation affects these variables.

As for reported direct effects, it appears that paddle boats on Landa Lake contribute to the reduction of both exotic and native vegetation (Bio-West for Edwards Aquifer, August 2007) which would both reduce the physical habitat of fountain darters as well as affect the amount of carbon dioxide in the water. Sedimentation and turbidity, which are both affected by recreation users, may also affect listed species albeit on a short term basis, but most significantly, as a result of low flow and shallow water depths, enabling water recreation enthusiasts to access more of the stream bed (Bio-West for Edwards Aquifer, August 2007) . Tubing is reported to be the most popular activity within the water with swimming, fishing as other common activities and rope jumping and

swift water rescue as seemingly less common activities. Along the banks, picnicking and wading and water lounging are activities that one could expect to affect the river. All these activities have varying degrees of direct physical contact/disturbance to the stream bed/bank and thereby affect the river in terms of turbidity but to what degree these activities affect sedimentation (through erosion of banks) and water quality was not precisely found, although water quality data is available for various parts of the river at various times of the year (Bio-West for Edwards Aquifer Authority, March 2010).

In the Comal Springs system, recreation occurs mostly downstream of the confluence of the Old Channel and Landa Lake, where salamanders and macro invertebrate species populations remain stable (BioWest for Edwards Aquifer Authority, August 2007) and higher quality habitat exists for the fountain darters (Edwards Aquifer Authority, December 2009) and thus the recreation along these downstream stretches are not of great concern (Edwards Aquifer Authority, December 2009). The salamander and macro invertebrate species were mostly found within the springs or near the springs and the fountain darters were found to be most populous in native *Cabomba* vegetation found in the deeper waters in the upper reaches of the Comal Springs system including Landa Lake (Bio-West for Edwards Aquifer Authority, March 2010a). Where more careful monitoring of recreation could take place then is within Landa Lake and all areas upstream as these areas are noted to be quality habitat (Edwards Aquifer Authority, December 2009).

As there are so many variables (nutrient levels, pH level, dissolved oxygen, carbon dioxide, temperature, sediment, flow, water depth, time of year, pollutant infiltration, herbivory, precipitation) that can affect listed species populations, it may be challenging to directly link any one source of species disruption. In so far as water-based recreation is seen as a cause for concern, it may be helpful to more closely examine the quality habitat areas (upper reaches of the Comal Springs system) and document the following at various times of the year for several cycles to augment other data that exists:

- Types of recreation (and direct physical contact with banks and stream channel)
- Number of users
- Documentation of pollutants and non-native species (organisms, plants and vertebrates)
- Water levels within the river channels
- Turbidity levels associated with specific recreation types
- Water quality: temperature, pH, nutrient levels
- Current flow

- Precipitation
- Substrate composition and changes in sedimentation in the riverbed
- Bank condition / geology / vegetation

At the same time, it would be useful to continue to:

- Map locations of species found
- Document habitat conditions
- Document life cycle stage of specimens

B. San Marcos

As reported by stakeholders, recreation activity along the San Marcos River is concentrated between Sewell Park on the Texas State University (TSU) campus and Rio Vista Park. This stretch of river is almost completely lined with public park lands with the exception of one residential area on the north bank. As such, much of this stretch of river is accessible except where riparian vegetation creates an obstacle.

From interviewing stakeholders, prime bank activity occurs at Sewell Park, City Park and Rio Vista Park, where people mostly picnic, socialize and access the river with tubes or for swimming. The banks along Sewell Park and City Park are, for the most part, walled with concrete so access in these areas is by ladder or steps. Erosion of the banks is not necessarily a concern in these parts of the river, but erosion of stream bank vegetation within the parks is a concern, along with a concern about disturbance to the stream bottom (Bio-West for Edwards Aquifer Authority, March 2010b) where people tend to congregate not far from their picnic sites.

Where there are no concrete walls there is evidence of trampled vegetation and eroded ground cover (Winters, 2010, unpublished). City of San Marcos park staff indicated river bank erosion issues. The City currently has begun a river bank stabilization project that occurs between Rio Vista falls and Interstate Highway 35. City representatives reported that their community parks master plan aims to provide controlled access points to the river (by planting native riparian vegetation) in an effort to protect their parks and banks from further erosion.

The overall sentiment from the various stakeholders is that even though these river side parks provide an opportunity for environmental stewardship and education, an economic resource and a source of mental and physical rejuvenation, the parks (and associated river banks) are experiencing a

noticeable degradation of landscape through trampling of vegetation, erosion, pollution and litter by the park users themselves.

An economic study in the year 2000 indicated 500,000 river recreation users come to the City on an annual basis (Greater San Marcos Economic Council, 2000). There was no other published information found in this regard. A doctoral research candidate at Texas State University who is currently studying recreation on the river, provided one account of 1,756 users on/in the river during a peak 2 hour period of time on one summer holiday Monday (peak season, but not necessarily a peak day) in 2007.

Over the course of a 3 year period in which this student has been working, she also documented precipitation rates and dates, turbidity, levels of the water, and also prepared a user survey with more than 700 participants over the course of a three year research project. The survey of park users (along the San Marcos River) indicated that 33% stated swimming as their primary activity and 16% stated tubing as their primary activity with an overall of 57% reporting their primary activity was some type of recreation in or on the water.

Other than this unpublished data, and information gathered from stakeholders, we found no other specific information on numbers, types of users nor specific locations for San Marcos users was identified.

Recreation posed the most direct and indirect effect on Texas wild rice (Bio-West for Edwards Aquifer Authority, March 2010b) with mechanical disturbance (by pulling, walking. wading) and in so doing, indirectly affecting fountain darters by compromising this habitat. Data documenting changes in Texas wild rice stands, along with corresponding flow and water levels quantifies the observation of deterioration and fragmentation of Texas wild rice stands by recreation in the San Marcos River (Bio-West for Edwards Aquifer Authority, August 2007). Correspondingly, population dynamics and habitat conditions were examined for each of the listed species.

The overall conclusions were that salamander species and fountain darter populations were stable while invertebrate populations fluctuated (without conclusive factors) for the period between 2000 and 2007 inclusive, while the range of the Comal Spring riffle beetle expanded (Bio-West for Edwards Aquifer Authority, August 2007). However, in looking more closely at population relationships with recreation activity, drought and corresponding low water levels in year 2006 provided greater opportunities for recreation and physical contact with the riverbed and in so doing, habitats of fountain darters (aquatic

vegetation and namely, Texas wild rice) and salamanders were directly adversely affected by increased recreation activity. Reasons cited for the overall stable trend in listed species populations are due to various factors of spring flow, precipitation events (making the salamander habitat spillway at Spring Lake Dam less accessible) and likely most significantly, the sanctifying and restriction of recreation use of Spring Lake, helping preserve quality habitat (characterized by certain vegetation types and low velocities) for namely fountain darters whose reproductive numbers help offset diminished numbers downstream (Bio-West for Edwards Aquifer Authority, August 2007).

In efforts to more closely examine the correlation between river recreation and listed species habitats, it may be of interest to investigate and document a comparison of river environment and habitat factors between Spring Lake and points between Sewell Park and Rio Vista Park where most recreation occurs. Factors to evaluate include temperature, current Flow, water depth, water quality: pH, nutrient levels, vegetation, bank condition, turbidity levels associated with various activities, substrate composition and changes in the riverbed, numbers and types of recreation users and documentation of pollutants and non-native species (organisms, plants and vertebrates).
It would also be prudent to record this data over a course of several seasons and for any critical events (such as flood or high precipitation, hazardous spills etc.).

CONCLUSION

It is clear that the delicate balance of society's needs for recreating while maintaining a healthy perpetually viable natural environment will become more of a challenge with time as population increases create growing demands on these spring and river resources.

While there are definitive observations that recreational activity is adversely affecting the river environment, there is an apparent lack of raw data that could lead to a conclusive threshold of numbers and types of recreational activities in which populations of endangered and threatened species are critically compromised.

Studies reviewed and data collected suggest recreational activities put great pressure on species habitat. With the exception of the unpublished data of Winters and the inaccessible Breslin and Bradsby studies, very little information was found that specifically evaluated recreation as a source of species habitat disruption. In studies about water flow and its affects on species, recreational activities were observed as a consequential impact. In studies about Texas wild rice, low current flow, resulting recreational activities and opportunities were noted to be factors affecting the wild rice populations.

To be conclusive about the impacts recreational activities have on listed species and habitats, a study that is focused on the effects of recreational activities should be conducted. Using water quality data taken from locations where habitats supported the highest populations as a basis, one could compare the same factors where recreation activity actually occurs or immediately downstream from where recreation activity occurs. Type and intensity of recreation use and physical contact, and resulting changes within the banks and river bed would need to be documented, measured and evaluated. From stakeholder interviews, crowding, litter and alcohol are top issues. Beyond the wear and tear human activities cause on the landscape, including riverbed disruption (and resulting turbidity) from shear numbers, humans contribute all kinds of pollutants to these rivers via food, alcohol (excrement, vomit and urine) and lotions worn on the skin.

These rivers offer unique and highly valued recreation opportunities and as the population of Central Texas grows, recreational users will undoubtedly correspondingly increase. Although the upper reaches of each of these springs are restricted in terms of recreation, it should be determined if these areas are adequate in cultivating the growth or at least stabilizing the listed species populations. The questions of adverse and beneficial attributes (of recreation) and threshold and capacity (of recreation users) remain to be determined.

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Appendix A: GIS Mapping Exhibits

EARIP
Recreation Areas
New Braunfels
Comal County, Texas

Map Key

- Recreation Area
- Entry/Exit Area
- Parks
- TCEQ Clean Rivers Water Quality Stations

Recreation Areas
Tubing
NB.1

0 550 1,100
Feet

N

HALFF

OCT 2010 AVO 27520

EARIP
Recreation Areas
New Braunfels
Comal County, Texas

Map Key

- Recreation Area
- Entry/Exit Area
- Parks
- TCEQ Clean Rivers Water Quality Stations

Recreation Areas

Paddle Boats

NB.2

0 550 1,100
Feet

N

HALFF

OCT 2010

AVO 27520

EARIP
Recreation Areas
New Braunfels
Comal County, Texas

Map Key

- Recreation Area
- Entry/Exit Area
- Parks
- TCEQ Clean Rivers Water Quality Stations

Recreation Areas
Picnic Areas,
RV Campgrounds
NB.9

0 550 1,100
Feet

HALFF

N

OCT 2010 AVO 27520

EARIP
Recreation Areas
New Braunfels
Comal County, Texas

Map Key

- Recreation Area
- Entry/Exit Area
- Parks
- TCEQ Clean Rivers Water Quality Stations

Recreation Areas

Swift Water Rescue Training

NB.4

0 550 1,100
Feet

HALFF

OCT 2010 AVO 27520

EARIP
Recreation Areas
New Braunfels
Comal County, Texas

Map Key

- Recreation Area
- Entry/Exit Area
- Parks
- TCEQ Clean Rivers Water Quality Stations

Recreation Areas

Swimming
NB.5

0 550 1,100
Feet

HALFF

OCT 2010 AVO 27520

EARIP
Recreation Areas
New Braunfels
Comal County, Texas

Map Key

- Recreation Area
- Entry/Exit Area
- Tube Rental Locations
- Paddle Boat, Kayak, Canoe Rental Locations

Recreation Areas
Tube, Paddle Boat, Kayak, Canoe Rentals
NB.6

0 550 1,100
Feet

N

HALFF

AVO 27520

OCT 2010

EARIP
Recreation Areas
New Braunfels
Comal County, Texas

Map Key

- Recreation Area
- Entry/Exit Area
- Parks
- TCEQ Clean Rivers Water Quality Stations

Recreation Areas
Fishing
NB.7

0 550 1,100
Feet

N

HALFF

OCT 2010 AVO 27520

EARIP
Recreation Areas
New Braunfels
Comal County, Texas

Map Key

- Recreation Area
- Entry/Exit Area
- Parks
- TCEQ Clean Rivers Water Quality Stations

Recreation Areas
Wading, Lounging, Playing, Rope Swing
NB.8

0 550 1,100
Feet

N

HALFF

OCT 2010

AVO 27520

EARIP
Recreation Areas
New Braunfels
Comal County, Texas

Map Key

- Recreation Area
- Entry/Exit Area
- Parks
- TCEQ Clean Rivers Water Quality Stations

Recreation Areas

All Uses
NB.9

0 550 1,100
Feet

N

HALFF

OCT 2010 AVO 27520

EARIP
Potential Wildlife Habitat
New Braunfels
Comal County, Texas

Map Key

- Area of Potential Habitat
- Parks
- TCEQ Clean Rivers Water Quality Stations

Potential Wildlife Habitat
Comal Springs Dryopid Beetle, Peck's Cave Amphipod
NB.10

0 550 1,100
Feet

HALFF

OCT 2010 AVO 27520

EARIP
Potential Wildlife Habitat
New Braunfels
Comal County, Texas

Map Key

- Area of Potential Habitat
- Parks
- TCEQ Clean Rivers Water Quality Stations

Potential Wildlife Habitat

Comal Springs Riffle Beetle

NB.11

0 550 1,100
Feet

HALFF

OCT 2010 AVO 27520

EARIP
Potential Wildlife Habitat
New Braunfels
Comal County, Texas

Map Key

- Area of Potential Habitat
- Parks
- TCEQ Clean Rivers Water Quality Stations

Potential Wildlife Habitat

Fountain Darter

NB.12

0 550 1,100
Feet

HALFF

OCT 2010 AVO 27520

EARIP
Recreation Areas
San Marcos
Hays County, Texas

Map Key

- Recreation Area
- Entry/Exit Area
- Parks
- TCEQ Clean Rivers Water Quality Stations

Recreation Areas
Tubing
SM.1

0 500 1,000
Feet

HALFF

AVO 27520

OCT. 2010

EARIP
Recreation Areas
San Marcos
Hays County, Texas

Map Key

- Recreation Area
- Entry/Exit Area
- Parks
- TCEQ Clean Rivers Water Quality Stations

Recreation Areas

Fishing
SM.2

0 500 1,000
Feet

HALFF

AVO 27520

OCT. 2010

EARIP
Recreation Areas
San Marcos
Hays County, Texas

Map Key

- Recreation Area
- Entry/Exit Area
- Parks
- TCEQ Clean Rivers Water Quality Stations

Recreation Areas
Kayaking, Canoeing
SM.3

0 500 1,000
Feet

HALFF

AVO 27520

OCT. 2010

EARIP
Recreation Areas
San Marcos
Hays County, Texas

Map Key

- Recreation Area
- Entry/Exit Area
- Parks
- TCEQ Clean Rivers Water Quality Stations

Recreation Areas
Picnicking
SM.3

0 500 1,000
Feet

HALFF

AVO 27520

OCT. 2010

EARIP
Recreation Areas
San Marcos
Hays County, Texas

Map Key

- Recreation Area
- Entry/Exit Area
- Parks
- TCEQ Clean Rivers Water Quality Stations

Recreation Areas
Swimming
SM.5

0 500 1,000
Feet

HALFF

AVO 27520

OCT. 2010

EARIP
Recreation Areas
San Marcos
Hays County, Texas

Map Key

- Recreation Area
- Entry/Exit Area
- Tube Rental Location
- Kayak, Canoe Rental Locations

Recreation Areas
Tube, Kayak, Canoe Rental Locations
SM.6

0 1,000 2,000
Feet

HALFF

AVO 27520

OCT. 2010

EARIP
Recreation Areas
San Marcos
Hays County, Texas

Map Key

- Recreation Area
- Entry/Exit Area
- Parks
- TCEQ Clean Rivers Water Quality Stations

Recreation Areas

Dog Parks
SM.7

0 500 1,000
Feet

HALFF

AVO 27520

OCT. 2010

EARIP
Recreation Areas
San Marcos
Hays County, Texas

Map Key

- Recreation Area
- Entry/Exit Area
- Parks
- TCEQ Clean Rivers Water Quality Stations

Recreation Areas
Wading, Lounging
SM.8

0 500 1,000
Feet

HALFF

AVO 27520

OCT. 2010

EARIP
Recreation Areas
San Marcos
Hays County, Texas

Map Key

- Recreation Area
- Entry/Exit Area
- Parks
- TCEQ Clean Rivers Water Quality Stations

Recreation Areas

All Uses
SM.9

0 500 1,000
Feet

HALFF

AVO 27520

OCT. 2010

EARIP
Potential Wildlife Habitat
San Marcos
Hays County, Texas

Map Key

- Area of Potential Habitat
- Parks
- TCEQ Clean Rivers Water Quality Stations

Potential Wildlife Habitat

Fountain Darter

SM.10

0 500 1,000
Feet

HALFF

AVO 27520

OCT. 2010

EARIP
Potential Wildlife Habitat
San Marcos
Hays County, Texas

Map Key

- Area of Potential Habitat
- Parks
- TCEQ Clean Rivers Water Quality Stations

Potential Wildlife Habitat

San Marcos Gambusia

SM.11

0 500 1,000
Feet

HALFF

AVO 27520

OCT. 2010

EARIP
Potential Wildlife Habitat
San Marcos
Hays County, Texas

Map Key

- Area of Potential Habitat
- Parks
- TCEQ Clean Rivers Water Quality Stations

Potential Wildlife Habitat

San Marcos Salamander, Texas Blind Salamander, Comal Springs Riffle Beetle

SM.12

0 500 1,000
Feet

HALFF

AVO 27520

OCT. 2010

EARIP
Potential Wildlife Habitat
San Marcos
Hays County, Texas

Map Key

- Area of Potential Habitat
- Parks
- TCEQ Clean Rivers Water Quality Stations

Potential Wildlife Habitat

Texas Wild-rice

SM.13

0 500 1,000
Feet

HALFF

OCT. 2010

AVO 27520

APPENDIX B: EARIP Interviews 6/30/2010 NEW BRAUNFELS

	NB-1	NB-2& NB-3	NB-4	NB-5	NB-6	NB-7	NB-8
1. What are the peak times of recreation use: days, seasons, months, holidays, hours?	Peak times 1-6 pm. Saturdays heavier than Sunday unless it is a holiday weekend.	Rent tubes/allow kayak on property – let tubers *** on shuttle back to drop in point. J/1 weekends – week before Monday – close Labor Day. Holidays busiest. July/May busiest months. (10a.m. – 5p.m. July – close @ 8p.m.	Year round open - - Memorial Day to Labor Day. River used anytime school is out and weather is warm. Memorial Day was over crowded. Canyon Lake was at right level in January, which guaranteed continue flow at 300cfs throughout the summer on Guadalupe River. Last 2 seasons there was 60 cfs flow (slow), now good flow is 200 cfs for good tubing on Guadalupe	Herron Island closed to vehicle traffic (weekends during Memorial/Labor Day) No need to restart times of use.	Memorial Day to Labor Day, primarily weekends, during afternoon hrs.	April thru first of September with peak useage on two holiday weekends	
a. How many people are using the river at these times?			Heat, drought, crowding made last year rough.	Hinman Island Drive 16th and 17th Lots of trash blows in from River area. Noise from adjacent foot traffic toward golf 18th fairway has stray golf balls into parking lot. Not enough parking for patrons.	Per typical peak season weekend: Comal – 3,000 – 5,000; Guadalupe in city limits 500 – 2,000	Unknown as the fee is not broken out by river. In one year the total in the City Limits between the rivers was 187,000 Divided by the 110 days of season is about 1700 people per day split between 10+ miles of rivers	
b. What areas of the river see the highest amount of use?	Hinman Island to last tubers exit				Comal: Hinman Island to last exit; Guadalupe: Gruene Bridge to Cypress Bend Park Exit	Those with free entrance	
2. Should there be restrictions on times of use or hours of use?					Daylight hours only – safety factor	You can legally limit public property access but not private …. So use of the river cannot be restricted by State Law	No
3. Does use have any correlation with water flow or river levels?	Comal River is almost constant flow. Guadalupe river varies with season and year. When Guadalupe River has low flow, tubers switch to Comal River.		Perception people have of water flow – flood is worse because visitors think it is unsafe.	POS visual beauty of river adjacent to golf course, wonderful experience. Small % of golfers use river.	Use increases with CFS flow > 150. Declines when <750 CFS	Use is limited based on too much or too little flow and limits to public access, however, State Law supersedes and enables access to all Texans unless under a Declaration of Disaster	Yes. This user recirculates the river water, and there was a time in the 1980's that the river was low enough to cause concern about availability to recirculate the water. But in general, what occurs on one part of the river, or rivers, affects use on the other parts. For example, a flooding event on the Guadalupe River might have a negative affect on the Comal because visitors would think both rivers had been damaged in the flood. The New Braunfels Chamber recently did a study that indicated that the City lost over $1 million of potential business each day as a result of the recent flood.
4. Can recreational activities on the river continue at current levels of activity?	#'s in park are highest. Lots of wear and tear in park. Picnic areas are always at or beyond capacity. City trying to limit # of people who rent pavilion areas, and also breaking rental units up into smaller components (Dance Slab only rented with Area #4).			Fishing; tubing; camp out; swimming;	Yes	Price point dictates volume, behavior, and resource support.	Yes
a. Why or why not?	Trying to use capacity of restrooms to determine maximum number of people who can be in an area, or when to rent porta-potties. City needs to update picnic ordinances (killing grass, stopped up restrooms) Real solution is to develop Fisher Park. Spring Fed Pool, Hinman Island.				Very limited already due to summer vacation schedules. Basically 20/30 days/afternoon per year for peak use.	The above and State Law says it belongs to Texas Citizens	Activities have occurred on the river for years and the habitats are surviving and thriving.

5. If arriving at the river by vehicle, where do people park (private lots, owned by recreation outfitters or other private lots? Street? Public park?).	All outfitters run shuttles, All outfitters at Prince Solms across street.				Designated lots by city ordinance. Businesses/outfitters provide majority of space.	Satellite lots and shuttled in, small on street parking, and public owned lots	
a. Do the majority of recreational users use commercial shuttle buses and are those desirable?	Shuttle 50/50 tube rental vs. bring own tube. Circle Arts parking lot allows parking. Elizabeth Street parking lots used by picnickers.				No. Trend is for private equipment/tubes and non-use of outfitters.	70% use outfitters and 30% or less have the ability to access public locations or public parking. Outfitters shuttle 20% of private equipment users	
b. How many people (or what percentage of people) arrive at river tubing/raft launch locations by private vehicle versus shuttle bus?					60 private/40 shuttle	15%	
c.Is one method of arrival preferable over the other?					Prefer all shuttle	Shuttle is preferable	
6. Do most users access / launch from public/city owned property or private property?					Public	On the Comal – public 50% Private 50% (including Texas Tubes and Wurstfest) On Guadalupe all access via Private Property with one publicly owned exit on the Guadalupe	Most of the users form this providers facility enter and exit the river on this user's property.
a. Please list all known points of access and launching.	Hinman Island, Prince Solms				Comal: Wurstfest grounds, Hinman Island, Prince Solms Park/Tube Chute	Comal – launch at Wurstfest, Texas Tubes, Hinman & Prince Solms as well as from Resort properties that line the Comal River. Guadalupe launch from private property	
7. Do most users exit the river at public/city owned property or private property?	Public				Public	70% public exit on Comal and 30% private. On Guadalupe 100% launch private and 35% exit public	
a. Please list all known points of exit.	Last tubers exit (Union St.) Garden Street Tube Chute Gruene Bridge @ Cypress Bend Park (Guadalupe River)				Comal: Last exit & Union St. & Garden St. Guadalupe: Gruene Bridge or Cypress Bend Park	Resort Properties, Rockin R, and Last Public Exit on Comal, Guadalupe – private property and Cypress Bend or River Acres	
8. What recreational activities other than tubing, rafting and fishing occur along the river?	Tubing/swimming majority on Comal. Scuba diving. Swift water training at tube chute during off season. Socializing, wading, water play, drinking, grilling Off season: swift water rescue training Difference between tubers and picnickers – picnic and barbeque all day. No open containers in Herron Island Park	Picnicking Nefarious activity		picnicking	Camping along Guadalupe. Comal is primarily Surstfest Grounds, City property and Schlitterbahn before private residentces. Not much camping along comal except across Wurstfest grounds.	Scuba, Swift water rescue and triatholon training on Comal, Fishing, Kayaking, and rafting on the Guadalupe	
9. What specific locations are most frequented by these other users?	Hinman Island, Prince Solms, Landa Park	Picnicking at Wursfest & parks Wading at parks Nefarious activity up stream from Wurstfest		Hinman Island	Gruene	Tube Chute and Hinman Island	The new channel

10. What are the positive aspects of recreation on the river?	Rivers are best of what NB know for, character, notoriety. Reason was settled. Positive on the economy	Economics – employment for young people, education for young in town (31 employees) **** large part of business is visitors. *****		Nice backdrop for the golfcourse	Outdoor enjoyment, fresh air, relaxation, cool water	Tourism generated 469.7 million dollars to the New Braunfels economy in 2009.	Positive impacts to local economy; job creation, pleasure or recreation in natural setting.
11. What are the negative aspects of recreation on the river?	Behavior/mess and trash/infrastructure needs re-investment (the stairway going down to the Tube Chute needs a face lift) Parks are at overcapacity/degradation of parks, landscape	Kayakers stop at their property without paying	70% of trouble on the river is alcohol related	Trash on the golfcourse that is carried in by wind	Sunburn, dehydration	Same as at any major attraction with high visitation – litter and behavior	River has to be managed. Police it, preserve it, maintain it.
12. How important are river-based recreational activities to the local economy?					Water is the brand of New Braunfels. Impacts entire economy of tourism, even those not water-related.	Huge – they are the anchors to our community from a heritage point of view, a cultural point of view, industrial relocation, as well as quality of life – besides being the "only place in Texas" anchor for our number 1 industry – tourism – as it has been for over 150 years.	VERY
a. What are its contributions: i.e. sales tax, property taxes, other taxes/fees, spin-off businesses (related revenue sources for the city)?				Convention $: some people golf, some people tube		According to a recent study done by Impact Data Sources – 469.7 Million in 2009, employed 5181, another 1798 indirect jobs, paid over 70-.3 million in local wages and supported another 51.5 Million in wages to indirect workers. Hospitality industry paid over 10.5million in taxes and other revenues to the City of New Braunfels and in total contributed 13.7 million in taxes and all local taxing districts.	
b. How much does recreation activity contribute to the local economy? (in $ or % of city revenue)		Lots of restaurants, souvenir shops, etc. Water 72-degrees year round; people use water year round.	River makes it desirable as a backdrop and as an attractant.		$12 million annually direct to tax rev. contribution/economy. Indirect - $1 Million per day if not operating.	$469.7 million in 2009	
13. What is your perception of the level of enforcement on the river? Too much, not enough? Why?	Enforcement in fluid situation – changes every day, every year. More people, more behavior issues. 3 to 5% of visitors cause trouble – 1/2 of them for New Braunfels (less than River Walk) Attraction-based leisure visitation. The River has been an attraction for over 125 years. Hard to enforce so many rules.	Locking lid requirement for coolers is good. The size restriction limitation is bad.		Good as it is. Police Dept. does good job at keeping rowdy people off (golf) course.	Anouth. Has been consistent for several years – needed.	Admirable and good Why? Courteous and proud of our community.	Fine as is. July 4th holiday seemed to be a little overstaffed, but other than that is OK.

14. Is the amount of regulation with regards to activities on the river acceptable? Should there be more? Or less?	Alcohol is an issue. Hard to enforce all rules. Park rangers not certified peace officers, hey collect picnic fees. Can't legislate stupidity; price point dictates everything; value correlates with expectations	Too many regulations to be enforced. Cooler law increases # of tubes b/c of limit of cooler size and limited # of coolers per tube. City occasionally closes river due to bacteria due to overcrowding (but not public access points) Union Street is better exit point (free) Garden Street is smaller, less developed exit point. Entrance at **** no regulation to dropping off tubers.	Alcohol causes 70% of problems on river. Mob mentality; legal to drink. Visitors are slobs, they litter and they have basic disregard for environmental responsibility. Enforcement difficult with large masses or people.	Better regulation/reduction in alcohol use.	No more. Just right.	Yes Should there be more? Or less? No more – price point dictates behavior, demographic, etc…	Fine as is, but maybe a little over regulated. Some ordinances seem to be attempts to control issues that no longer exist. Regulations need to be periodically reevaluated for applicability.
a. Are there certain things that should be regulated that aren't currently?			Editor of local paper called for a ban of alcohol on the river		Access points aren't managed - controlled	No	
b. Are there certain things that are currently regulated that shouldn't be?					No	Maybe	
15. What is your perception of the level of maintenance? Too much, not enough? Why?	Pay company to scuba dive and clean river. Trash is big issue. Litter contract to clean parks and separate contract to work river edge. River fund contributes to this (in addition to other river management issues).	OK as is; Trash Fest in October at end of the summer season, and another night after Labor Day and small ones through out season			Good. Consistent last 3 years with new river manager	Infrastructure needs some help…	Acceptable
16. Are there operational issues with regards to emergency flood situations?	Fees – $1.25 for every tube that's rented goes to river fund litter bags, litter pick-up, the Watershed Program Manager's salary, police overtime, and ½ of a Park Ranger salary. Study done 2 years ago about river recreation impacts to economy. Overall impact positive, but not as great as people thought				None	Our community takes care of itself and always has.	
	Additional notes: regulating alcohol is an ongoing contentious issue		Additional Notes: NBU has waster water plant that has flooded 3 times in last 12 years. Unnecessary contaminate; 100 yards away is land above 100 year floodplain				

APPENDIX C: EARIP Interviews 6/29/2010 SAN MARCOS

	SM-1	SM-2 SM- 3	SM-4, SM-5, SM-6	SM-7, SM-7	SM-8	SM-9	SM-10
1. What are the peak times of recreation use: days, seasons, months, holidays, hours?	Long weekends and in general: Memorial Day to Labor Day/Kids out of school/would start during Spring Break, but didn't happen this year because no bldg. (at Lions Club). Rio Vista Dam brought new group to the city. Very popular with visitors – not allow pop up tents or barbecue pits on Cheatham Street side of River. Limited space for people to get out of river w/tents and pits in the way there at Cheatham Street.	Sat/Sun in the Summer Canoes & kayaks 9pm-9am during tubing months to avoid conflicts	11 – 4 pm on weekends for tubers. Lots of kayakers in the off season. .Kayakers allowed at Rio Vista Falls after 10 p.m. and before 9 a.m. Last Lion's Club shuttle at 7p.m.. Lions Club dictates when season starts (1-2 weeks before Memorial Day.)	Canoeing in early May & September. All during school year when weather is nice people are at Sewell Park (TSU).		*Weekends, summer time, June-early August, especially holidays, noon-4 pm*	
a. How many people are using the river at these times?	There have been tube counts, Melanie has some of these. Weekends highest use.	+/- 3400 people/year on river in kayaks. Boaters/swimmers #'s dwindling. Majority of users are tubers/waders, but also a lot of people on the shore barbequing and waiting on bus.	Jack has counts of people on river. 2005 tube rentals: 29,829 (May- Sept)			*I don't know, but either the numbers or the practices indicate too many.*	
b. What areas of the river see the highest amount of use?	Rio Vista; Sewell Park	Launch @ City Park and pick people up 7 miles out of town. Swimming by Salt Grass Restaurant (former Ice House)	Ducky Derby – Duck Raffle; Occasional big raft w/rafting groups; kayak events 2 times/year (kayak basketball or rugby) Cables are installed at Rio Vista from Oct thru Feb for kayak events.		Rio Vista	*City Park and Rio Vista (bank users) and from city park to Rio Vista (tubers)*	
2. Should there be restrictions on times of use or hours of use?	Restrictions on alcohol use have been suggested, but might not be good for city because of actual volume of alcohol sales.	No restrictions on times of use		April – May for this park. 10 a.m. – 6 p.m. Outdoor center closes @6 pm. "Thug" community comes out at 6 pm	No issue w/ current hours restrictions	No	
3. Does use have any correlation with water flow or river levels?	Float time varies with river flow. 45 minutes t0 1 hour depending on amount of flow.	River is hardly used in winter months, except by kayakers (Nov-May). Water flow has no real impact on # of users. If Guadalupe River slows down, and/or Comal gets too busy, San Marcos River use increases.	City has low flow/high flow #'s. Melanie has city counts. Katherine Nichols has #'s posted on website. TX State has done studies. Geography Dept has done counts. 50 – 60% of tubes are Lion's Club tubes	More a correlation with Weather than water flow. If Guadalupe floods, will see more users on the San Marcos		*No, not direct river use. Aquifer use does.*	
4. Can recreational activities on the river continue at current levels of activity?	Tubing is limited by having only one tubing vendor	Too may tubers in river spoil experience for other users. Yes ..see a. below	Appendix in Master Plan discusses overcrowding issues and encroachments on bank at Rio Vista by shore users; lack of signage or bad signage		No issue with # people on river, don't want any limitations.	*Yes it can, but*	
a. Why or why not?		With good rules, good patrol, good park maintenance Huge increases would be detrimental to everyone's enjoyment				Yes it can, but the quality of water and parks will continue to be degraded at this rate. If we wish to see the quality of water and parks maintained or even enhanced then something has to give. Either the recreational activities, including the shear number of users, or the practices of recreational users must change. I'd prefer that it be done by creating a culture of respect and stewardship of the river, rather than totalitarian regulations. I believe this can be achieved, but then again I have full faith in my fellow man and woman.	
5. If arriving at the river by vehicle, where do people park (private lots, owned by recreation outfitters or other private lots? Street? Public park?).	Parking is an issue; not enough	'I do not think we should building parking lots anywhere near the river to accommodate river use. Having people park in university parking lots on the weekend and getting shuttled to the river is a good idea. Thos eparkin glots are basically empty except during occasional special events. This would require an interlocal agreement with the university.	Street & park parking	Parking is an issue in County. Lots of people parking illegally on campus property. (no public parking at TSU) Crowding/traffic		*City parking lots (public parks)*	Parking is always an issue. Will change configuration of parking around the river corridor; purchased 3 trollies from Austin to move people between hotels. Could use as a pilot program to move people around.
a. Do the majority of recreational users use commercial shuttle		Blue Bus. Shuttle around (leased bus for Lions Club.	Majority use trails along the river to repeat tube float		Springtown Shopping Center is vacated; could be used for remote	*No. Most people drive. Even those that use commercial shuttle buses*	

buses and are those desirable?					parking and shuttled to the river.	*drive to get to the river and then they get a shuttle back to their car. I'd prefer that those who are able bodied walk back to their car. It's about a 10-15 minute walk.*	
b. How many people (or what percentage of people) arrive at river tubing/raft launch locations by private vehicle versus shuttle bus?						*I don't think that the person who wrote this questionnaire lives in, or understands how people use the San Marcos River. Again, the majority of people drive to the river. Then some people tube the river from City Park to Rio Vista. Then some of those people take a shuttle back to their car, which again is parked at a city park parking lot.*	
c. Is one method of arrival preferable over the other?						*Walking and/or riding a bicycle. Driving to the river is kind of like shitting in the river.*	
6. Do most users access / launch from public/city owned property or private property?	Parks & University	Most use public property to launch	90% of users launch at City Park and take out at Rio Vista. City will eventually have designated in and out locations				
a. Please list all known points of access and launching.	Sewell Park, City Park, Dog Park(San Marcos Plaza), Don's Fish Camp (tube rentals)	City Park	City Park			*Public. City parks and university property.*	
7. Do most users exit the river at public/city owned property or private property?	*** Outdoor Center has kayak week at Rio Vista Falls to teach kayaking						
a. Please list all known points of exit.		Beyond city limits	out at Rio Vista		Other than Rio Vista: Cape's Camp and Don's fish Camp, Hwy 123, Redwood	*City parks.*	
8. What recreational activities other than tubing, rafting and fishing occur along the river?	Swimming/kayaking/canoeing	Wading, Swimming, canoeing & kayaking (3400/yr), dog play, picnicking, Running, wading, sitting and staring. Used to be diving but now too shallow	Kayak, canoe	Picnicking & glass bottom boat tours	Water lounging (chairs in the river/drinking/eating) Special Olympics and junior Olympic kayak trials, veteran's rehabilitation program	*Well, swimming constitutes the highest percentage of all uses. There is also the praying, the drinking, the snorkeling, the thinking, the watching, the eating, the singing and the living.*	
9. What specific locations are most frequented by these other users?	Outdoor Center has kayak week at Rio Vista Dam to provide kayak instruction & kayak course	Spring Lake Dam/Icehouse (swim), wading @ Rio Vista, dog play at Dog Park (San Marcos Plaza)	Kayak slalom in October Canoe Race from Aquarena City Park to Rio Vista	Picnics & glass bottom boat tours at Spring Lake	Above occur at Rio Vista	*All city and university parks.*	
10. What are the positive aspects of recreation on the river?	Tourism; enjoy beauty of river. Constant 72 water temperature. November – March	Positive: exercise, being in nature, economic good, creating an appreciation for nature and the river will help protect it (stewardship) No restrictions on times of use.		Spring Lake recreation is good because it frames the golf course		*The re-creation of ourselves*	Health/wellness of community; Quality of life; more families to river together, sense of community, increase use increases care stewardship of river
11. What are the negative aspects of recreation on the river?	Trash; parking shortage; more traffic; perception of gang activities because of sports wear.	Not a lot of funds to clean up/maintain river, so nip it in the bud. Erosion on the banks, litter, damage to endangered species, loud obnoxious boom boxes, smell of smoking, cars congestion, bad language, dog feces	Water safety problem – people do un-smart things. More warning signs? More education. People don't pay attention. Provide a video to show users various features along the river. Not Schlitterbahn – natural river that changes daily. Have users understand (not a man made environment. Naturally flowing stream.)			*The lack of respect and stewardship, or culture, leads to all of the negative aspects of river usage. This leads to trash, degraded banks, ripped up stands of Texas wild-rice, loud music, fist fights, dog poop, point and non-point source pollution.*	Population growth has issues; lewd acts, illicit & nefarious activities, Flow of water over falls and currents that people aren't prepared for. EMS response/access and /crowd control/management. Too many people: sanitary issues

			Crowding issues including pop-up tents & too many barbecues Not enough facilities: restrooms				
12. How important are river-based recreational activities to the local economy?		Recreational aspects are important to the economy, but not driving factor. Politicians should realize this and help to keep river nice. 900k/year to maintain river use in New Braunfels is not effective. Fairly important but there are a lot of costs to patrolling and keeping the river clean, and the additional congestion to city streets (probably a wash)		It is the setting for TSU and students are attracted here because of it. River is a draw for Golfers			
a. What are its contributions: i.e. sales tax, property taxes, other taxes/fees, spin-off businesses (related revenue sources for the city)?	Restaurants/bars close to river. (Herbert's on Riverside Drive)			River recreation is a desirable feature to economics and quality of life, if not able to quantify amount. Tom Keys, Wal Mart busy w/visitors to his camp. Water Safari – Starts at Aquarena Springs and to the coast. 6, 4, 3 solo teams. Several thousand people buy gas, stay @ nearby lodging, etc. .		*I don't know the numbers, but you can attribute every single dollar that I've ever spent in this town to the river.*	
b. How much does recreation activity contribute to the local economy? (in $ or % of city revenue)	A lot, but hard to calculate improvements to river are starting to generate businesses year round.		Lion's Club gives $110-125k/yr to local charities. That amount again for training staff to help tube business. TSU geography dept may have studies (Michael Ravel) (geography dept: Richard Earl)	Quality of life facility attracts people to move to the area.		*I would imagine a large amount, but I don't know.*	Not major economic draw, but a reason for people to come. One of top 10 reasons to come to town.
13. What is your perception of the level of enforcement on the river? Too much, not enough? Why?	OK w/current, but more OK. A 'surcharge' for river maintenance would be OK.	About right in town, too little east of the interstate.	1 full time park ranger. More part time staff (rangers) along the river during peak season. Have off duty police officers and use volunteers. All EMT certified.		Enforcement not really an issue	*I've never seen an officer cite someone for littering, yet I see trash at all parks all the time.*	Law enforcement – add more officers/enforcement each year.
14. Is the amount of regulation with regards to activities on the river acceptable? Should there be more? Or less?		It would be great to regulate the use of Styrofoam, glass, aluminum, and plastic bags in and around the river. It would be great to keep dogs out of the SM river within the city limits. It would be great to have a designated area for BBQing that was not to close to the river. It would be great to limit alcohol consumption in the river and parks within town. I'd also be in favor of eliminating loud music – but that is probably not possible.		No, Be careful about restricting recreation on river because users need to learn about the river. Save the wild rice, but don't prohibit use of the river as a recreational resource.			Ensure that there is order and safety, but not ever regulate. Stabilizing banks at City Park and at Rio Vista could help disperse crowds better
a. Are there certain things that should be regulated that aren't currently?		Better litter control/laws needed. Better regulations on type of containers that food/drinks are stored in. Tubers have more impact to environment than swimmers or canoers. No BBQ pits close to river at Rio Vista Dam. Pull them away. Looks like Woodstock. Dangerous for coal disposal. Dog Beach good for dog owner use – but no designated dog area. Dogs are supposed to be on leash. Alcohol is big cause of problems along river. Regulations are administered well with current regulations. Need more trash pick up: would be ice to park rangers or volunteer rangers in the river in canoes going up and down the river on weekend s picking up trash and reminding tubers of the litter rules.	Eliminate alcohol in river and in parks. Make it a family friendly river. City caters to families.	Limit # of people at Rio Vistsa; Limit # of people at Sewell Park; Limit # of people at Lion's club tube rental. Limit access to spring Lake – Texas river safari already limits access to Spring Lake, scuba diver are all people allowed in the lake.		*No Styrofoam. No pop-up tents within 100' of the river. No bar-b-q pits within 100' of the river. No loud stereo systems.*	Provide more access points to disperse the crowds. More public access and****.
b. Are there certain things that are currently regulated that shouldn't be?	Don't understand concern w/saving natural organisms	Limit dog areas More stringent litter laws				No.	Alcohol on the river may be an issue.
15. What is your perception of	More would be good. Better manage	Never enough; too much trash	More funding needed for	Maintenance – good job w/yearly		*Not enough.The University has*	Perception that dredging should

	the level of maintenance? Too much, not enough? Why?	floating islands of debris.		maintenance and cleanup along river. Trash; bbq coals/pup up tents are an issue. Pop up tent overcrowd access points to river and cause conflicts with tubers and swimmers.	cleanups all the way to Gonzalez, but not enough funding. Numerous small cleanups on upper river are good idea. Better control of use and abuse of river – more funding. Volunteers make it a lease viable. Too much trash along the shores – more control in this area would be good. Ban glass bottles on river. Container deposit would be a good idea. with more education. Limit alcohol		*removed a trash can from the headwaters. Trash cans should also be located 100' from the river. The city and university should also abide by storm water protection standards and practice erosion control.*	resume to keep flows to where they used to be. People don't trust science or understand it (dredging the river & it's positive and negative impacts).
16.	Are there operational issues with regards to emergency flood situations?	Dams control a lot of severe floods.					*The university should regularly clean the silt out the retention ponds on Sessom's creek so that this sediment doesn't continue to be deposited into the river at times of flooding.*	Well prepared for floods/****. Well invested in the facilities More wild****
		Additional Notes: Nobody taking initiative w/signage along the River. "Everything" is about the experience of tubing on the river.	Having some informational/ warning signs around the wild rice areas would probably be a good idea.	Additional Notes: Mem. Day – Labor Day – TIBH Easter Seal Group 1 – 9 p Sat/Sun pick trash & empty trashcans. City removed over 60 cubic yards of trash at Rio Vista Dam during memorial day 2010. Provide "boat trash cans" in river to throw empties in. Parking is a huge issue due to shortage of available spaces. Issue more extreme of the extremities of park areas. Parking out of neighborhoods is a good thing. Restrooms are an issue. Drinking fountains are concern as well, and are a big issue during heavy use period of the year. Need to seek balance for demand. Changing rooms needed as well. Lion's Club will have better location.	Additional Notes: Land owners fill stock ponds w/river water and claim it is for domestic use (Smith Ranch) San Marcos River Ranch uses river water to fill lakes on site	Additional Notes: Education Center. Off Site Parking? What about entity?		Additional Notes: Rehab – for veterans coming back from war & folks with disabilities. Junion Olympic trials (kayak)

Appendix D: USGS Water-Quality Assessment of the Comal Springs Riverine System, New Branfels, Texas, 1993-94

Water-Quality Assessment of the Comal Springs Riverine System, New Braunfels, Texas, 1993–94

U.S. Department of the Interior
U.S. Geological Survey

Comal Springs of Central Texas are the largest springs in the southwestern United States. The long-term average flow of the Comal River, which essentially is the flow from Comal Springs, is 284 cubic feet per second (ft^3/s). The artesian springs emerge at the base of an escarpment formed by the Comal Springs fault. The Comal River (fig. 1) is approximately 2 miles (mi) long and is a tributary of the Guadalupe River. Most of the Comal River follows the path of an old mill race, here referred to as New Channel, then flows through a channel carved by a tributary stream (Dry Comal Creek), eventually rejoining its original watercourse. The original watercourse, here referred to as Old Channel, has been reduced to a small stream, the source of which is water diverted from Landa Lake and several springs in the channel. In addition to being an important economic resource of the region, the springs and associated river system are home to unique aquatic species such as the endangered fountain darter (*Etheostoma fonticola*). The Comal Springs riffle beetle (*Heterelmis comalensis*), which exists in the springflow channel upstream of Landa Lake, has been proposed for listing as endangered. The Comal Springs dryopid beetle (*Stygoparmus comalensis*) and the Peck's cave amphipod (*Stygobromus pecki*) are two subterranean species associated with Comal Springs also proposed for endangered listing.

The population in the region has increased 20 to 30 percent per decade for the last 3 decades. This increase in population has correspondingly increased the use of both surface- and ground-water resources in the region, which in turn has prompted concern for habitats of endangered species that depend on the spring water. To better understand the environmental needs of threatened or endangered species, the U.S. Fish and Wildlife Service (USFWS) undertook an intensive ecological assessment of the Comal Springs riverine system. One component of the study involved the effects of varied springflows on water chemistry and aquatic-species habitat in the riverine system. For that study component, the U.S. Geological Survey (USGS) provided continuous monitoring of selected water-quality properties and collected discrete water samples for analysis at selected sites along the Comal Springs riverine system. The purpose of this fact sheet is to summarize the principal results of the USGS water-quality monitoring, sampling, and analyses for selected properties, major ions, nutrients, trace elements, and pesticides during selected periods in the summer and winter of 1993–94. Only high flow (greater than 300 ft^3/s) occurred during the monitoring periods; therefore, effects of lesser flows on water quality were not measured. Data collected from this study and subsequent monitoring

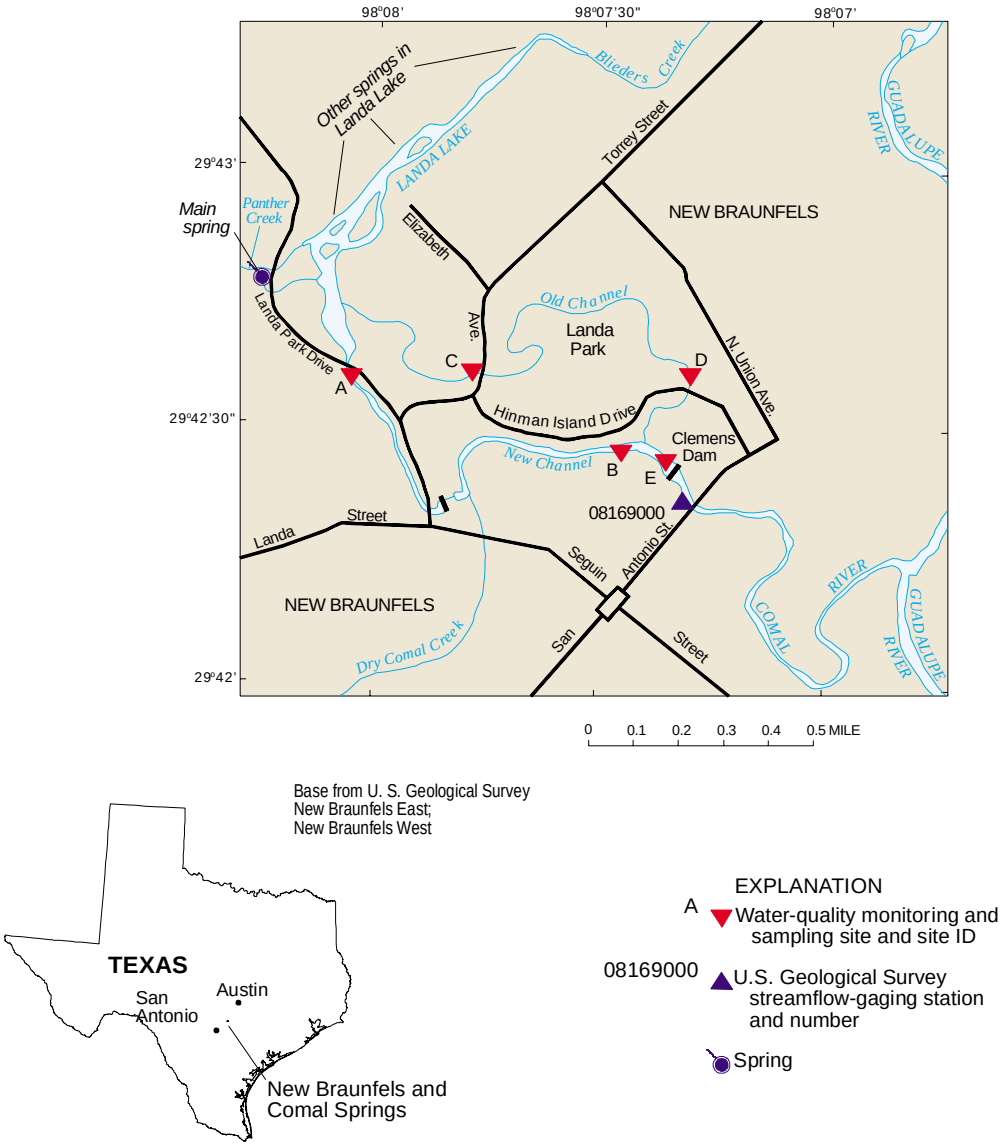

Figure 1. Comal Springs riverine system, New Braunfels, Texas.

can be used to evaluate instream flow habitat requirements of the fountain darter and other aquatic species.

During the monitoring periods, the New Channel received approximately 92 percent of the total volume of springflow by way of Landa Lake. New Channel has a uniform stream channel and higher velocities than Old Channel. In the upper reach of New Channel, west of Landa Park Drive, stream velocities are lowest and the bottom is predominantly large gravel and cobbles. In the lower reach, from Landa Park Drive to Clemens Dam, the velocities are highest and the streambed predominantly is bedrock and large gravel. In contrast, Old Channel received about 8 percent of the total volume of springflow. Old Channel has the meandering characteristics of a natural stream. In the upper reach of Old Channel, from Landa Lake to Elizabeth Avenue, are intermittent riffles and pools and a streambed of silt and assorted gravels. Downstream of Elizabeth Avenue, the stream mostly comprises slow runs and pools with very little riffle habitat; water velocities are minimal and the water appears turbid. The streambed is mostly coarse sediment and mud.

Collection of Water-Quality Data

Site selection and data collection were designed to evaluate physical and chemical properties of the riverine system. Five sites were selected for monitoring the upper and lower reaches of the two stream channels. These sites were evaluated to ensure uniform mixing of water and that monitoring points were representative of the sites. Two sites were selected on New Channel. Site A is at the Landa Lake outfall into New Channel. This site represents the start of the riverine system and a composite of the spring-fed lake waters. Site B is immediately upstream of the confluence of Old and New Channels. This site was selected to monitor changes to water chemistry that might have occurred as water passed through New Channel. Within Old Channel, two sites also were selected. Site C is immediately upstream of Elizabeth Avenue and represents a composite of spring-fed lake water as it enters Old Channel. Site D is on Old Channel upstream of Hinman Island Drive and the confluence of Old and New Channels. Data from site E, downstream of the confluence of the two channels and on the Comal River immediately upstream of Clemens Dam, represent the cumulative effects of Old and New Channels.

The properties of pH, temperature, specific conductance, and dissolved oxygen were monitored continuously during selected periods in the summer and winter of 1993–94. Continuous monitoring of water properties required use of a four-parameter monitoring probe, which was connected to a data storage device and powered by a solar battery. The sites are inaccessible and required use of portable, self-contained floating shelters. To ensure data quality, the instruments were calibrated before and periodically during operation. Monitors measured and logged parameters at 30-minute intervals for periods of 3 to 8 weeks, depending on the site. Property data at the New Channel sites were monitored in the summer from August 20 to September 20, 1993, and in the winter from January 4 to February 3, 1994. Property data at the Old Channel sites were monitored in the summer from June 30 to August 18, 1993, and in the winter from

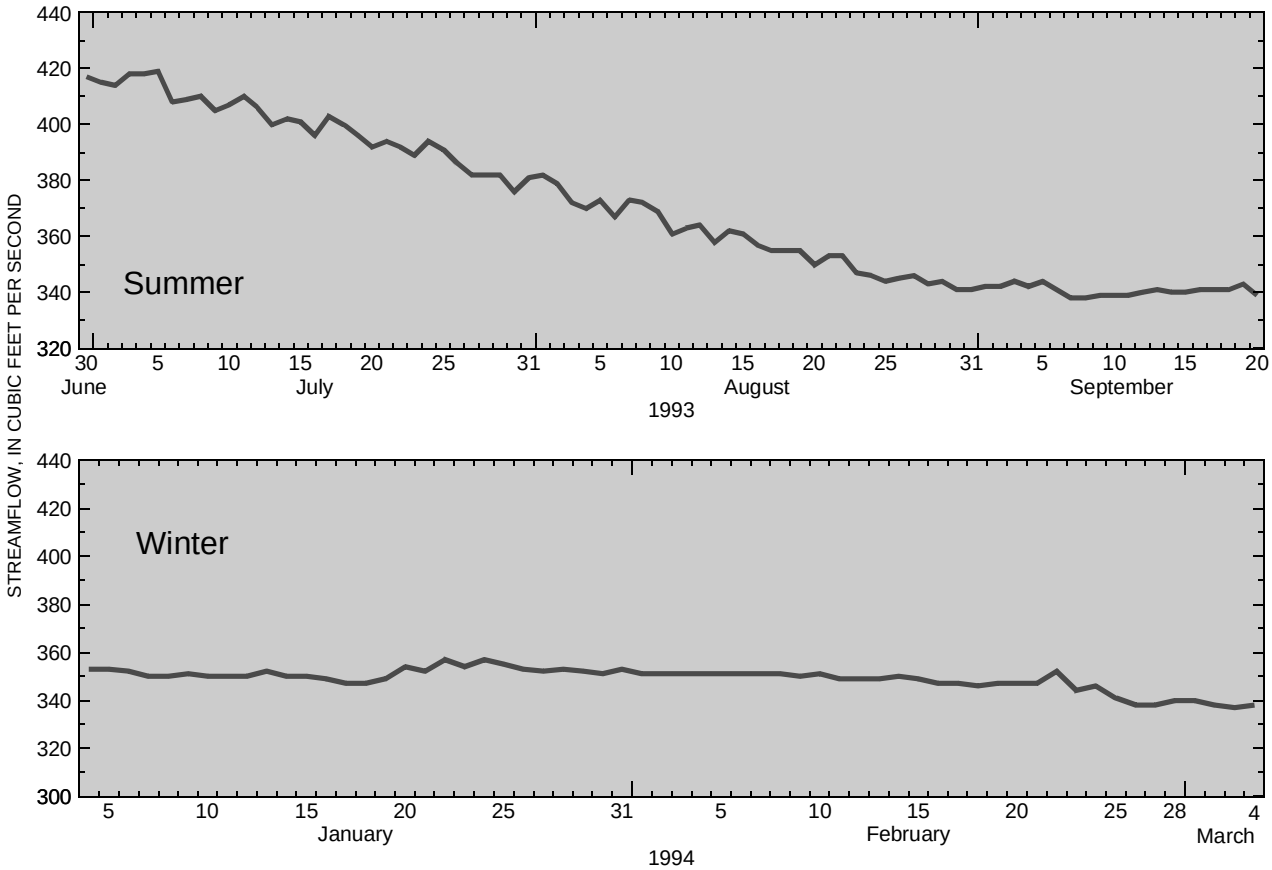

Figure 2. Daily mean streamflow, Comal River at New Braunfels, Texas, during water-quality monitoring periods, 1993–94.

February 7 to March 4, 1994. Property data at the Comal River site were monitored during all four periods. Periodic water-quality samples were collected at each of the five sites. Samples from New Channel and the Comal River were collected near the end of the monitoring periods on September 20, 1993, and February 3, 1994. Samples from Old Channel and the Comal River were collected on August 20, 1993, and March 3, 1994. Samples for major ions, nutrients, and trace elements were collected using a depth-integrated method at multiple intervals along the cross section, then composited. Samples for pesticides were collected using a depth-integrated method at a single interval at the midpoint of the stream.

Table 1. Water properties and major ion concentrations, Comal Springs riverine system, New Braunfels, Texas, 1993–94

[µS/cm, microsiemens per centimeter at 25 °C; °C, degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; <, less than; NA, not available; ft^3/s, cubic feet per second]

Constituent	New Channel				Comal River[1]	
	Site A		Site B		Site E	
	Summer (9/20/93)	Winter (2/3/94)	Summer (9/20/93)	Winter (2/3/94)	Summer (9/20/93)	Winter (2/3/94)
Specific conductance (µS/cm)	548	509	547	509	544	514
pH (standard units)	7.6	7.4	7.8	7.3	7.8	7.1
Temperature (°C)	24.0	23.0	24.0	22.5	24.5	22.0
Dissolved oxygen (mg/L)	7.2	8.2	9.0	9.5	9.0	9.4
Calcium, dissolved (mg/L)	83	82	81	82	80	82
Magnesium, dissolved (mg/L)	16	16	16	16	16	16
Sodium, dissolved (mg/L)	9.9	9.7	11	10	10	10
Potassium, dissolved (mg/L)	.70	1.3	.70	1.3	.70	1.3
Alkalinity (mg/L as $CaCO_3$)	230	230	230	230	240	230
Sulfate, dissolved (mg/L)	23	24	24	24	23	24
Chloride, dissolved (mg/L)	15	16	15	16	15	16
Fluoride, dissolved (mg/L)	.20	.20	.20	.20	.20	.20
Silica, dissolved (mg/L)	12	11	12	11	12	11
Dissolved solids, sum of constituents (mg/L)	307	309	308	309	307	310

Constituent	Old Channel				Comal River[1]	
	Site C		Site D		Site E	
	Summer (8/20/93)	Winter (3/3/94)	Summer (8/20/93)	Winter (3/3/94)	Summer (8/20/93)	Winter (3/3/94)
Specific conductance (µS/cm)	552	529	565	523	547	541
pH (standard units)	7.7	6.9	7.5	7.3	7.6	7.3
Temperature (°C)	24.0	21.5	25.5	20.5	26.0	23.0
Dissolved oxygen (mg/L)	8.1	11.4	4.4	11.8	9.2	12.0
Calcium, dissolved (mg/L)	83	82	85	81	84	81
Magnesium, dissolved (mg/L)	16	16	16	16	16	16
Sodium, dissolved (mg/L)	9.6	10	10	11	9.5	11
Potassium, dissolved (mg/L)	1.9	1.3	1.6	1.3	<.10	1.3
Alkalinity (mg/L as $CaCO_3$)	230	240	240	240	230	240
Sulfate, dissolved (mg/L)	25	24	26	24	25	24
Chloride, dissolved (mg/L)	16	15	16	16	16	15
Fluoride, dissolved (mg/L)	.30	.20	.20	.20	.20	.20
Silica, dissolved (mg/L)	12	12	11	10	12	11
Dissolved solids, sum of constituents (mg/L)	309	310	314	310	NA	309

[1] Daily mean flow, 08169000 Comal River at New Braunfels: 350 ft^3/s - 8/20/93, 339 ft^3/s - 9/20/93, 351 ft^3/s - 2/3/94, 337 ft^3/s - 3/3/94.

Streamflow

Continuous streamflow data (fig. 2) were collected from USGS streamflow-gaging station 08169000 Comal River at New Braunfels during the water-quality monitoring periods. Initial daily mean streamflow of the Comal River for the summer monitoring period was 417 ft^3/s on June 30, 1993, and ending streamflow was 339 ft^3/s on Sept. 20, 1993. A peak flow of 419 ft^3/s occurred on July 5, 1993, and a minimum flow of 338 ft^3/s occurred on Sept. 7 and 8, 1993. Initial daily mean streamflow for the winter monitoring period was 353 ft^3/s on January 4, 1994, and ending streamflow was 338 ft^3/s on March 4, 1994. A peak flow of 357 ft^3/s occurred on January 22 and 24, 1994, and a minimum flow of 337 ft^3/s occurred on March 3, 1994.

Water Quality

Water Properties

Boxplots summarize the distributions of continuously monitored water-property data at the five sites (fig. 3). In some instances, the median is the same as the 25th or 75th percentile. Data were edited to correct for instrument drift and to exclude instrument malfunction. The number of data values per property per site ranged from 1,054 to 2,644.

For New Channel and Comal River, summer median specific conductance shows little variability along the reach, ranging from 547 to 551 microsiemens per centimeter at 25 °C (µS/cm). Winter median specific conductance shows more variability than summer, ranging from 525 µS/cm at site A to 551 µS/cm at site E. Summer median pH increases downstream from 7.3 at site A to 7.6 at sites B and E. Similarly during winter, median pH increases from 7.2 to 7.5. Summer median water temperature increases downstream from 23.5 degrees Celsius (°C) at sites A and B to 23.7 °C at site E.

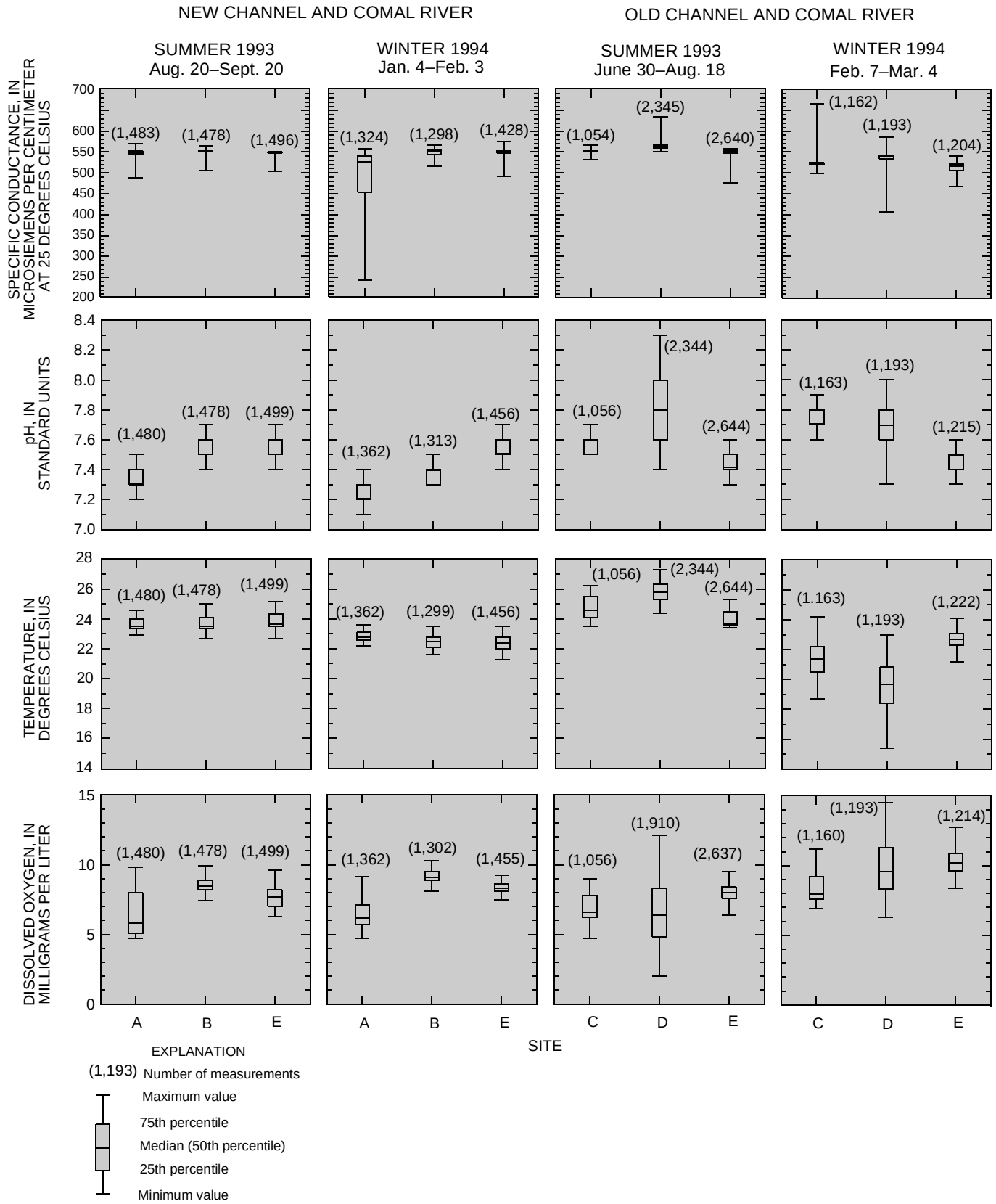

Figure 3. Distributions of specific conductance, pH, temperature, and dissolved oxygen, Comal Springs riverine system, New Braunfels, Texas, 1993–94.

Conversely, winter median water temperature decreases from 22.8 to 22.4 °C. Summer median dissolved oxygen increases downstream from 5.8 milligrams per liter (mg/L) at site A to 8.5 mg/L at site B and subsequently decreases to 7.7 mg/L at site E.

Table 2. Nutrient concentrations, Comal Springs riverine system, New Braunfels, Texas, 1993–94

[mg/L, milligrams per liter; NA, not available; <, less than; ft^3/s, cubic feet per second]

Constituent (mg/L)	New Channel				Comal River[1]	
	Site A		Site B		Site E	
	Summer (9/20/93)	Winter (2/3/94)	Summer (9/20/93)	Winter (2/3/94)	Summer (9/20/93)	Winter (2/3/94)
Nitrogen, nitrate, dissolved	NA	1.87	NA	1.87	NA	2.38
Nitrogen, nitrite, dissolved	<0.010	.030	<0.010	.030	<0.010	.020
Nitrogen, ammonia, dissolved	.030	.020	.030	.030	.030	.050
Nitrogen, organic, dissolved	NA	NA	NA	NA	NA	NA
Phosphorus, dissolved	<.010	<.010	<.010	<.010	<.010	<.010
Phosphorus, ortho, dissolved	NA	NA	NA	NA	.03	NA
Phosphate, ortho, dissolved (as P)	<.010	<.010	<.010	<.010	.010	<.010

Constituent (mg/L)	Old Channel				Comal River[1]	
	Site C		Site D		Site E	
	Summer (8/20/93)	Winter (3/3/94)	Summer (8/20/93)	Winter (3/3/94)	Summer (8/20/93)	Winter (3/3/94)
Nitrogen, nitrate, dissolved	NA	NA	1.39	NA	NA	NA
Nitrogen, nitrite, dissolved	<0.010	<0.010	.010	<0.010	<0.010	<0.010
Nitrogen, ammonia, dissolved	.030	.020	.060	.030	.030	.010
Nitrogen, organic, dissolved	NA	NA	NA	0.27	NA	NA
Phosphorus, dissolved	<.010	.010	<.010	.050	<.010	.010
Phosphorus, ortho, dissolved	.03	NA	.06	NA	.03	NA
Phosphate, ortho, dissolved (as P)	.010	<.010	.020	<.010	.010	<.010

[1] Daily mean flow, 08169000 Comal River at New Braunfels: 350 ft^3/s - 8/20/93, 339 ft^3/s - 9/20/93, 351 ft^3/s - 2/3/94, 337 ft^3/s - 3/3/94.

Similarly, winter median dissolved oxygen increases from 6.2 mg/L at site A to 9.1 mg/L at site B, then decreases to 8.3 mg/L at site E.

For Old Channel and Comal River, summer median specific conductance increases from 550 µS/cm at site C to 562 µS/cm at site D, then decreases to 549 µS/cm at site E. Similarly, winter median specific conductance increases from 523 µS/cm at site C to 540 µS/cm at site D, then decreases to 517 µS/cm at site E. Summer median pH increases downstream from 7.6 at site C to 7.8 at site D, then decreases to 7.4 at site E. Winter median pH is 7.7 at sites C and D and 7.5 at site E. Summer median temperature increases from 24.6 °C at site C to 25.8 °C at site D and subsequently decreases to 23.8 °C at site E. Conversely, winter median temperature decreases from 21.4 °C at site C to 19.7 °C at site D, then increases to 22.7 °C at site E. Summer median dissolved oxygen decreases from 6.6. mg/L at site C to 6.4 mg/L at site D and increases to 8.0 mg/L at site E. Winter median dissolved oxygen increases from 8.0 mg/L at site C to 10.2 mg/L at site E.

In general, specific conductance, pH, temperature, and dissolved oxygen measured at the time of collection of discrete samples (table 1) fall within the range of measurements made by the continuous monitors.

Major Ions

Only slight variability in concentrations of major ions either along reaches or between seasons (along a reach) is observed for the periodic water-quality samples collected during high-flow conditions (table 1). For example, dissolved solids range from 307 to 309 mg/L for New Channel and from 309 to 314 mg/L for Old Channel.

Nutrients

Where measured, concentrations of nutrients and variations in concentrations (table 2) are small. For all sites, nitrate nitrogen concentrations range from 1.39 to 2.38 mg/L, nitrite nitrogen concentrations range from less than 0.010 to 0.030 mg/L, and ammonia concentrations range from 0.010 to 0.060 mg/L. Phosphorus concentrations range from less than 0.010 to 0.050 mg/L, orthophosphorus concentrations range from 0.03 to 0.06 mg/L, and orthophosphate concentrations range from less than 0.010 to 0.020 mg/L.

Trace Elements

Trace elements (table 3) show little variability in concentration either along the reaches or between seasons. Differences in concentrations between sites in the same reach and seasons are small, less than 5 micrograms per liter (µg/L), except for strontium in Old Channel, which decreases by 50 µg/L from site D to site E in both seasons and increases by 50 µg/L from summer to winter at site C. Concentrations of strontium (610 to 690 µg/L) are 1 to 2 orders of magnitude larger than that of other trace elements. Trace elements for which analyses were below detection limits are beryllium (less than 0.5 µg/L), cadmium (less than 1.0 µg/L), chromium (less than 5 µg/L), cobalt (less than 3 µg/L), copper (less than 10 µg/L), mercury (less than 0.1 µg/L), molybdenum (less than 10 µg/L), nickel (less than 10 µg/L), silver (less than 10 µg/L), and vanadium (less than 6 µg/L).

Pesticides

Of 29 pesticides for which samples were analyzed (table 4) only diazinon was detected during the summer at sites D and E, in concentrations of 0.01 and 0.02 µg/L, respectively.

Selected References

Brown, D.S., Petri, B.L., and Nalley, G.M., 1992, Compilation of hydrologic data for the Edwards aquifer, San Antonio area, Texas, 1991, with 1934–91 summary: San Antonio, Edwards Underground Water District Bulletin 51, 169 p.

Table 3. Trace element concentrations, Comal Springs riverine system, New Braunfels, Texas, 1993–94

[Constituents not detected include beryllium, cadmium, chromium, cobalt, copper, mercury, molybdenum, nickel, silver, and vanadium. µg/L, micrograms per liter; <, less than; ft^3/s, cubic feet per second]

Constituent (µg/L)	New Channel				Comal River[1]	
	Site A		Site B		Site E	
	Summer (9/20/93)	Winter (2/3/94)	Summer (9/20/93)	Winter (2/3/94)	Summer (9/20/93)	Winter (2/3/94)
Arsenic, dissolved	<1	<1	<1	<1	<1	<1
Barium, dissolved	51	51	52	51	52	51
Iron, dissolved	<3	<3	<3	<3	3	<3
Lead, dissolved	<10	<10	10	<10	<10	<10
Lithium, dissolved	7	6	8	6	7	7
Manganese, dissolved	<1	<1	<1	<1	<1	<1
Selenium, dissolved	1	<1	1	<1	1	<1
Strontium, dissolved	610	610	620	620	610	620
Zinc, dissolved	3	<3	<3	5	<3	<3

Constituent (µg/L)	Old Channel				Comal River[1]	
	Site C		Site D		Site E	
	Summer (8/20/93)	Winter (3/3/94)	Summer (8/20/93)	Winter (3/3/94)	Summer (8/20/93)	Winter (3/3/94)
Arsenic, dissolved	<1	2	<1	1	<1	1
Barium, dissolved	51	55	53	55	49	51
Iron, dissolved	3	<3	4	<3	<3	<3
Lead, dissolved	<10	10	<10	10	<10	<10
Lithium, dissolved	12	8	13	8	12	8
Manganese, dissolved	2	2	5	4	<1	2
Selenium, dissolved	<1	<1	<1	<1	<1	1
Strontium, dissolved	620	670	650	690	600	640
Zinc, dissolved	6	<3	4	<3	<3	5

[1] Daily mean flow, 08169000 Comal River at New Braunfels: 350 ft^3/s - 8/20/93, 339 ft^3/s - 9/20/93, 351 ft^3/s - 2/3/94, 337 ft^3/s - 3/3/94.

Table 4. Pesticide concentrations, Comal Springs riverine system, New Braunfels, Texas, 1993–94

[µg/L, micrograms per liter; compound in bold was detected]

Pesticide	Detection limit (µg/L)
PCB	0.1
Polychlorinated naphthalenes	.10
Aldrin	.010
Chlordane	.1
DDD	.010
DDE	.010
DDT	.010
Diazinon	.01
Dieldrin	.010
Disyston	.01
Endosulfan	.010
Endrin	.010
Ethion	.01
Heptachlor	.010
Heptachlor epoxide	.010
Lindane	.010
Malathion	.01
Methoxychlor	.01
Methylparathion	.01
Mirex	.01
Parathion	.01
Perthane	.1
Phorate	.01
Silvex	.01
Toxaphene	1
Trithion	.01
2,4-D	.01
2,4-DP	.01
2,4,5-T	.01

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Wells, F.C., 1985, Statistical summary of water-quality data collected from selected wells and springs in the Edwards aquifer near San Antonio, Texas: U.S. Geological Survey Open-File Report 85–182, 162 p.

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—Lynne Fahlquist and R.N. Slattery

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U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Information on technical reports and hydrologic data related to this and other studies can be obtained from:

San Antonio Subdistrict Chief
U.S. Geological Survey
435 Isom Road, Suite 234
San Antonio, Texas 78216
Phone: 210–321–5200
FAX: 210–530–6008
E-mail: gbozuna@usgs.gov
World Wide Web: http://txwww.cr.usgs.gov/

Appendix E: Lodging Revenues

New Braunfels

Hotel / motel tax receipts (rate = 13%)	full year	1st & 2nd Quarters
2005	$ 1,875,936.60	$1,424,537.30
2006	$ 1,991,734.20	$ 1,452,416.00
2007	$ 2,116,439.60	$ 1,458,819.80
2008	$ 2,319,141.70	$ 1,682,902.80
2009	$ 2,151,495.20	$ 1,548,257.20

San Marcos

Hotel / motel taxes

2008	$ 1,698,905.00
2009	$ 2,030,247.00

HALFF

November 4, 2010
AVO 27520

Mr. Robert L. Gulley, Program Director
Edwards Aquifer Recovery Implementation Program
2632 Broadway, South Building, Suite 301
San Antonio, Texas 78215

RE: Response to TWDB comments to Draft Report for "Initial Study of Recreational Impacts to Protected Species and Habitats in the Comal and San Marcos Springs Ecosystems", as a part of the Research Contract for the Implementation of the Edwards aquifer Recovery Program between the Texas Water Development Board (TWDB) and the Texas AgriLife Extension Service (TAES). TWDB Contract No. 1004831037

Dear Mr. Gulley:

Halff Associates has read the comments to the draft report identified above, submitted by the TWDB. As an aid to clarify our responses and proposed actions, we will refer to Attachment I of the TWDB comments by paragraph. Our responses are as follows:

Paragraph One – Executive Summary

The Executive Summary portion of the report revised during preparation of the Final Report to conform to the requirements of Task 11j of the Contract Scope of Work.

Paragraph Two – Tabular Format

Available information has been presented in tabular format throughout the report when possible.

Paragraph Three – Recreational Providers (Pages 4-7)

The list of tube rental and other recreational providers was current during assembly and preparation of data for the report. As mentioned in the body of the report, the tube rental business is a seasonal enterprise, and new businesses readily come and go. Significant flooding events also occurred immediately before and during the time when data was assembled along the Comal River, which resulted in several businesses ceasing to operate for the remainder of the summer season or until further notice. The information shown reflects what was available at the time of the study.

Paragraph Four – Data Collection (Page 7)

Data collection activities conformed to the approved scope of work for the project. All information provided by and for recreational providers is illustrated in the report.

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Paragraph Five – Interview Documentation (Pages 28-38)

Stakeholder participation has been documented in the final report, including number of participants, and locations and dates of interviews.

Paragraph Six – Prioritized Needs and Desires List (Pages 28-38)

Based on comments received from stakeholders who participated in the study, a list of issues, both negative and positive, was compiled. This list of issues is ranked by priority, to coincide with the number of responses and issue related comments provided by stakeholder participants.

Paragraph Seven – Sampling Appendix (Page 39)

In the Final Report, a list of the TCEQ Clean Rivers Program water quality sampling parameters has been included in a tabular format. There is no longer a reference to an appendix in the document.

Paragraph Eight – TCEQ Water Quality (Page 39)

The Final Report discusses the two fact sheets prepared by the USGS between 1994 and 1998, and the relevance to future studies. The TCEQ Clean Rivers data, which includes the same parameters as the previous USGS, is the preferred source for electronic water quality data. The TCEQ data includes more sampling point locations, and is the umbrella program for the state that includes data collected by various agencies such as Texas State University data.

Paragraph Nine – Scientific Studies (Page 41)

The final report includes several scientific studies that are pertinent to the issue of recreational impacts on the two springs and their ecosystems, in addition to those provided in the draft report. As noted in the final report, there were several previous studies that were not accessible by members of the Halff Associates team, including three previous studies cited in the TWDB comment letter. There are also several other research teams and consulting groups conducting on-going projects in the two spring watersheds. Information from these on-going studies was largely unavailable to the Halff team, but may have a bearing on the final outcome of the study of recreational impacts in either watershed.

Paragraph Ten – Economic Studies (Page 50)

The three previous economic studies cited in the final report were the only resources available for review, according to the Chambers of Commerce for both New Braunfels and San Marcos.

Paragraph Eleven – Assessment of Recreational Impacts (Page 55)

In accord with our scope of services, Halff Associates reviewed and recorded data provided by the EARIP, the cities of New Braunfels and San Marcos, their Chambers of Commerce, and various other participants in the study. The final report identifies the results of this data gathering, and summarizes the next steps in the study process that might be undertaken by the EARIP. The final report also offers a conclusion that there is a

significant shortfall in available data related to recreational impacts to listed species and their habitats within either spring's ecosystems. In the absence of any studies that specifically identify recreational activities as an impact or hazard to the ecosystems, there can be no assessment of recreational impacts, or suggestions for mitigation measures to lessen impacts from recreational activities

As stated in the letter from the TWDB to the TAES, Halff Associates will include a copy of this response letter, along with the review comments from the TWDB to the TAES, bound into our final report. Please feel free to contact me via e-mail at wcooper@halff.com, or via telephone at (512) 252-8184 with any questions or comments that you may have.

Sincerely,
HALFF ASSOCIATES, INC.

H. Wayne Cooper, ASLA, AICP
Vice President

Attachments

TEXAS WATER DEVELOPMENT BOARD

James E. Herring, *Chairman*
Lewis H. McMahan, *Member*
Edward G. Vaughan, *Member*

J. Kevin Ward
Executive Administrator

Jack Hunt, *Vice Chairman*
Thomas Weir Labatt III, *Member*
Joe M. Crutcher, *Member*

October 22, 2010

Dr. Edward G. Smith
Director
Texas AgriLife Extension Service
2147 TAMU
College Station, Texas 77843-2147

Re: Research Contract for the Implementation of the Edwards Aquifer Recovery Program between the Texas Water Development Board (TWDB) and the Texas AgriLife Extension Service (TAES), TWDB Contract No. 1004831037, Draft Report Comments for "Initial Study of the Recreational Impacts to Protected Species and Habitats in the Comal and San Marcos Springs Ecosystems"

Dear Dr. Smith:

Staff members of the TWDB have completed a review of the draft report prepared under the above-referenced contract. ATTACHMENT I provides the comments resulting from this review. As stated in the TWDB contract, the TAES will consider incorporating draft report comments from the EXECUTIVE ADMINISTRATOR as well as other reviewers into the final report. In addition, the TAES will include a copy of the EXECUTIVE ADMINISTRATOR'S draft report comments in the Final Report.

The TWDB looks forward to receiving one (1) electronic copy of the entire Final Report in Portable Document Format (PDF) and six (6) bound double-sided copies. The TAES shall also submit one (1) electronic copy of any computer programs or models, and, if applicable, an operations manual developed under the terms of this Contract.

If you have any questions concerning the contract, please contact Matt Nelson, the TWDB's designated Contract Manager for this project at (512) 936-2550.

Sincerely,

Carolyn L. Brittin
Deputy Executive Administrator
Water Resources Planning and Information

Enclosures

c: Matt Nelson, TWDB

Our Mission
To provide leadership, planning, financial assistance, information, and education for the conservation and responsible development of water for Texas

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TNRIS

Attachment I

Review of TWDB Contract No. 1004831037
"Initial Study on the Recreational Impacts to Protected Species and Habitats in the Comal and San Marcos Springs Ecosystems"

Executive Summary: Report does not provide an executive summary "suitable for distribution to third party reviewers and the general public that provides an overview of the study process and resulting recommendations." Please provide an executive summary in the final report that is in accordance with Task 11j of the Contract Scope of Work that includes specific recommendations out of the report.

Throughout report: Report findings in report are not provided in tabular format. Please present report findings in tabular format in accordance with Tasks 11a, 11b, 11c, 11e, 11f, 11g of the Contract Scope of Work.

Pages 4-7: Report lists 6 entities that rent inner tubes in New Braunfels and San Marcos. Please confirm that there are not additional entities that should be included in the report (e.g., R B's Tube Rental, New Braunfels; Riverbank Raft & Tube Rentals, New Braunfels). Please confirm that the report includes a comprehensive list of recreational providers in accordance with Task 11a of the Contract Scope of Work.

Page 7, Section I: Data collection appears incomplete. Information cited as deliverables in the Contract Scope of Work Task 1a (e.g., areas of service, access points, periods of operation, number of participants etc.) are absent for many of the recreational providers. Please include all information for recreational providers in accordance with Task 1a of the Contract Scope of Work.

Pages 28-38: Interviews are not documented in the draft report. Please document the number of interviewees, locations, and dates of occurrence of interviews performed for both the Comal and San Marcos systems under task 11d of the Contract Scope of Work.

Pages 28-38: Report does not provide a prioritized list of needs, desire, likes, and dislikes or an evaluation matrix. Please provide 1) a prioritized list of needs, desire, likes, and dislikes, and 2) an evaluation matrix in accordance with Task 11d of the Contract Scope of Work.

Page 39: In the final paragraph on page 39 there is mention of an appendix containing the parameters that were sampled, yet there is no such appendix. Please include the appendix in the final report.

Page 39 Section V: Report only mentions TCEQ water quality data under Task 11f. Other sources of water quality data should also be considered under Task 11f of the Contract Scope of Work, (if appropriate) including, for example, USGS and Texas State University data. The US Geological Survey collected four water quality samples at the Highway 82 Bridge below Spring Lake (location of USGS gage 08170500) between August 1994 and October 1996. The USGS

has produced a fact sheet related to water quality data collections at other locations on the San Marcos (http://pubs.usgs.gov/fs/Fs05997/05997.pdf). On the Comal River, the USGS collected 29 water quality samples at the San Antonio Street Bridge (location of USGS gage 08169000) between August 1995 and June 1998. A fact sheet http://pubs.usgs.gov/fs/Fs09997/09997.pdf) describes a water quality assessment of the Comal River carried out in 1993 and 1994. Water quality data from the USGS is available online (http://nwis.waterdata.usgs.gov/).

Page 41: Report Section VI includes five scientific studies. Please consider summarizing other pertinent studies under Task 11g of the Contract Scope of Work including, for example:

- Variable Flow Study published in August 2007 (http://edwardsaquifer.org/files/Summary_of_Monitoring_and_Research_for_2000-2007.pdf) which provides information about the impact of recreation on threatened and endangered species in these systems. Other studies of the Comal and San Marcos systems that should be summarized include:
- Bradsby, D.D., 1994, A recreational use survey of the San Marcos River: San Marcos, Tex., Southwest Texas State University, M.S. thesis, 82 p.
- Breslin, S. L. 1997. The impact of recreation on Texas wild rice. M.S. thesis, Southwest Texas State University, San Marcos, TX. 69 pp.
- Stanton, L. L. 1992. Assessment of changes in the aquatic macrophyte community in the upper San Marcos River. M.S. thesis, Southwest Texas State University, San Marcos, TX.
- Owens, et al. 2001 http://www.apms.org/japm/vol39/v39p75.pdf

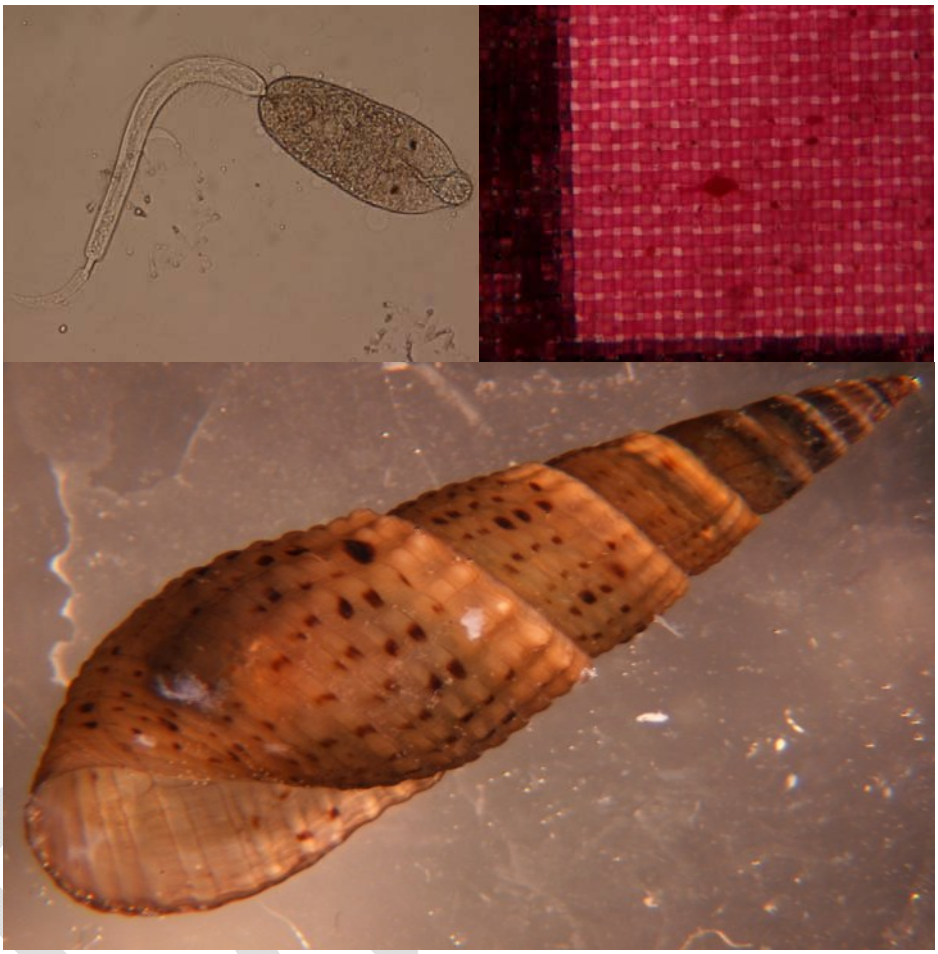
Page 50, Section VII: Report identified and summarized three economic study components. It is unclear if these are all the existing economic study components that are available. Please clarify if these are the only existing study components available related to Task 11h of the Contract Scope of Work.

Page 55, Section VIII: Report does not include two key scope of work deliverables: assessment of recreational impacts; and, suggested actions to reduce negative impacts as required by Task 11e, 1 and 4 of the Contract Scope of Work (Task 11e budget $10,140). Please provide further explanation for why this information required under the scope of work was not included in the report.

APPENDIX M:

UNITED STATES FISH AND WILDLIFE SERVICE SAN MARCOS NATIONAL FISH HATCHERY AND TECHNOLOGY CENTER AND BIO-WEST, INC., "EFFECTIVENESS OF HOST SNAIL REMOVAL IN THE COMAL RIVER, TEXAS AND ITS IMPACT ON DENSITIES OF THE GILL PARASITE *CENTROCESTUS FORMOSANUS* (TREMOTADA: HETEROPHYIDAE)," FEBRUARY 2011

Effectiveness of Host Snail Removal in the Comal River, Texas and its Impact on Densities of the Gill Parasite *Centrocestus formosanus* (Trematoda: Heterophyidae)



Submitted to:

Edwards Aquifer Recovery Implementation Program
Attn: Dr. Robert Gulley

Prepared by:

USFWS San Marcos National Fish Hatchery and Technology Center
and BIO-WEST, Inc.

February 2011

This report summarizes the effort by the United States Fish and Wildlife Service (USFWS) San Marcos National Fish Hatchery and Technology Center (SMNFHTC) and BIO-WEST, Inc. to determine the effectiveness of *Melanoides tuberculatus* removal on lowering drifting gill parasite (*Centrocestus formosanus* cercariae) numbers in the Comal River.

INTRODUCTION

Centrocestus formosanus (Nishigori 1924) is a digenetic trematode originally described in Taiwan that has become widely distributed throughout Asia and warm-watered areas of the world (Mitchell et al. 2000). The trematode was likely introduced into Mexico in 1979 but was not confirmed until 1985 (Scholz and Zalgado-Maldonado 2000) and possibly spread to the United States in the early 1980's (Blazer and Gratzek 1985, Mitchell et al. 2000, 2002). In 1996, metacercariae of the invasive trematode were observed infecting the gills of the endangered fountain darter, *Etheostoma fonticola* (Jordan and Gilbert 1886), in the Comal River in Comal County, Texas (Mitchell et al. 2000). USFWS SMNFHTC biologists observed considerable gill damage caused by the encystment of up to 1,500 metacercariae per fish.

The life cycle of *C. formosanus* has three stages, including a definitive host, a first intermediate host, and a second intermediate host. The definitive host for *C. formosanus* in central Texas appears to be the Green Heron, *Butorides virescens* (Linnaeus 1758), where adult trematodes colonize the colon (Kuhlman 2007). The adult trematodes release eggs into the avian host's feces which, when released into a water body, can infect the first intermediate host, the invasive red-rimmed melania, *Melanoides tuberculatus* (Müller 1774) (Mitchell et al. 2005). The snail is infected either by directly consuming trematode eggs or by being penetrated by free-swimming miracidium that are produced from the eggs (Lo and Lee 1996). Once inside the snail, the miracidium transforms into a sporocyst and asexually produces rediae larvae, which produce cercariae (Schell 1970). Cercariae are released in the exhalant respiratory current and are free to infect the second intermediate host, one of which is the fountain darter. Cercariae penetrate the gill filaments and precipitate cartilage hyperplasia resulting in severe gill lesions, which subsequently reduces respiratory function (Balasuriya 1988, Velez-Hernandez et al. 1988, Alcaraz et al. 1999, McDermott 2000, Mitchell et al. 2000). Once the definitive host consumes the second intermediate host, the life cycle is complete.

In 2009/2010, a study was conducted to 1) evaluate gill parasite concentrations in the water column following an extended drought, and 2) to compare to a similar study completed in 2006/2007 to evaluate gill parasite trends in the Comal system over time (USFWS in preparation). A significant decline in the gill parasite in the water column from July 2006 to July 2010 was observed in the Comal River (USFWS in preparation). Although cercarial densities may be abating, *C. formosanus* still poses a threat to fountain darters in the Comal River. Informal observations suggest that the density of *C. formosanus* cercariae in the water column may increase as stream discharge decreases and vice versa (T. Brandt, USFWS SMNFHTC, personal communication). Upatham (1973) observed that the ability of the bloodfluke, *Schistosoma mansoni* (Sambon 1907),

to infect the bloodfluke planor, *Biomphalaria glabrata* (Say 1818), decreased as stream discharge increased. If this same relationship exists between the *C. formosanus* cercariae and discharge in the Comal River, there are concerns that increased levels of infection pressure could exacerbate the other stresses of low spring discharge on the fountain darter, and could negatively impact fountain darters in the Comal River during low-flow periods.

Elimination of the gill parasite from the Comal River is unlikely. However, a practical approach to manage the parasite in the river might be to control the parasite's snail host, *M tuberculatus*. United States Fish and Wildlife Service and U.S. Environmental Protection Agency authorizations to use chemicals known to be lethal to the snail likely cannot be obtained for the Comal River due to potential impacts to endangered species. Therefore, alternative methods for decreasing abundances of *M. tuberculatus* and the associated parasite need to be evaluated. The goal of this study was to determine the effectiveness of *M. tuberculatus* removal by physical methods on lowering drifting gill parasite numbers in the Comal River.

MATERIALS AND METHODS

The Comal River in New Braunfels, Comal County, Texas, is an approximately 5 kilometer (km) long river issuing from the state's largest spring complex at the edge of the Edwards Plateau region of central Texas (Brune 1981). The headsprings are impounded by two dams to form Landa Lake, from which the spring water flows into two channels, the New Channel and the Old Channel. These channels converge approximately 2.5 km downstream of Landa Lake and flow another 2.5 km before the Comal River converges with the Guadalupe River (USFWS 1996).

A reconnaissance survey of the Comal Springs system was initially conducted to identify areas with high densities of *M. tuberculatus*. This survey focused on areas of high snail density (> 25 *M. tuberculatus*/square meter [m^2]) 5 m^2 or larger. Other considerations for site selection included avoiding potential outside influences which could affect the outcome of the study, such as flood-flows from tributaries or recreational activities. Additionally, the ability to make an accurate and repeatable cross-sectional measurement of gill parasites in the water column immediately below the location was also considered in the selection of study sites.

During the reconnaissance survey, 20 individual locations were selected. At each location, preliminary water samples were collected to evaluate the current level of drifting gill parasites in the water column. Locations with water column concentrations of gill parasites greater than 5 cercariae / liter (L) were considered for study sites while locations with less than 5 cercariae/L were discounted for this study.

Three high density snail areas (snail hotspots) were identified near Spring Island in Landa Lake which had adequate densities of drifting cercariae (Sites S1, S2, and S3) to test the effects of snail removal (Figure 1). One site (Site US) was placed upstream as a control to measure cercarial densities in the water column before approaching snail hotspots

(Figure 1). A fifth site (Site DS) was placed downstream to measure total cercarial densities after passing through all three snail hotspots (Figure 1).

Figure 1. Map of sites sampled near Spring Island in Landa Lake (Comal River, Texas), including three snail hotspots (Sites S1, S2, and S3), Upstream (Site US) and Downstream (Site DS) sites.

At Spring Island, the Comal River splits into two channels immediately below the area of snail hotspots (Figure 1). To determine the downstream site (Site DS) location, cercarial densities in each channel were compared to the upstream site (Site US). This preliminary sampling determined that a significant number of the cercariae released within the study area were passing down the river-right channel ($p < 0.05$), opposed to the river-left channel, which showed no significant change in cercarial density ($p > 0.05$) when compared to Site US.

Once sites were selected, three collection points were established at each of the five sites. Each point was marked with a flagged stake to ensure that subsequent samples would be collected from the same location. At each of the collection points, 5 L water samples were taken at 60% depth from the water's surface. Each water sample was pumped through a flexible acrylic tube (6.4 millimeter [mm] internal diameter) into a 10 L bucket via a battery-operated submersible pump (Attwood aerator pump, Model A500, Lowell, Michigan). The submersible pump was positioned at the desired depth on an adjustable 1.5 meter (m) rod before pumping was initiated. Immediately following collection, 5 milliliters (mL) of 10% formalin was added to each water sample to fix the cercariae. This procedure was performed at each of the five collection sites. Sampling was initiated at Site DS and continued at successive upstream sites, until Site US was reached. This sampling pattern was performed three times per day, at 9:00 AM, 11:00 AM, and 1:00 PM, for three successive days prior to snail removal.

Each water sample was then filtered using an apparatus described in Theron (1969) and Prentice (1984), but using modifications developed by Cantu (2003). Each sample was passed through three successive mesh filters with pore sizes of 220 µm, 86 µm, and 30 µm, respectively. The 220 µm and 86 µm filters were used to filter out larger debris. Cercariae freely passed through the 220 µm and 86 µm pre-filters, and collected on the final 30 µm filter. A new 30 µm filter was used for each water sample. After each sample was filtered, the 30 µm filter was placed in a Petri dish and covered with 3 mL of 10% formalin. The cercariae were then stained on the filters with a 10% Rose Bengal solution. Filters were then transported to the SMNFHTC laboratory where the number of cercariae on each filter was counted with the aid of a dissecting microscope. Formalin wastewater was collected in 18 L jugs and transported to the laboratory. All wastewater was detoxified using DeToX Formaldehyde neutralizer (Scientific Device Laboratory, Inc., Des Plaines, IL) (0.05 oz. DeToX neutralizer/L formalin wastewater) and discarded.

Following three days of baseline water sampling, snails were removed by placing a 2 m x 1 m drop net over the snail hotspot area to be sampled and using a 1 m^2 dip net within the enclosed area to collect all exotic snails to the extent possible. Dip-netting consisted of pushing the dip net across the site bottom and extending down to 5 centimeters (cm) below the surface of the substrate. The area within each drop net was searched until no more *M. tuberculata* were collected. The drop net was then moved to an adjacent area and the procedure repeated until all of the snail hotspot had been covered. This process was continued until snails were removed from approximately 10 m^2 of substrate surrounding each hotspot. All live *M. tuberculatus* were collected, counted, and measured in order to quantify the total number and density of host snails removed from the hotspot.

Following exhaustive snail removal from 10 m^2 around all three hotspots, additional snail removal was conducted for a 30 minute period (3.0 person-hours total) at other locations within the general area. The area covered during this additional removal process was not quantified. As with the snails collected during the previous removal process, snails collected during the timed removal were counted and measured.

Finally, three days following snail removal, cercariae collection was repeated exactly as described above (three water samples per day at five sites for three consecutive days).

RESULTS

Pre-removal gill parasite sampling was conducted from November 9 to November 11, 2010. Prior to snail removal, the furthest upstream site, Site US, had the lowest densities of *C. formosanus* cercariae. Of the three snail hotspots sampled prior to snail removal, the highest densities of cercariae were observed at Site S1, followed by Sites S3 and S2. Site DS showed higher cercarial densities than Site US, but lower densities than Sites S1, S2, and S3. Table 1 shows the densities of cercariae at each site prior to snail removal.

Table 1. Number and densities of cercariae at each site prior to snail removal.

Site	Number of Samples	Total Cercariae	Range (Cercariae/L)	Mean (Cercariae/L)	Standard Deviation
DS	27	379	0.2 - 9.6	2.81	2.24
S1	26	1077	1.6 - 23.4	8.28	4.93
S2	27	572	1.0 - 12.0	4.24	3.18
S3	18	796	1.2 - 23.2	7.24	5.08
US	27	286	0.2 - 4.2	2.12	1.11

The number of samples at some sites was slightly lower due to the occurrence of excessive silt. Excessive silt can cloud filters and prevent accurate counting of cercariae in a sample. One sample from the 9:00 AM round of sampling at Site S1 on November 10, 2010 could not be analyzed because of excessive amounts of silt on the filter. Similarly, five samples collected on November 9, 2010 from Site S3 were also covered with excessive amounts of silt. Consequently, all samples collected from Site S3 on this date were removed from further analysis.

Snail removal was conducted as described in the methods section on November 12, 2010. Snail density was highest at Site S1 followed by S3 and S2. Table 2 shows the number of snails collected, densities, average length, and percentage of snails greater than or equal to 17 mm total length at each snail removal site. The parasite is usually only present in snails larger than 17 mm (Mitchell et al. 2000). The additional 30-minute effort resulted in collection of 859 snails with an average length of 33 mm, of which 93% were 17 mm or larger.

Table 2. Details of *M. tuberculatus* collected at Sites S1, S2, and S3.

Site	Number of Snails Collected	Density (snails/m^2)	Average Total Length (mm)	Percentage ≥ 17mm TL
S1	676	67.6	30	89%
S2	299	29.9	29	98%
S3	374	37.4	20	48%

DRAFT

Post-removal gill parasite sampling was conducted between November 15 and November 17, 2010. Following snail removal, Site US continued to have the lowest cercarial densities. Sites S1, S3, and S2 remained in the same order of declining cercarial densities among the three hotspots. Table 3 shows the densities of cercariae at each site post snail removal.

Table 3. Number and densities of cercariae at each site following snail removal.

Site	Number of samples	Total Cercariae	Range (Cercariae/L)	Mean (Cercariae/L)	Standard Deviation
DS	27	367	0.4 - 7.2	2.72	2.03
S1	27	650	0.8 - 11.8	4.82	2.73
S2	27	408	0.6 - 8.4	3.02	2.03
S3	27	647	1.0 - 15.0	4.79	2.89
US	27	272	0.0 - 4.6	2.02	1.33

Analysis of the pre- and post-snail removal densities (using a paired *t*-test) determined that differences in cercarial densities between the pre- and post-snail removal samples are significant for Sites S1, S2, and S3 ($p < 0.05$; Table 4). Differences in densities were not found to be significant for Sites US or DS ($p > 0.05$). Figure 2 shows a graphical representation of pre- and post-removal cercarial densities.

Table 4. Statistical comparisons of pre- and post-snail removal cercariae densities.

Site	Mean Density (Cercariae/L)		t	p
	Pre-removal	Post-removal		
DS	2.81	2.72	0.316	0.754
S1	8.28	4.82	3.563	0.002
S2	4.24	3.02	2.276	0.031
S3	7.24	4.79	3.463	0.003
US	2.12	2.02	0.435	0.667

DRAFT

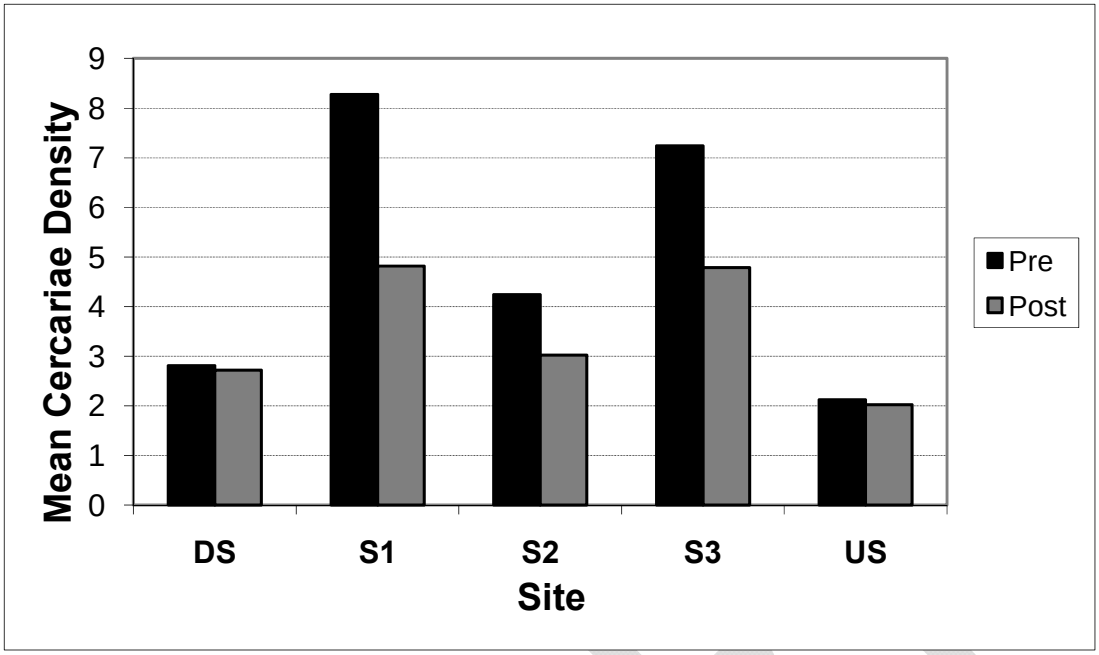


Figure 2. Mean pre- and post-removal cercariae density at each study site.

Cercarial densities varied greatly among the three sampling time periods at each collection site (Figure 3). One-way ANOVA with Fisher's LSD multiple comparison testing determined that cercarial densities declined significantly between the 9:00 AM sampling period and the 11:00 AM and 1:00 PM sampling periods for all five sites ($p < 0.05$). No significant differences were detected between cercarial densities collected during the 11:00 AM and 1:00 PM sampling periods ($p > 0.05$). Only pre-snail removal density data were used in these comparisons to avoid any biases in data that may have been caused by snail removal.

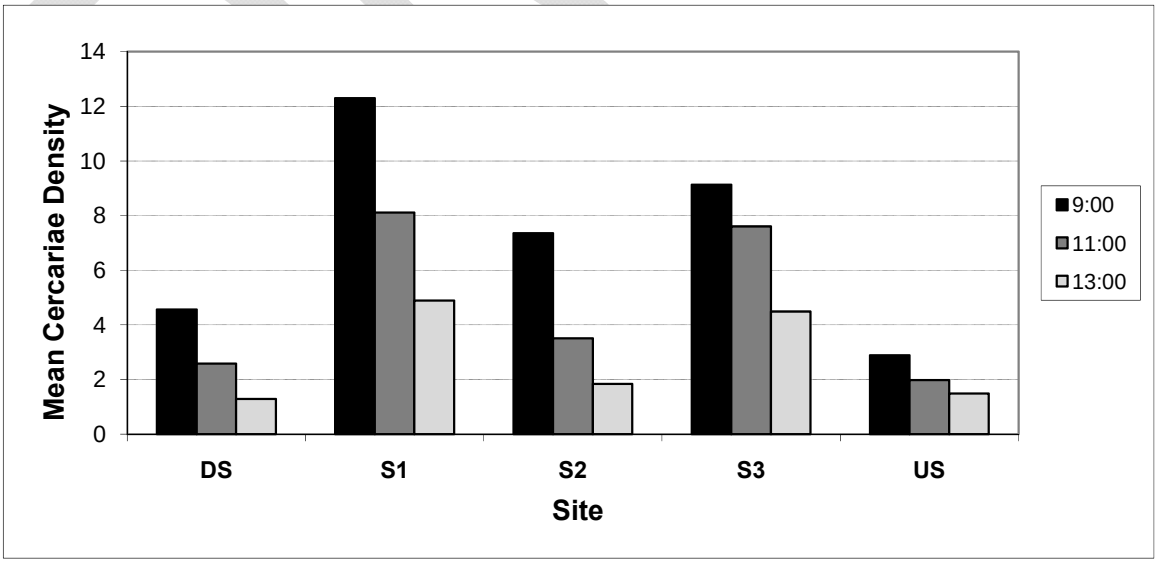


Figure 3. Pre-snail removal cercariae densities at each site across three sample times.

DISCUSSION

The results of this study support the hypothesis that removing *M. tuberculatus* from the Comal River will result in a decrease in *C. formosanus* cercariae in the water column. This was accomplished with a rather modest effort of approximately eight hours of labor by a team of six biologists. However, the effect was localized. Although significant differences in cercarial density were noted in the immediate vicinity of snail removal areas, the downstream site showed no difference, suggesting that a more intensive effort is required to affect snail densities at this location. This downstream location is influenced by cercarial contributions from snails residing outside the specific snail hotspots where intensive removal occurred.

Cercarial densities documented both pre- and post-removal were correlated with the densities of snails at each hotspot. For example, Site S1 had the highest density of snails, as well as the highest cercarial density (both pre- and post-removal), whereas Site S2 had the lowest snail density and the lowest cercarial density of the snail removal sites. Another factor which could have led to differences in cercarial densities between sites is the amount of upstream contribution. Site S1 is the most downstream of the snail removal sites and may have had higher cercarial densities due to contributions by the other hotspots upstream.

Differences in cercarial density between time periods are obviously influenced by time of day. This study found that cercarial concentrations were highest at 9:00 AM and declined at 11:00 AM and 1:00 PM. Cantu (2003) showed a similar trend, with *C. formosanus* cercarial abundance increasing sharply after dawn, peaking around 9:30 AM, and then declining until approximately 3:30 PM. This emphasizes the importance of examining time of day when comparing between samples.

During this study, snails were removed by dragging dip nets across the top layer of the substrate. Drop nets were only used as a means to quantify the area sampled. This dip net method seemed to be rather efficient, especially after biologists became familiar with the habitats where snails were most abundant (low-flow edges and depositional areas). However, this method is only applicable in areas that are wadeable.

This study did not analyze the long-term effects of snail removal on cercarial density. Effects were apparent up to five days after snail removal when sampling ceased. It is not known if these effects would persist. The persistence of low cercarial numbers after snail removal is dependent on snail re-colonization and reproduction rates.

As a result of the potential impact of gill parasites under low flows, *C. formosanus* cercarial concentrations should be monitored in multiple areas along the Comal River on a semi-annual basis, and more frequently when spring flow drops below 150 cfs. The frequency of monitoring should correlate with the rate of decreasing spring flow. Results from this study, as well as Cantu (2003), suggest that monitoring should take place during mid-morning (9:00 AM and 10:00 AM) to capture the daily peak in cercariae release

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within the Comal River. At the least, collection times should be similar at a given site, or between any samples to be compared.

Monitoring should focus on areas with high density of *M. tuberculatus*. To identify such areas, a system-wide survey of snail population density needs to be conducted. Then, to assess the influence of these areas on density of drifting cercariae, cercarial density should be examined just upstream and just downstream of each snail hotspot. Periodically, the river should be examined for new areas of high *M. tuberculatus* densities and those areas should be included in each monitoring event.

Given that the density of drifting cercariae has declined in recent surveys (USFWS in preparation), a system-wide intensive snail removal effort may not be necessary at this time. However, this type of effort may be necessary if snail abundance and/or gill parasite concentrations increase over time or are exacerbated by low flows. The exact density of drifting cercariae which becomes problematic to fountain darters is also unclear. Continued monitoring of the fountain darter population is necessary to examine correlations between cercariae densities and fountain darter infections (documented by inflamed gills). Additionally, water temperature may also play a role in cercariae release (McClelland 1965, Lo and Lee 1996) as Lo and Lee (1996) showed that as temperature increases above 15 °C, cercariae release begins and increases exponentially. As such, continued water quality monitoring is also important.

SUMMARY AND RECOMMENDATIONS

The results of this study confirm that removing *M. tuberculatus* from the Comal River will result in a decrease in *C. formosanus* cercariae in the water column. However, several unknowns remain regarding magnitude and duration of benefits from snail removal in the Comal system, and thus, specific study recommendations are presented to the EARIP as follows:

- evaluate alternative methods for snail removal;
- evaluate magnitude of snail removal necessary to affect downstream conditions; and
- evaluate the long-term benefit of snail removal;

Additionally, although cercarial densities may be abating, *C. formosanus* still poses a threat to fountain darters in the Comal River, especially during low-flows. As such, continued monitoring is essential along with targeted conservation efforts focused on reducing levels of infection pressure from the parasite where possible. The following activities and monitoring recommendations are presented to the EARIP as follows:

- continue existing water temperature monitoring;
- conduct a system-wide survey of snail population density and cercarial concentrations;
- based on system-wide survey, determine whether a system-wide removal effort is necessary, and if so, conduct said effort;

- based on the system-wide survey, design and implement a monitoring program for cercarial concentrations to be monitored in multiple areas along the Comal River on a semi-annual basis, and more frequently when spring flow drops below 150 cfs; and
- continue existing monitoring of the fountain darter population to examine correlations between cercariae densities and fountain darter impacts in the wild.

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APPENDIX N:

UNITED STATES FISH AND WILDLIFE SERVICE, AUSTIN, TEXAS FISH AND WILDLIFE SERVICE OFFICE, "DRAFT 2003 COMAL SPRINGS ECOSYSTEM MANAGEMENT PLAN," JUNE 2003

For Internal Review Only

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Comal Springs Ecosystem Management Plan

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U.S. Fish and Wildlife Service
Austin Fish and Wildlife Service Office

<u>June 2003 Version</u>

For Internal Review Only

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I. BACKGROUND [1]

A. PURPOSE AND INTRODUCTION

The Comal Springs Ecosystem Management Plan (Comal Plan) was developed to help protect and maintain existing populations of endangered and other native species in the Comal aquatic ecosystem. The U.S. Fish and Wildlife Service (USFWS or Service) listed the fountain darter (*Etheostoma fonticola*) as endangered October 13, 1970, (35 FR 16047). The species occurs throughout the Comal Springs and River and in the San Marcos Springs and River. The Comal Springs riffle beetle (*Heterelmis comalensis*), Comal Springs dryopid beetle (*Stygoparnus comalensis*), and Peck's cave amphipod (*Stygobromus pecki*), three aquatic invertebrates, were also listed as endangered December 18, 1997, (50 FR 6629). The Comal Springs riffle beetle is known from specific **habitats** in the Comal spring runs and near spring outlets in Landa Lake, the other two invertebrates are subterranean aquatic species. The Comal Springs dryopid beetle is found in subterranean areas near Comal Springs and Fern Bark Springs in adjacent Hays County. Peck's Cave amphipod is found in subterranean areas near Comal Springs and Hueco Springs, also in Hays County. A number of other unique species also occur in the Comal Springs ecosystem.

The City of New Braunfels has expressed appreciation for this natural treasure and a desire to continue careful stewardship of the ecosystem. They have frequently sought information and advice from various technical experts to assist them in determining the best management practices for protecting the natural resources of Comal Springs. This Plan serves as an aid in managing various public lands consistent with maintaining this unique environment. By using management procedures that are compatible with the long-term survival of the unique species in Comal Springs, the City of New Braunfels will

[1] Appendix B contains a glossary of terms used in this document. Terms defined in the glossary are indicated by **bold** face type in the text wherever they first appear in the document.

help keep the ecosystem healthy and attractive, and help assure its quality for human use into the future. The Comal Plan addresses areas owned or managed by the City of New Braunfels (City), Lower Colorado River Authority (LCRA), and New Braunfels Utilities (NBU).

The Comal Springs system is the largest spring system in Texas. It consists of several major springs and numerous small springs and seeps. The source of its spring flow is the Edwards-Balcones Fault Zone Aquifer (Edwards Aquifer). Two large springs systems (San Marcos and Comal) fed by the Edwards Aquifer support diverse habitats and organisms and are considered biologically unique systems, and many species in the headwaters of these springs are found nowhere else. Several species are found only in the headwaters and first few miles of the Comal and San Marcos rivers. The persistence of these species depends on flows from the Edwards Aquifer.

The San Marcos and Comal Springs & Associated Aquatic Ecosystems (Revised) Recovery Plan (Recovery Plan) (USFWS 1996) is an extensive plan that outlines the goals and actions needed for long-term protection of the threatened and endangered plants and animals in the Edwards Aquifer and the Comal and San Marcos spring systems. The Recovery Plan specifies a number of tasks addressing both regional and local threats to these species. The regional threats include loss of adequate springflow and water quality impacts, while local threats include impacts from **non-native species**, local water quality impacts, habitat alterations, and recreational impacts. One task recommended in the Recovery Plan is the development of local management plans for addressing local threats to the species. This Comal Plan was developed as a response to both the City's active interest in protecting their resource and to Task #2.42 (Develop and implement management plans for the Comal system) identified in the Recovery Plan (USFWS 1996).

Although the objective of the Comal Plan is to maintain the high quality of the Comal ecosystem, it is outside the scope of this plan to address major threats to spring flow, such as groundwater pumping from the Edwards Aquifer, and if the springs cease to flow, the best local management practices will not prevent ecosystem failure. The

Recovery Plan outlines and recommends steps for addressing this regional threat. The Comal Plan concentrates exclusively on local management practices that can minimize local threats to the listed species.

The Comal Plan includes two sections. This section (Section I) provides background information on the Comal Springs ecosystem to assist local managers in making resource-sensitive decisions. It covers the physical environment, biological characteristics, and the influence of human activities on the ecosystem. Private and commercial properties are mentioned in this section to provide historical perspective, but are not considered part of the management plan. Section II is the Management Plan. It contains specific recommendations for management of areas owned or managed by the City, LCRA, and NBU in a manner compatible with endangered species and other unique aquatic resources in the Comal ecosystem.

Once the Comal Plan is finalized, the Service and partners may draft a other documents that describe how management actions would be implemented. The Service may also issue a Biological Opinion and Incidental Take Statement as a part of the Intra-Service Consultation that considers the effects of implementation of the Comal Plan, pursuant to Section 7(a)(2) of the Endangered Species Act of 1973, as amended. Finally, the Service must comply with the National Environmental Policy Act for implementation of the Comal Plan.

B. DESCRIPTION OF THE COMAL SPRINGS ECOSYSTEM

1. PHYSICAL DESCRIPTION. The Comal River is about 3.2 miles (5 km) long. The river has three tributaries, Blieders Creek, Panther Canyon, and Dry Comal Creek (Figure 1). All three tributaries are **intermittent streams**. Hardy et al. (1999) provides a detailed description of Comal Springs.

A number of springs contribute to flow in the Comal system, with most discharging into its impounded headwaters (Landa Lake). Along with numerous small seeps on the banks and bottom of Landa Lake, there are four major **spring runs** flowing directly into

Landa Lake, spring runs 1, 2, 3, and 4 (numbered in descending order of elevation; Figure 1).

Spring run 1 has the second largest discharge of the four major springs. Its orifices are located at the highest elevation (about 600 ft above mean sea level), so this run is the first to stop flowing when total discharge of the springs falls to about 100 **cubic feet / second (cfs)**.

Spring run 2 has numerous **low volume springs**. Spring run 3 has the largest discharge and is composed of many springs ranging from moderately large outlets to small seeps (Barr 1993, Rothermel and Ogden 1987). Spring run 4, located at the northeastern end of Landa Lake, has two main spring heads at either side of the base of a concrete wall at the head of the run. They are both low volume springs.

The depth, width, and flow velocity in the spring runs at any given time is dependent on the amount of total spring discharge at that time. This makes it impractical to present absolute values for these measurements without also presenting total spring or river discharge. Rothermel and Ogden (1987) measured spring discharge in 1982-1983 on a weekly basis yielding values ranging from 6 to 29 cfs for spring run 1; 1 to 2.5 cfs for spring run 2; 15 to 53 cfs for spring run 3; and 0.8 to 0.9 cfs for spring run 4. For the same period, the daily mean Comal springs discharge was 246 cfs as measured downstream in the river at the U.S. Geological Survey (USGS) dam (Figure 1) (USGS Station #08168710). Total river discharge measured at this point can be higher than total spring run discharge due to contributions to river flow from non-spring run sources (for instance, springs located in other areas and/or rainfall run-off into the river).

Additional spring input comes from seeps along the north bank of Landa Lake and numerous small springs that bubble up from the lake and spring run **substrates**. Based on springflow discharge measurements in December 1992 (USFWS) and June 1993 (USGS), Marshall Jennings (USGS, personal communication, 1993) determined that at the time of these measurements 78% of Comal's spring flow came from the many small springs on the bottom and along the shores of Landa Lake.

In the late 1930s, all the spring runs were channeled by rockwork, and a children's pool was built at the lower end of spring run 2 (Gregory and Goff 1993). Spring runs 1 and 3 have a substrate of gravel and cobble with some bedrock, while spring run 2 has pebble and larger cobble. In the lower portion of spring runs 1 and 2 (below their confluence), the substrate is silt. Spring run 4 has a sand/gravel substrate near the spring outlets which changes to a silt/clay mixture (Crowe 1994; Melani Howard, USFWS, personal communication, 1995).

Impoundment has significantly enlarged the headwaters of the Comal River and modified flow velocity in this area. The width, depth, and surface area of Landa Lake depend largely on the total spring discharge at the time of the measurements. Landa Lake's surface area is approximately 910,000 ft^2 (82,000 m^2), but can vary with spring discharge. In October 1995, when spring discharge was 211 cfs (which is lower than the average daily spring discharge for the years 1929 through 1992), the lake's depths ranged from 0.6 ft to 10.8 ft (18 cm to 3.23 m) and its widths ranged from 3 ft to 290 ft (1 m to 88 m) (David Whatley, New Braunfels Parks and Recreation Department, unpublished data, Hardy et. al. 1999).

Substrates vary in Landa Lake. Where vegetation is present, the substrate is usually a silt/clay mix. Exposed substrates are usually gravel ranging from granule-sized to large gravel and cobble (Linam et al. 1993). Some open areas that were previously vegetated, now have a silty substrate.

Outflow from Landa Lake occurs at three points:

1. to the "new channel", which historically serviced a power plant;
2. through the inlet to the spring-fed swimming pool;
3. to three gated culverts by-passing the spring-fed pool (Figure 1).

These latter two points supply water to the "old channel" (the original Comal River bed). The depths and widths of the old and new channel vary with total spring discharge and flow partitioning between the channels.

This needs work
In 1994, the total spring discharge averaged 329 cfs (range __to___?), while the old channel ranged in depth from 1.2 ft to 4.7 ft (0.36 to 1.4 m) and discharge ranged from 10 to 30 cfs (Hardy et al. 1999). The remainder of the flow went down the new channel. The substrate is primarily a thick silt/clay mix covered by vegetation. The old channel joins the new channel just above the tube chute dam (Figure 1).

In 1847, the Comal River was dammed (same location as spring-fed pool dam) and the upper section of the new channel was excavated to provide water to Merriwether's Mill. Since then, the new channel has been widened and dredged to impose a uniform width and straight course. It was last dredged in 1983 (Gregory and Goff 1993). Presently, part of the new channel water section flows through a non-working hydroelectric plant, and the remainder flows through gates that bypass the hydroelectric plant to continue down the lower half of the new channel (Figure 1). The new channel ranges from 3 ft to 6 ft (0.9 to 1.8 m) deep with flow velocity at about 1 to 2 ft/sec *at flow of __ to __ cfs* (McKinney and Sharp 1995; Hardy et al. 1999). Bedrock is the dominant substrate, occasionally interspersed with mid-channel silt/clay mixture and large gravel (Crowe 1994).

Substrate in the lower section of the Comal River (below the confluence of the old and new channels) is primarily bedrock and large gravel (Crowe 1994). Average depth is 8 ft (2.4 m) with flow velocities about 2 ft/sec *at flows of ___ cfs* (Hardy et al. 1999). Toward the confluence with the Guadalupe River, there is a **backwater effect** on the Comal River. The river's velocity drops significantly, while **turbidity** and river depth greatly increase due to Guadalupe River water filling the Comal River channel.

2. HYDROLOGY. Comal Springs flow from the confined freshwater portion of the Edwards Aquifer (Figure 2). The water's journey through the aquifer originates in the recharge area about 62 to 124 mi. (100 to 200 km) west in Kinney, Uvalde and Medina counties (Kuniansky and Holligon 1994). McKinney and Sharp (1995) state that 70% of

Comal Springs' water comes from recharge zones west of Cibolo Creek basin. The remaining 30% is recharged locally by Cibolo Creek and Dry Comal Creek. About __% of the Recharge occurs through rainfall and stream flow entering sinkholes and cavities, especially where faults cross the creeks. The remaining __% is recharged in features outside stream channels.*EAA? USGS?* After entering the Edwards limestone, the water generally travels eastward and northeastward, moving along faults and caverns resulting from solution enlargement of faults (Crowe 1994). According to Pearson et al. (1975), most of the water has been in the aquifer system for over 20 years, and only a small portion is less than 10 years old.

After a rain event in the western recharge area, flows peak in the Comal River 1 or 2 months later. After local rains, however, minimal response is noted in the springs. *USGS Comal hydrogeology*. Rothermel and Ogden (1987) suggested that the faults act as barriers to local groundwater flow, thus preventing recharge waters originating from around New Braunfels from traveling to Comal Springs. Based on USGS annual recharge estimates (1934 to 1992), Cibolo and Dry Comal Creeks contribute 106,700 ac-ft/yr of local recharge, but McKinney and Sharp (1995) suggested that Comal Springs is not receiving a significant portion of this recharge. However, Rothermel and Ogden (1987) found spring run 3 to be strongly influenced by local recharge. They measured spring discharges following local rainfall and found that spring run 3 discharge increased immediately. Dye injected into a well about 500 ft to the west of spring run 3 emerged only at spring run 3 and not at spring run 1, which is closer, indicating that separate flow paths feed the individual spring orifices (Rothermel and Ogden 1987). Several previous studies, however, do not support the role of local recharge (Thompson and Hayes 1979, Pearson et al. 1975, and Ogden et al. 1986).

FIGURE 2

Monthly statistics of the daily river flow below the confluence of the old and new channels (1929- present) are shown in Table 1. Mean flow rates for December through June usually run above the average annual flow rate of 295 cfs * use last Edwards hydrogeo. Report*, while mean flow rates for July through November are usually below the average (USGS records 1933-present). *check figures for accuracy*

The springs were dry from June 13, 1956, to November 3, 1956 *is this date correct?

Why 0 for monthly average?*, when aquifer levels reached a record low after 7 years of drought (Brune 1981) (Figure 3). Some of the springs have also ceased flowing more recently during less severe droughts. During the summers of 1984, 1989, and 1990, several springs ceased flowing for 1 to 3 weeks (Melani Howard, USFWS, personal communication, 1990; David Whatley, New Braunfels Parks and Recreation Parks, personal communication, 1984; and Tom Arsuffi, Southwest Texas State University, personal communication, 1989). Comal Springs dropped below 100 cfs for 99 days in 1989, to a low of 46 cfs. The minimum total discharge from the springs was 26 cfs (August) in 1984, 57 cfs (September) in 1989, and 46 cfs (June 29) in 1990. The all-time maximum recorded discharge of the springs was 666 cfs on December 22, 1991 (USGS records). Hardy et al. (1999) includes a historic overview of the hydrology of the Comal Springs system.

Recent hydrological events demonstrate the range of flows from Comal Springs resulting from precipitation patterns. At the USGS gaging station for the Comal River at New Braunfels, the mean daily discharge was near or below 100 cfs for about 2 months during the summer of 1996. In contrast, a severe thunderstorm in 1998 resulted in heavy precipitation on the New Braunfels area, and the discharge peaked at over 22,000 cfs, primarily from surface runoff, on October 17, 1998, the flood of record (Slade and Persky 1999).

3. GEOLOGY AND SOILS. The Comal Springs issue from the Edwards Aquifer at the base of the Balcones Escarpment where the aquifer has been **down-dropped** by the Comal Springs fault and several adjacent minor faults. The Comal Springs fault, which is the main conduit for flow to the springs, places the Edwards Group (limestone) against the Taylor Group (clayey marl), forming a barrier. The water, under artesian pressure, is forced upward along the fault forming Comal Springs. Solution-enhanced faults in the Edwards Group limestone form interconnected caverns, which can create tremendous underground reservoirs within the aquifer (Guyton and Associates 1979).

The soils immediately surrounding the Comal River are Oakalla soils. Oakalla soils are silty and clayey loams typically found on stream terraces and in flood plains. They are deep, nearly level, alkaline, and calcareous. These soils are typically well-drained and flooded more than once every 2 years for brief periods.

Between 1960 and 1980, five flood control structures were built in the Comal River watershed to control the frequency and intensity of flooding. These structures are at the following locations (Figure 4*no reference to figure 3 yet*): Site 1 - west fork of the Dry Comal Creek; Site 2 - on the Dry Comal Creek; Site 3 - Blieders Creek; Site 4 - Bear Creek (a tributary to Dry Comal); and Site 5 - tributary of the west fork of Dry Comal Creek. The Natural Resources Conservation Service (NRCS - formerly the Soil Conservation Service) stated that decreased flooding has little effect on Oakalla soils and associated vegetation (Michael Raney, NRCS, personal communication, 1995). These soils have a moderate permeability with high water capacity. The potential for

soil erosion is slight (Soil Conservation Service 1984). The Oakalla soils are probably a primary constituent of the muddy substrate often found in vegetated areas of the river. Other less dominant soils within 100 m of the river have a slight to moderate erosion potential.

The outcrop along the northern bank of Landa Lake (Eckrant-Rock complex) consists of a mix of extremely stony clay about 10 inches thick with patches of exposed barren limestone. Eckrant soil is well drained. Surface **runoff** is rapid and there is a severe soil erosion potential (Soil Conservation Service 1984).

4. WATER QUALITY. Water quality includes chemical and physical parameters. Some of the chemical parameters are dissolved ions, trace elements, pH, nutrients, dissolved oxygen, and organic contaminants (for example, compounds of petrochemicals or pesticides). Physical parameters include water temperature and turbidity. Water quality in the Edwards Aquifer has been monitored since the 1930s and has been found suitable for all uses, including human consumption (USGS 1987). It is, however, susceptible to groundwater contamination because it has a rapid rate of recharge (*Allen Clark vulnerability study*). Rainfall and streams enter sinkholes and cavities in some places and flow directly into the aquifer. There is minimal layering of soil and rock to filter contaminants from the entering waters. However, the aquifer currently has low contamination levels because a majority of the water in the Edwards Aquifer originates as precipitation on the Edwards plateau, which is mostly undeveloped range land (*Vulnerability Study*). The Texas Commission on Environmental Quality (TCEQ) (formerly the Texas Natural Resource Conservation Commission and the Texas Water Commission) has identified the Edwards Aquifer as one of the most sensitive aquifers in Texas to groundwater pollution (Texas Water Commission 1989).

Water quality data collected from area monitoring wells, Comal Springs discharges, and in the Comal River are displayed in Table 2. The Comal River exhibits generally stable values for most water quality parameters. Comal spring water temperature normally ranges from 74°F to 75°F (23.1°C to 23.9°C), about 3°C higher than the average annual air temperature at New Braunfels. Rothermel and Ogden (1987) suggested the long

residence time of the water in the aquifer before discharge at the springs produces a very constant chemical composition. Minor variation in Comal River water quality includes a natural gradient of slightly increasing or decreasing water temperature, depending on air temperature, from the headwaters to the lower reaches as well as fluctuations in dissolved oxygen concentrations due to the presence or absence of aquatic plants and structural and natural stream aeration. However, water quality can be rapidly impacted by such things as decreasing flows, surface runoff, and pollutants. Variations in water quality due to local recharge are minimal and short in duration because local recharge occurs in such relatively small quantities.

Decreased spring discharge could affect water quality in many ways. Lower water levels can lead to elevated or reduced water temperatures, particularly in the areas downstream*cite Comal Report*. Lowered spring flow would also result in less water available to dilute pollutants in the system and higher pollutant concentrations.

5. PLANTS AND ANIMALS. Most available studies on Comal plants and animals have been conducted within the last decade. The following studies have sampled for animals in the Comal River: Hubbs et al. 1953; Espey, Huston and Associates 1975; Whiteside, unpublished data, 1974-90; Barr and Spangler 1992; Linam et al. 1993; Barr 1993; Bowles et al. 1994; Chippendale et al. 1994; Hardy et al. 1999 *Hubbs, BioWest, Arsuffi, Bowles*. Species lists from past surveys of Comal animals are shown in Tables 3 - 6. These tables do not reflect a complete list of all species occurring within the ecosystem as intensive surveys have not been done on amphibians, reptiles, and invertebrates.

The following studies have surveyed vegetation in the Comal River: Espey, Huston, and Associates 1975; Angerstein - unpublished data 1990-1992; Linam et al. 1993; USFWS, unpublished data, 1994; Lemke 1994; Angerstein and Lemke 1994; Crowe 1994; and Hardy et al. 1999 *Oborny?*. Plant species composition appears to change frequently over time in the Comal River (Tom Arsuffi, Southwest Texas State University, and David Whatley, Parks and Recreation Department, personal communications, **need date**), but as yet, no quantitative studies have been conducted to determine the pattern of change. Table 7 is a partial list of native terrestrial *and aquatic* plants of the Comal River.

Many of the plant and animal species found in Comal Springs depend on the pristine conditions of the system. These conditions can be degraded by increased sedimentation, scouring, introduction or proliferation of non-native species, and changes in water quality, which would adversely affect the plants and animals. These changes can be caused by many factors including a decrease in spring flow, stormwater and non-point source runoff, increased flooding (due to urbanization), and erosion. Non-native aquatic species can be introduced by dumping bait buckets and aquaria and by use of boats that have been used in waters containing non natives.

6. ADJACENT LAND USES. Lands along the Comal River are used for residential, public, commercial, and industrial purposes (Figure 5). Public land use includes camping facilities, a golf course, and city parks. Commercial land use includes Schlitterbahn Water Park and resorts. The only industries on the river are Archer Daniels Midland (ADM) (grain supplier) and NBU. The entire Comal River runs through an urban area and intermittent tributaries drain urban, suburban, and agricultural lands.

7. PUBLIC RECREATION. The Comal River is a popular recreation site that provides a variety of activities such as tubing, canoeing, and fishing. In the Landa Park area, swimming is not allowed. Paddle boats and glass-bottomed boat tours are available for rental during the summer season and fishing is allowed year round. Landa Park hosts about 1,200 picnic groups annually (City of New Braunfels Parks and Recreation Dept. 1995). The City's Parks and Recreation Department published a "2000 Program Guide" that provides a comprehensive overview of the recreational opportunities and programs offered by the City. *update this information* The mission statement of the Parks and Recreation Department is:

> *"Within the annual operating budget, it is the mission of the New Braunfels Parks and Recreation Department to fulfill the recreation needs and desires of the citizens of New Braunfels in a comprehensive, efficient, and effective manner."*

Besides Land Park, the City has two additional parks that provide public access to the river - Prince Solms Park and Hinman Island Park (Figure 1). Activities in these two parks include swimming, tubing, canoeing, and fishing. Prince Solms Park and its tube chute have more than 50,000 visitors during its five month operating season. Tubers float to a choice of two public exits located a short distance above the confluence of the Comal and Guadalupe rivers (City of New Braunfels Parks and Recreation Dept. 1995).

add: road crossing, railroad crossing?

8. ARTIFICIAL STRUCTURES. The river course and certain characteristics of flow from Comal Springs are modified by artificial structures in a number of places below the springs. The most prominent modifications are dams. There are eight dams on the Comal River, which typically pool water above, and increase flow velocity immediately below, the dams (Figure 1).

One of the first modifications of the Comal River occurred in 1847 when William Merriwether built a small overflow dam on the original course of the Comal River (about where the spring-fed pool dam is now located) to divert a portion of the river into a mill race. The mill race has been further developed and is now called the new channel (Figure 1). The historic path of the river is the old channel. The dam raised the surface water elevation in the headwater area. As a result, the headwater area was marsh-like and had abundant riparian vegetation (Gregory and Goff 1993). Brune (1981) described an 1868 Map of New Braunfels that showed a large swamp downstream from the Comal Springs.

In 1898 the spring-fed swimming pool was built just below Landa Lake on the old channel (Gregory and Goff 1993) (Figure 1). At the same time, a bypass was built alongside the pool to carry more water from Landa Lake into the old channel.

Areas of Landa Lake were used as landfills in the early 1900's. In fact, the back nine holes of Landa Park golf course, which opened in 1939, was built over a land fill (David Whatley, Parks and Recreation Department, personal communication, 1995).

In 1926, the San Antonio Public Service Company dammed the new channel about 1/2 mile downstream of the Comal Canal dam to create a small "reservoir" for a hydroelectric plant (Figure 1). Both the Comal Canal dam and the "reservoir" dam are owned by the LCRA. Waters in the 150 ac-ft "reservoir" pass through the hydroelectric plant, over and around the dam, and into the Comal River at its confluence with Dry Comal Creek. The hydroelectric plant closed from 1984 to 1987, and again from 1990 to the present for economic reasons. **NBU has a long term goal to automate the entire plant (Roger Biggers, NBU, personal communication, 2003 *). The plant requires a minimum of 100 cfs for operation, and has a maximum capacity of 393 cfs.**

When the plant is closed, most of the river flow passes over the dam. If the plant were to reopen, most of the water would enter the plant. The water would flow through grates (with 3 inch spacing) into the hydroelectric plant, through the hydrogenerator, and back into the Comal River. The grates are 28 feet across and reach the substrate of the river. As water flows through, floating vegetation is caught on the grates.

In 1926, the Comal cogeneration power plant was built on the west bank of the new channel across from the present location of the hydroelectric plant. Water was pumped from the new channel through surface culverts through the cogeneration plant for cooling purposes. As a result of the 1950's drought, which caused the springs to stop flowing for 5 months beginning June of 1956, the Comal Canal Dam (Figure 1) was built in the late 1956 to keep water pumped from the aquifer in the new channel for the power plant. This is why support structures were placed on the upstream side of this dam (Martyn Turner, LCRA, personal communication, 1995) (Figure 1). The power plant closed in 1973 and the Comal Canal dam presently acts to maintain water levels in Landa Lake (David Whatley, personal communication, 1995). In 1991, NBU cut a 4-ft hole in the west side of the dam to relieve the pressure of unusually high flows resulting from flooding. Since that time, the dam has begun to erode and the opposite bank has been undermined. The LCRA filled the opening with boulders in 1994.

The two dams below the spring-fed pool on the old channel are located in the river section covered by the Bad Schloess Inc. (Schlitterbahn) surface water rights permit. They are both low water dams (Figure 1) *designed to _____*. The first dam does not completely cross the river, but directs the water toward the right bank (looking downstream) and forms a small pool of water on the left. The second dam was built by Schlitterbahn in 1984 (David Whatley, New Braunfels Parks and Recreation Department, personal communication, 1995) and is located in a small residential area.

The public tube chute is part of a large dam (tube chute dam) that lies below the confluence of the new and old channels and is owned by the City of New Braunfels (City) (Figure 1). The dam was originally built in 1848 by John Torrey to run a mill. Destroyed by floods several times, the dam (Clemen's dam) was rebuilt in 1882 (Gregory and Goff 1993). Today, it serves only a recreational function as a tube chute. Immediately below this dam is a low water dam built by USGS in 1956 with help from the City and Guadalupe-Blanco River Authority (GBRA) to gage flows (David Whatley, Parks and Recreation Department, personal communication, 1995) (Figure 1).

The final dam is located in the former Camp Warnecke area and is owned by Schlitterbahn (Figure 1). It is also a low water dam, built for recreational purposes and has a notch on the left bank (looking downstream).

9. HISTORY. [2] “Comal” is the Spanish word for basin, probably referring to the bowl-like valley surrounding the springs (Brune 1981). But according to Roemer (1849), “comal” was a term used by the Mexicans to designate the plate on which tortillas are baked. "Why the stream was named thus was not clear to me" (Roemer 1849).

The Comal Springs were an often used camping place of the Tonkawas and their predecessors for many thousands of years. The 1600s and 1700s brought many Spanish expeditions to the area. In 1691, Domingo Teran and Fray Damian Massanet,

[2] Much of the historical information presented here can be found in Gregory and Goff (1993).

Spanish explorers, blazed a trail across the Guadalupe River known as the San Antonio-Nacogdoches Road Crossing. They found a large concentration of Indians at Comal Springs, some from as far away as New Mexico and Parral, Mexico (Grist 1987). During the Texas Revolution, both Mexican and Texan armies used the springs as a stopping place (Gregory and Goff 1993).

In 1845, a group of German immigrants with Prince Carl of Solms-Braunfels traveled the San Antonio-Nacogdoches Road Crossing and settled New Braunfels, calling the springs Las Fontanas. They purchased the 1,297 acres surrounding the springs (the Comal Tract) for $1,111 from Governor Juan Martin de Veramandi. The first winter for the new settlers was difficult, and about 800 became ill and died. Despite the hardships, New Braunfels continued to grow. By 1850, New Braunfels was the fourth largest town in Texas (Brune 1981).

New Braunfels was originally a precinct of Bexar County. Comal County was created by the legislature on March 24, 1846. The charter for the city of New Braunfels was ratified on June 7, 1847. Because of the city's ideal climate and abundant natural resources, agriculture and industry thrived. As early as 1847, industries were being established. William Merriwether, using slave labor, built a dam and dug a channel off the Comal River to power his sawmill. In 1848, John Torrey built a gristmill and dam where the tube chute is presently located. By 1860, seven grist, flour, and sawmills were using the spring waters for power. *did all have dams? What happened to them?* Cotton and woolen factories, a paper mill, an ice plant, and a brewery also used Comal's water (Brune 1981).

John Torrey's dam was destroyed by a flood in 1870, and a second flood in 1872 destroyed both the gristmill and rebuilt dam. Torrey finally gave up and left New Braunfels. Clemen’s dam replaced the old Torrey mill dam in 1882.

In 1850, Friedrich Holekamp built a mill on the river, at the foot of Garza Street, that served numerous capacities: a sawmill, gristmill, paper pulp mill, and ice plant. In 1869, a flash flood almost completely destroyed the mill, but it was quickly rebuilt. At one

time, Harry Landa used the mill to pump water into his private "trout" pond in Landa Park. (Native largemouth bass were commonly called trout). The remains of the mill were completely washed away in the September 1952 flood. Schlitterbahn later acquired that property to develop a water park (Gregory and Goff 1993).

Landa Park and the springfed swimming pool were opened to the public in 1898. The history of the park is eventful, with both difficulties and successes. William Merriwether owned much of the property along the headwaters of the Comal River. Joseph Landa purchased the land from Merriwether and it became known as "Landa's Estate". When Joseph's son, Harry Landa, took over the property, he built the covered dance hall and gazebo seen in Landa Park today. Steamboat excursions became a common sight on Landa Lake. Harry Landa introduced cabbage palms, banana palms, and elephant ears, as well as built a fenced-off alligator pond, which once discharged its occupants during a flood. Many cedar branch bridges and benches were constructed. When opened to the public, the park flourished (Gregory and Goff 1993).

In 1927, Landa Park was sold to investors. They went bankrupt in 1933 and closed the park to the public, surrounding it with a 12 ft.-tall barbed wire fence. The gates to the springfed pool were shut, leaving only a shallow stream of water flowing through the pool area. The City purchased the park with an $80,000 bond and reopened it in 1936 (Gregory and Goff 1993).

Below the confluence of the old and new channels, another public area was gaining recognition. Camp Warnecke opened in 1918. Otto and Marsha Warnecke bought land along the Comal River and built several cabins. Over several years they built 103 cabins, a recreation hall and a restaurant. It became quite a popular tourist area. In fact, it made the cover of LIFE magazine on August 6, 1951, the ultimate in national recognition at that time. Camp Warnecke is now part of Schlitterbahn, a water park which occupies the former Camp Warnecke and Camp Landa properties (Gregory and Goff 1993).

Among river resorts attracting tourists in the 1940s and 1950s, was Camp Ulbricht near the headwater springs. They pumped water from a well to supplement decreasing spring flow from 1954 to 1956. The resort closed in 1956 when the springs dried up. All water-oriented tourist businesses collapsed until the abundant rains of the following fall and winter raised the water levels in the aquifer enough to return spring discharge to the Comal River (Gregory and Goff 1993).

A few years prior to the 1956 drought, Paul Jahn, chairman of the New Braunfels Chamber of Commerce for Water Conservation, warned that without conservation the springs would not last. He eventually succeeded in having the Edwards Underground Water District formed in 1959 to guard the purity of the area's drinking water and encourage recharge of the Edwards Aquifer (Grist 1987). Tourism began replacing agriculture as the major economic industry for New Braunfels in the 1960s. At the center of this industry is New Braunfels' jewel - the Comal Springs.

10. SURFACE WATER RIGHTS. There are three permit holders for the surface water rights of the Comal River: 1) City of New Braunfels, 2) NBU and, 3) Bad Schloess Inc. (Schlitterbahn). The amounts and purpose of water diverted annually are included in Table 8.

NBU has the only permit for new channel water. It authorizes non-consumptive diversion of 345 cfs (124,870 acre-ft/yr), which is necessary for maximum operation of a **run-of-river hydroelectric plant**, although the plant can handle up to 393 cfs. The plant has not been in operation since 1990.

NBU also has a water rights permit on the new channel for the Comal Canal dam, which was originally designed to keep water in the new channel during the 1956 drought. The dam presently helps to maintain water levels in Landa Lake.

Water entering the old channel can be regulated by the bypass structure installed in ___. Current flows are regulated to a maximum of about 110 cfs around the spring-fed pool plus about 5 cfs from the spring-fed pool overflow. The City consumes 1 cfs (100 ac-ft/yr) of old channel flow for irrigation of the golf course and some residential use.

Bad Schloess Inc. has a non-consumptive permit to divert 111.5 cfs (5000 ac-ft/yr) *is right af or cfs?*. The diverted water is returned to the old channel at several locations above the point it was pumped from the river. However, because of spillover within the park and evaporation, not all water is returned to the Comal River. *does water temperature change?*

Below the confluence of the old and new channels, the City has a permit covering water use of the tube chute dam. Bad Schloess Inc. has a permit for the Camp Warnecke dam and irrigation of 3 acres at a diversion rate of less than 1 cfs *what is water right?*. The previous owner of Camp Warnecke used this permit to run a sprinkler system on the tin roof of their pavilion for cooling. Bad Schloess Inc. does not currently use this permitted water (*reference?*).

C. HABITAT REQUIREMENTS

The organisms inhabiting the Comal Springs system are numerous and diverse. Four species (fountain darter, Comal Springs riffle beetle, Comal Springs dryopid beetle, and Peck's cave amphipod) are federally listed endangered species because of their limited geographic range and threats to their existence, primarily by habitat loss or destruction. Other rare species also occur here and may also be vulnerable to extinction. A new species of stygobiontic dytiscid beetle was discovered and described in the literature as recently as 1995 (Spangler and Barr 1995). To preserve the quality of this spring ecosystem, the natural physical, biological, and chemical parameters required by these species need to remain intact. Full species descriptions, habitat requirements and distributions of listed species except the invertebrates can be found in the San Marcos & Comal Springs and Associated Aquatic Ecosystems (Revised) Recovery Plan (USFWS 1996).

1. HABITAT TYPES. Habitats are the living places of organisms and are characterized by their physical and biological properties. For aquatic communities, they include combinations of such things as vegetation, substrate, water quality, and **flow type**. Linam et al. (1993) described the different types of vegetation, substrate, and flow throughout the Comal River.

2. TARGET ORGANISMS. The following species are highlighted because they are believed to be one or more of the following: (1) intolerant of wide ranges in physical, chemical, and/or biological parameters induced by human actions; (2) relatively rare, unique, and/or limited to very few locations; and (3) particularly sensitive to changes in habitat. Some of the more sensitive organisms may be indicators of water quality and ecosystem health.

Fountain darter (*Etheostoma fonticola*)

The fountain darter is a small fish that was listed as endangered on October 13, 1970, and critical habitat was designated on July 14, 1980. Critical habitat was designated in Hays County and includes Spring Lake and its outflow, the San Marcos River, downstream to about 0.5 mile below the Interstate Highway 35 bridge. There is no critical habitat designated for this species in the Comal Springs system. *explain why Comal not designated as CH*

General habitat: Habitat requirements described in the recovery plan (USFWS 1996) include: undisturbed stream floor habitats; a mix of submergent plants (algae, mosses, and vascular plants), in part for cover; clear and clean water; food supply of living organisms; constant water temperatures within the natural and normal river gradients; and adequate springflows. Fountain darters use and prefer a mix of submergent vegetation including algae, mosses, and higher plants (Schenck and Whiteside 1976, Linam et al. 1993, Hardy et al. 1999). Schenck and Whiteside (1976) found that young fish prefer vegetated habitats in areas with little water velocity.

Fountain darters feed primarily during daylight in response to visual cues (Schenck and Whiteside 1976). Bergin (1996) investigated the fountain darter's diet in detail. The food items selected depended on the size of the individual, but primarily included copepods, dipteran larvae, and ephemeropteran larvae (Bergin 1996).

Although natural populations of fountain darters appear to spawn year-round (Schenck and Whiteside 1976), they appear to have two peak spawning periods, in August and late winter to early spring (Schenck and Whiteside 1976). Bonner et al. (1998) described the effects of temperature on egg production and early stages of the fountain darter.

Distribution and abundance: The fountain darter is found throughout the Comal River. Linam et al. (1993) collected the largest numbers per unit area in the old channel area. Blieders Creek, parts of Landa Lake, portions of the old channel and some of the stream bank areas in the new channel provide good darter habitat. Texas Parks and Wildlife Department (TPWD) sampled seven transects in Landa Lake and the Comal River in 1990 and estimated the fountain darter population above the tube chute dam to be between about 115,000 and 250,000 (Linam et al. 1993).

The fountain darter was most likely eliminated from the Comal River during the 1956 drought. The pools that remained after springs ceased to flow probably underwent drastic temperature fluctuations creating a highly stressful environment for the fountain darter. Unsuitable temperatures and increased predation and competition likely resulted. Schenck and Whiteside (1976) spent 300 hours sampling the Comal River from 1973 to 1975 and did not find any fountain darters. They reestablished the population by releasing 457 adult fountain darters (collected from the San Marcos River) into the headsprings of the Comal River from February 1975 through March 1976 (USFWS 1996).

A significant threat to the health of fountain darters is the damage to gills and gill arches caused by a recently-discovered introduced trematode. The risk posed by these parasites appears to increased during low spring discharge. *cite and elaborate*

Thomas Brandt (in litt. 1997) has summarized the parasite problems faced by the fountain darter. None of the fountain darters collected in the Comal system in June

and early July, 1996 were observed to have swollen gills. On July 19, 1996, one of 11 fountain darters collected and released was noted as having swollen gills. This was the first indication of an apparently recently introduced heterophyid trematode parasite attacking fountain darter gills in the Comal system. In October, 1996, heavy parasite loads were documented in Comal fountain darters including the trematode of concern (as well as a myxosporean and an epithelial flagellate). Publication of an article on their research on this trematode and the fountain darter by Dr. Brandt, Melissa Salmon, Drew Mitchell, Dr. David Huffman and A. Goodwin is expected in 2000. *update* Alternate hosts for these gill parasites may include animals found in both Comal and San Marcos systems. Yellow-crowned night herons, one of the trematode's putative hosts, may easily fly from Comal to San Marcos.

Flow requirements: An instream flow study by Hardy et al. (1999) concluded that useable habitat for fountain darters declined with declining total spring flow rates, most notably below 150 cfs. As total flows fall below 150 cfs, declines in hydraulic (velocity-depth relationships) and temperature parameters are evident. Below 100 cfs, temperature *and other parameters, such as water surface elevation*, contribute to the overall decline in useable habitat availability for fountain darters. Flows should be partitioned equally in the old and new channels to provide fountain darter habitat, up to a maximum of 110 cfs flow in the old channel (220 cfs total spring flow). Above that total springflow, all flows in excess of 110 cfs should be routed down the old channel (Hardy et al. 1999). These recommendations are designed to provide optimum habitat for the fountain dater and to prevent flooding in the old channel.

Comal Springs salamander (*Eurycea* sp.):

Genetic studies using **allozyme electrophoresis** and **ribosomal RNA** data determined that the Comal Springs salamander population is not the same species as the San Marcos salamander (*Eurycea nana*) and is molecularly unique in that it shares an **allele** found only in the Texas blind salamander (*Typhlomolge rathbuni*) (Chippindale et al. 1992, 1994). Although Chippindale et al. (1994) believe the Comal Springs salamander is probably a unique species, the taxonomic status of the

species warrants further investigation. It appears to be geographically isolated, but additional surveys and genetic work are needed for verification.

General habitat: The habitat requirements of the Comal Springs salamander are not fully known but are probably similar to those of the closely related San Marcos salamander. Both of these species live in the thermally constant, clean and clear waters flowing from the Edwards Aquifer. Nelson (1993) found San Marcos salamanders associated with gravel and rock substrates with little mud or detritus, as well as some vegetated areas. In general, central Texas *Eurycea* salamanders are often closely associated with spring openings and have been found in highest abundances in waters with constant water temperature (Sweet 1984). Some are known to enter spaces within gravel substrates making them difficult to find.

Distribution and abundance: The Comal Springs salamander has been found in spring runs 1, 2, and 3. Two sightings also occurred 10 to 20 ft (3 to 6 m) upstream of "Casey Island" in Landa Lake, possibly near spring openings within the lake (Figure 1) (Casey Berkhouse, USFWS, personal communication, 1995). No population estimates or thorough surveys have been done. *update found in spring on island? *

Flow requirements: Under normal flow conditions no specimens have been found in still water areas, so flowing waters seem to be a prerequisite for suitable habitat. However, the Comal Springs salamander apparently survived the temporary loss of springflow in 1956. Although they appear to be able to retreat into the aquifer and wet gravel for a time, the effect on the population from these conditions and from increased duration or frequency of drought is not known.

Comal Springs riffle beetle (*Heterelmis comalensis*)

The Comal Springs riffle beetle was added to the Federal endangered species list in December 1997 (*FR December 18, 1997 (Volume 62, Number 243*). No critical habitat was designated for the species.

General habitat: **Larvae** and adults have been collected in gravel/cobble substrate in the headwater spring runs of the Comal River. *update w/ Oborny info spring openings in lake?* General habitat preferences for riffle beetles include flowing streams with pebble/cobble-sized rocks.

Distribution and abundance: The beetle has been found in spring runs 1, 2 and 3 (Barr 1993) of the Comal River. It is believed to be in greatest densities from February through April (Bosse et al. 1988). A single specimen was also found along the margin of Spring Lake in the San Marcos River (Barr 1993). No population estimates have been made.

Flow requirements: Flow requirements for survival are not known. They apparently survived the 1950's drought, during which water ceased to flow from the springs for 6 months, probably by retreating into the springheads and/or burrowing into the substrate at their specific habitats. It is not known how much of an impact this drought had on the population or if they could survive a longer or more frequent drought conditions. *check on Bowles' paper*

Aquifer-dwelling invertebrates

Comal Springs dryopid beetle (*Stygoparnus comalensis*), Peck's cave amphipod (*Stygobromus pecki*), subterranean **amphipods** (*Mexiweckelia hardeni* and *Seborgia relicta*), and two predaceous diving dytiscid beetles, *Haideoporus texanus* and *Comaldessus stygius*. The Comal Springs dryopid beetle and the Peck's cave amphipod were added to the Federal endangered species list in December 1997 (get FR citation*). The dryopid beetle is a monotypic genus and is the only subterranean dryopid beetle known *check*. No critical habitat was designated for these species. The other four species have no status under the ESA.

General habitat: These subterranean invertebrates inhabit the aquifer and can also be found close to the spring outlets. Substrate of the spring outlets and runs

consists of gravel and cobble. Because all other known dryopid beetle larvae are terrestrial, the Comal Springs dryopid beetle is presumed to be associated with the soil, roots, and debris lining the ceiling of the subterranean orifices (Barr and Spangler 1992).

Distribution and abundance: The Comal Springs dryopid beetle was found at spring runs 2, 3 and 4 in small numbers (*citation*). It has also been found at Fern Bank (Little Arkansas) Springs about 20 mi. (32 km) to the northeast of the Comal River (Barr 1993). Peck's cave amphipod occurs near the heads of all four spring runs (*citation*). It has also been found in Hueco Springs about 4 mi. (7 km) north of the Comal River (Barr 1993). *Haideoporus texanus*, previously known only from San Marcos, was found near the heads of Comal spring runs 2 and 3; and a previously undescribed dytiscid beetle, *name* (*citation*) was found at the heads of spring runs 3 and 4 (Barr 1993). *Mexiweckelia hardeni*, a species formerly only known from Medina County, was found at the head of Comal spring runs 2 and 4 (Barr 1993). *Seborgia relicta* was discovered in spring run 3 and specimens have also been found in Hondo Creek, Hueco Springs, and an artesian well in San Marcos (Barr 1993). These invertebrates were collected by placing drift nets over the spring outlets of low volume springs and seeps as well as high volume springs.

Roundnose minnow (***Dionda episcopa* complex**) *update information*

This fish is part of a large complex of closely related forms and is believed to be one of two unnamed forms. It is believed by some experts to be a possibly unique form.

General habitat: This small fish is primarily found in channels of fast-flowing, spring-fed water over gravel bottoms (Harrell 1978). They have been observed breeding in seep springs (Lee and Gilbert 1980). Many species of *Dionda* exhibit a limited tolerance for a broad spectrum of environmental conditions and are restricted to headwaters and springs (Mayden et al. 1993).

Distribution and abundance: *Dionda episcopa* complex is composed of several species: *D. episcopa, D. serena, D. melanops, D. argentosa, D. diaboli,* and perhaps

D. punctifer, as well as two unnamed forms (one from the Guadalupe and Colorado rivers and one from the upper Rio Conchos, Mexico) (Mayden et al. 1993). David Hillis (University of Texas, personal communication, 1995) believes that the *Dionda* species in the Comal River is one of the two unnamed forms. Hubbs (1956) noted that Dionda in the Comal River were quite distinct from those in other tributaries of the Guadalupe River. Population estimates have not been made.

Big Claw River Shrimp (*Macrobrachium carcinus*)

This is the largest species of river shrimp (sometimes called **prawns**) in the United States. Adult males can approach 12 in. (30 cm) in length and weigh 2.2 lbs (1 kg), while females typically range from 5 to 7 in. (13 to 17 cm).

General Habitat: River shrimp hatch in **estuaries**. The larvae require **brackish** water for development and can survive only 5 to 6 days in freshwater (Hughes and Richard 1973). Juvenile prawns move upstream into freshwater and travel inland several hundred miles, as far as San Marcos and Austin, where they spend their adult lives. Therefore, their main requirements are accessibility to estuaries as well as freshwater ecosystems (David Bowles, TPWD, unpublished).

Distribution and abundance: In the United States, the big claw river shrimp is found in Florida, Mississippi, and Texas. It is also known from the Caribbean Islands, Mexico and southward to Brazil (David Bowles, TPWD, unpublished *update*). In the Comal River, the big claw river shrimp can be found throughout the system. No population estimates have been made.

Cagle's Map Turtle (*Graptemys caglei*)

The Cagle’s map turtle is included as a Federal candidate species for possible future listing as a threatened or endangered species. *(Federal Register: February 28, 1996, Volume 61, Number 40, Page 7595-7613)*

General habitat: Cagle's map turtles prefer short stretches of shallow water with swift to moderate flow and gravel/cobble bottoms (riffles), connected by long stretches of deeper pooled waters with slower flow rates and mud/silt bottoms. Ideally, the banks should support a diverse growth of vegetation. It is also important for the river banks to have fallen trees and logs that can be used as basking sites (Killebrew 1991*additional references*).

Distribution and abundance: Cagle's Map turtle is restricted to segments of the Guadalupe and San Marcos river systems. It has been found in Kerr, Kendall, Comal, Guadalupe, Gonzales, Dewitt, and Victoria counties. The largest continuous population occurs in the Guadalupe River between Cuero and Seguin, Texas (Killebrew and Porter 1991). Cagle's map turtle has not been sighted in the Comal River, however its presence above and below New Braunfels in the Guadalupe River suggests the possibility of occurrence in the Comal River system.

3. PROBLEMATIC ORGANISMS. Non-native species can represent a threat to native species because their populations can rapidly increase in a system that lacks their native predators and competitors. Also, where a habitat has been altered as a result of human activity, the changes may be more favorable toward non-native species than native species. An increase in non-native species can lead to their replacement of native species. Some of the known impacts non-natives can have are removal of vegetation, degradation of water quality, introduction of parasites and diseases, hybridization, competition, and predation.

Non-natives species are introduced in numerous ways. Some examples include, including through aquarium “dumping”, planting exotic plants, releasing baitfish, adhering to hull surfaces on boats used in other water bodies or pumping of bilge water, and intentional stocking. As non-native densities increase, interactions between non-native and native populations may become more frequent. This interaction may directly affect the distribution, density, and survival of native organisms. Native populations may be displaced from preferred feeding, resting, and spawning grounds. Cessation of

reproduction in the presence of high densities of non-natives has been repeatedly demonstrated in populations of largemouth bass and other species (Smith 1976, Dean and Bailey 1977).

The following species do not represent all known non-natives in the Comal ecosystem, just those that pose a known threat, or are most likely to pose a threat, to native species.

Rio Grande cichlid (*Cichlasoma cyanoguttatum*)

Native range: This fish is native to the lower Rio Grande drainage in Texas and Mexico. However, a number of populations have been established in large springs and rivers of Central Texas' Edwards Plateau including the Comal, San Marcos, Guadalupe, San Antonio and Colorado rivers.

Impact: Overcrowding by the Rio Grande cichlid can cause negative effects on reproduction as well as displacement of native fish (Chew 1972). They primarily consume aquatic plants, which could increase loss of vegetation and thereby loss of habitat for native species (Birkhead 1980).

Common carp (*Cyprinus carpio*)

Native range: This fish is imported from temperate portions of Eurasia (Banarescu 1964).

Impact: The common carp causes impacts similar to the Rio Grande cichlid, but in addition stirs up the bottom sediments during feeding, which increases siltation and turbidity of the aquatic systems (Allen 1980).

Tilapia (*Oreochromis* species)

Native range: These fishes are imported from Africa and parts of the Middle East. The exact identity of the tilapia in the Comal River system is unclear but probably is the blue tilapia (*Oreochromis aurea*), the Mozambique tilapia (*Oreochromis mossambica*), and/or hybrids between these two species (Hensley and Courtenay 1980).

Impact: Tilapia destroy vegetation through consumption and maintenance of large bareground nests within plant stands. Increases in turbidity have been attributed to digging associated with nest-making. Tilapia have also demonstrated the capacity for rapid expansion and explosive population increases in several states, which could crowd native fauna from their habitat or repress reproduction (Swingle 1960, Courtenay and Stauffer 1984).

Giant ramshorn snail (*Marisa cornuarietis*)

Native range: This snail is imported from southern Central America and northern South America (Horne et al. 1992).

Impact: Giant ramshorn snail populations in Landa Lake have increased dramatically since they were first observed there in 1984. They have spread throughout Landa Lake and into the river and have been implicated in the elimination of several vegetative stands (Horne et al. 1992). Their populations were reduced some during 1991, possibly due to high flows, and have not yet rebounded to previous levels. Populations of this snail are much smaller below Landa Lake, probably due to higher flow velocity. *update with info from Arsuffi report? Oborney results?*

Elephant Ear (*Colocasia esculenta*)

Native range: This large, emergent plant is imported from Asia (Godfrey and Wooten 1979)

Impact: This plant was initially brought into the United States as food for African slaves. It was subsequently cultivated by the Department of Agriculture in the 1900s for its starchy and edible (when well-cooked) tubers. Improperly cooked tubers can be toxic. Elephant ear can spread rapidly and replace native vegetation. This alters the vegetative structure and dynamics of the spring ecosystem. Elephant ear also modifies the stream channel through accumulation of sediment and narrowing of the channel.

Hydrilla (*Hydrilla verticillata*)

Native range: This submergent plant is imported from Europe (Godfrey and Wooten 1979).

Impact: *Hydrilla* is a pest in many aquatic systems including clear water springs. It grows rapidly, choking aquatic systems and displacing native plants.

Nutria (*Myocastor coypus*)

Native range: This aquatic mammal is native to South America.

Impact: Nutria feed on valuable wetland vegetation. Their burrowing activities can severely damage stream banks, levees, dikes, earthen dams, and other structures (USDA 1990).

Exotic gill trematode **(*scientific name*?)**:

Native range: **Asia?** *update*

Impact: The trematode infests gills of fish (heavily in fountain darters) causing physiological stress and possibly death to infected individuals.

intermediate host

II. MANAGEMENT PROCEDURES

This portion of the Comal Plan identifies management practices currently used or, in some cases, proposed to be used on the public portions of the Comal Springs, Landa Lake, and the Comal River that may have an impact on aquatic habitats, individuals, or populations of listed species.

This section is organized by management topics. For each management topic the current management practices are identified and described. Problems and concerns related to each practice are discussed and recommendations are made to avoid significant impacts to fountain darters and riffle beetles. In making these recommendations, we have also considered feasibility of implementation, including costs. The Service has worked with the City, NBU, and LCRA to develop practical management options.

Because this plan is being developed to assist in conservation, we have made recommendations that, in some cases, go beyond just avoiding or minimizing take. In some cases we have made recommendations that would benefit the overall health of the ecosystem upon which the listed species, as well as many other native species, depends. *Additional documents will be developed after this document is finalized. *delete the following? Included in this documentation isA Biological Opinion (BO) for the intra-Service section 7 consultation for the technical guidance and implementation of this plan will be issued once this Plan and a MOA with all of the Plan partners is finalized. The BO will provide a list of recommendations that the Service, City, NBU, and LCRA agree must be taken to avoid and/or minimize take and to satisfy the requirements of the section 7 consultation. Also included in the BO will be a list of conservation recommendations, which are not required but would be beneficial to the overall health of the ecosystem and, therefore, the listed species.*

Because the Service believes that the implementation of these recommendations will have an overall beneficial effect for the conservation of the listed species' and their habitats, the Service intends to seek funding from various sources to assist in the implementation of some of the recommendations.

A. MAINTENANCE OF SPRING-FED SWIMMING POOL

Objective: Maintain spring-fed swimming pool to provide similar recreational opportunities as the Olympic pool, but in a more natural setting.

Current practice: The pool previously held up to 1.5 million gallons, but construction of the shallow children's area in *19__* has reduced this capacity some. Water enters the pool from Landa Lake through a 10-inch (25-cm) diameter pipe located in the shallow section (cement area) of the pool. The intake is covered with a screen that has a 0.00155 (1mm) in. mesh, which is small enough to help prevent adult darters from entering the pool. However, it does not prevent fountain darter eggs and juveniles from entering and residing in the pool. A few (three to five) fountain darters were collected in the gravel and cobble area (deeper end of the pool) in 1993 and 1995 (Casey Berkhouse, USFWS, personal communication, 1995). Debris that collects on the screen is removed every few days by the aquatic staff to prevent the screen from clogging.

During the summer (May through September), the pool is drained and cleaned every Monday and Thursday at 5:00 p.m., after closing. The primary purpose of the cleaning is to remove algae from the bottom and sides of the pool, and to control the growth of aquatic **macrophyte**s and algae in the gravel and cobble section. This is done for both aesthetic and safety reasons.

The outflow gate is raised for about 30 minutes before beginning cleaning operations. The outflow gate drains from the bottom of the pool. It takes about 2 hours to drain the pool. However, pool personnel do not close the inflow gate, so there is always a

narrow, shallow stream of water (about 5 cfs) flowing through the pool during the cleaning process. The pool cannot be entirely drained because the bottom of the outflow gate is slightly higher than the bottom of the pool.

Cleaning operations begin in the shallow, concrete section of the pool. A pressure hose supplied with municipal water is used to remove algae. Personnel hose the concrete areas for about 4 hours. After one hour, when the water level has sufficiently dropped, the deeper, gravel and cobble portion of the pool is cleaned. A tractor pulling a 5 ft x 4 ft (1.5 m x 1.2 m) wire brush is driven in circles over the gravel and cobble for about one hour (due to the inability to completely drain the pool, standing water prevents the use of the tractor in some areas of the gravel and cobble portion of the pool). This practice is used to help remove vegetation by fragmenting the plants. Some of the plant fragments float downstream, and some remain in the pool area. The outflow gate is then closed, and the pool refills overnight (about 8 - 10 hours). After September, the outflow gate is left open and no maintenance is done until December. In December, general repairs and overall cleaning begin. In May, the outflow gate is closed, the pool is allowed to fill, and semi-weekly cleanings begin again.

<u>Problems and concerns</u>:

1) Algal growth in the shallow end of the pool - Algal growth on the concrete surfaces in this end of the pool makes surfaces slippery and unsafe for swimmers. The standard method of eliminating algae from a pool area is the use of chlorine. However, chlorine is toxic to aquatic organisms, and EPA toxicity tests have shown aquatic animals to be even more sensitive to chlorine than aquatic plants (EPA 1984). The use of chlorine could severely impact fountain darter populations and other animals and plants immediately downstream of the pool. The City has been using pressure hoses to control algal growth, but because of the amount of time it requires and its effectiveness, the City would like another alternative. Also, pressure hosing uses chlorinated water without a dechlorination procedure, which may have an impact on fountain darters in the pool. An alternative procedure is needed to effectively deal with the problem without impacting plants and animals.

2) Vegetation growth in the deep end of the pool - This plant growth impairs lifeguards' view of the pool bottom and is a safety concern. Also, it is considered unattractive by many of the pool's guests. The practice of dragging a wire brush with a tractor over the cobble could harm or kill any fountain darters in the pool.

3) Sediment plume and water surge during pool cleanings - As a result of opening the outflow gate to drain the pool for cleanings, the rate of flow in the channel below the pool increases from about 0.6 to 2.1 cfs for about 1.5 hours (Melani Howard and Casey Berkhouse, USFWS, personal observation, 1995). Some sediment is released with the outflow, increasing the turbidity of the water temporarily. Increased current velocities are observed down the old channel to at least the Schlitterbahn dam. Schlitterbahn personnel are aware of this procedure and remove boards from their dam on the old channel to moderate the extra surge of water. The increased turbidity potentially disrupts feeding and breeding behaviors of fountain darter populations in a *small portion of *the old channel for *less than 4 Hours?*a short time.

Recommendations:

1) Algal growth in the shallow end of the pool - A mechanical means of algae removal is the most desirable control technique; however, as part of the modifications for the new children's pool area, play equipment was set up at various locations in the shallow end, making it hard to get at certain areas with machinery, such as a tractor pulling a roller brush. Other non-chemical alternatives include shading the concreted area to slow the rate of algal growth and selling or renting "aqua socks" to decrease slipping.

Though the use of chlorine is not usually recommended in sensitive areas, the City and Service have made preliminary investigations of a chemical method of controlling algal growth in the New Braunfels spring-fed pool and the method appears acceptable. This method includes the use of chlorine followed by treatment with sodium thiosulfate (a dechlorinating agent). Sodium thiosulfate neutralizes free chlorine immediately upon application, which should eliminate the negative impacts of chlorine on animals and plants both in the deep end of the pool and downstream. The recommended procedure

is as follows (it is also important to follow the manufacturer's safety instructions when using these chemicals):

1. After the pool is drained, the main outflow and inflow gates would be closed.
2. Calcium hypochlorite (no more than 100 lbs [45 kg]) would be applied to algae on the concrete surfaces in the shallow end of the pool and allowed to sit for about 10 minutes (or as long as necessary to kill the algae), then followed with an application of sodium thiosulfate (200 lbs [90 kg]). Sodium thiosulfate and hypochlorite must be used in a 2:1 ratio (2 parts sodium thiosulfate to 1 part calcium hypochlorite). Make sure that all surfaces treated with calcium hypochlorite are treated with sodium thiosulfate. <u>This step is critical to neutralize the toxic effects of chlorine</u>.
3. Neutralization occurs immediately, so the inflow gate could be opened anytime <u>after</u> the application of sodium thiosulfate is complete.
4. Allow the pool to fill completely so that water spills over the dam - leave the outflow gate closed. This is important to get the maximum dilution of any residual chlorine prior to discharging water to the old channel.

This procedure should control the algal growth without harming other aquatic life in the gravel and cobble section of the pool or downstream. Tim Dean (Aquatic Superintendent of the New Braunfels Parks and Recreation Department at the time) applied calcium hypochlorite and sodium thiosulfate to the concrete section of the spring-fed pool in August 1995 as a trial run of this procedure. The Service collected the first 100 ml of water that ran off the concrete area onto the gravel/cobble section after the inflow gate was reopened. The LCRA lab found the sample to have less than 0.01 mg/L residual chlorine. The EPA (1984) recommends that the total residual chlorine concentration in freshwater should not average in excess of 0.019 mg/L for one hour during any 3 year period. The procedure presented above has been in use regularly since 1995 and should be checked to assure that it meets EPA criteria and modified if necessary. The following precautions should be taken when using this procedure:

1. An experienced supervisor should be on hand throughout the procedure.

2. Water samples should be taken as described above for the first month this procedure is used and the first two times this procedure is used each season thereafter to ensure that the chlorine concentration is not exceeding an average of 0.019 mg/L for one hour.
3. The supervisor should experiment with lower concentrations of the calcium hypochlorite to determine the smallest amount needed to control the algae (this will keep the cost and use of chemicals to a minimum).

2) Vegetation growth in the deep end of the pool - Reducing the number of fountain darters in the pool is the first step toward reducing the number harmed during the gravel and cobble cleaning procedures. To help keep fountain darters and other animals out of the pool, the City should continue to maintain the screen over the inflow gate. The screen should be checked daily and cleaned and/or repaired as soon as a problem is noticed. However, even with the screen, some juvenile fountain darters and fountain darter eggs will enter the pool.

We also recommend adding a firm, rubber (or some other suitable material) skirt to the front edge of the wire brush used to fragment vegetation in the deep end of the pool. The skirt should be long enough to create a forward surge of water helping fountain darters avoid the brush. The procedure should be performed in water deep enough (3 to 4 inches) to allow fountain darters avenues of escape. Another technique that could be used in combination with the brush or by itself, is to grade the gravel bed so that gravel is higher on the sides, creating a channel to the outflow gate and increasing the chances for fountain darters to escape as water is drained from the pool. If a method that uses a tractor is chosen, the tractor should be inspected before each use for fuel, antifreeze, hydraulic, and oil leaks. Although harm to fountain darters in the pool may still occur, the above recommendations will reduce the harm.

3) Sediment plume and water surge during pool cleanings - Due to the limited duration and frequency of this event it is likely to have no detectible adverse impacts on fountain darters in the old channel.

B. REOPENING OF THE NEW BRAUNFELS UTILITIES HYDROELECTRIC PLANT

Objective: NBU is considering reopening the hydroelectric plant as both a minor producer of electricity and a historical building.

Current practice: The hydroelectric plant currently is not operating (Section I.B.8 - Artificial Structures), but NBU is considering reopening in the future. Water from the new channel flows into the plant's **forebay**. At this point, the water either enters the plant through a grated entrance or passes through bypass gates and over the 17-ft reservoir dam. When the plant is operating during flows below 300 cfs, the bypass gates are almost entirely closed, so 90% to 100% of the flow entering the forebay passes through the grates, passes through a turbine, exits the plant, and flows into the river. Any remaining portion of the water flows through the bypass gates and over the reservoir dam. The plant cannot handle flows over 300 cfs, so the bypass gates are opened further when flows are over 300 cfs, allowing more water to flow over the dam (Roger Biggers, NBU, personal communication, 1996). While the plant is not in operation, most of the water entering the forebay flows over the dam. For hydroelectric plant operations to remain feasible, at least 100 cfs of flow must be going down the new channel and through the plant (Gene Laponec and Roger Biggers, NBU, personal communication, 1995 and 1996).

The bars of the grate at the plant entrance are about 3 inches apart (Roger Biggers, NBU, personal communication, 1996), which allows the passage of fountain darters into the hydroelectric plant. As water flows through, floating vegetation gets caught on the bars. In the past, vegetation was removed from the grate by hand using rakes down to a point about 4 ft from the bottom because removing the upper vegetation is less likely to affect fountain darters. Vegetation was not removed from this lower portion of the grate. NBU plans to use an automatic grate cleaner to remove vegetation if the plant reopens. Once removed from the grate, the vegetation would be placed in a dump truck and hauled away. NBU stated that the grate cleaner could be set to not remove vegetation from the lower several feet of the grate (Roger Biggers, personal communication, January 1996).

Management Issues:

1) Partitioning of instream flow between the old and new channel - As discussed in Section II.C., it is desirable to maintain about 110 cfs for fountain darter habitat in the old channel. Maintaining certain flows in the new channel for plant operation will influence the amount of flow in the old channel. During periods of low spring discharge, flows could drop dramatically in the old channel. Below 40 cfs would cause a loss of habitat and negative effects to fountain darters.

2) Fish injury - Injury or death to fountain darters could occur in a number of ways as fish pass through the turbines. A study on survival results of fish passing through turbines indicated that about 83% of the fish studied survived turbine **entrainment** (Matousek et al. 1994). One of the turbines in this study is similar to the one in the NBU hydroelectric plant, but the majority of the experimental fish were larger than fountain darters. Matousek et al. (1994) noted that a smaller body size seemed to decrease the chance of a blade strike. Therefore, the percentage of fountain darters surviving passage through the turbine could be higher than 83%. A study by Bell (1972) found two factors dramatically increased mortalities as fish pass through a hydroelectric plant: 1) fish hitting the sides of the conduit during abrupt changes of direction, and 2) **cavitation** resulting from the action of the turbine.

Another impact associated with spillways and hydroelectric plants is the supersaturation of water with atmospheric gases, especially nitrogen. This is a potential issue with all low head dams in the Comal River. Fish exposed to supersaturated water often develop gas bubble disease which is characterized by disorientation, emphysema, gas **emboli**, lesions, exophthalmia ("popeye"), and death (USFWS 1977). Experiments at the San Marcos National Fish Hatchery and Technology Center suggest that in captivity fountain darters begin to die at 105 to 110% supersaturation (Tom Brandt, USFWS, personal communication, 1995).*Check on measurements below structure*

3) Vegetation removal procedures - Fountain darters might be harmed or killed during the collection and removal of vegetation from the grate in front of the hydroelectric plant.

Fountain darters have been found in the vegetation mats that float down the river (Hardy et al. 1999) and eventually collect in the grate.

Recommendations:

The purpose of this plan in relation to the NBU hydroelectric plant is to begin to identify possible impacts to fountain darters from the reopening of the plant. Establishing detailed requirements for the operation of the NBU hydroelectric plant is beyond the scope of this management plan. The details of what would be required to minimize the take of fountain darters should the plant reopen would need to be determined in further consultation with the Service. This consultation may occur as a part of applying for hydropower licensing from the Federal Energy Regulatory Commission or as part of obtaining a permit for take under the Endangered Species Act from the Service. The following general recommendations are made as a preliminary step toward identifying areas of concern.

1) Partitioning of instream flow between the old and new channel - An agreement between NBU and the City (and any other parties deemed necessary) should be developed to assure an adequate flow regime, with a 40 cfs minimum, would be maintained in the old channel as spring discharge decreases. TCEQ should be contacted to assure that the partitioning of flows is consistent with state water rights regulations *has this been written out on 1st use in Part II?*. The ability to control flows would be enhanced by improving the LCRA dam on the new channel (as discussed in Section II.C.).

2 and 3) Fish injury, Vegetation removal procedures - Prior to consultation with the Service concerning the details of what is needed to minimize take should the hydroelectric plant reopen, more information and data need to be collected to better estimate the impact of the plant's operation on fountain darters (see below). The Service is willing to help in the collection and analysis of these data. In particular, the following information is needed:

1. Estimate extent of fountain darter death and injury that would occur as a result of passage through the hydroelectric plant, from the effects of supersaturation, and during vegetation removal needs to be determined.
2. Measure total dissolved gases in the area of the discharge from the plant (and the affected downstream area) through a range of conditions, including various flows.
3. Estimate fountain dater abundance in the vicinity of the grates and in mats of floating vegetation in the forebay to help evaluate the likelihood of fountain darters entering the hydroelectric plant or being injured during vegetation removal.

Once the extent of take is estimated using the collected information, the necessity and methods of minimizing take can be addressed. There are resources and references available to use for deciding on applicable methods. For instance, the Service (USFWS 1977) describes several measures that have successfully minimized and/or offset fish passage through hydroelectric plants. It may be necessary to develop a protocol for cleaning the grate and maintaining the vegetation in parts of the forebay as a way to reduce the probability of fountain darters entering the plant.

C. MANAGEMENT OF FLOWS TO THE OLD AND NEW CHANNELS

Objective: To better manage the flow regime from Landa Lake to the old and new channels to maximize fountain darter habitat availability throughout the system, particularly during low-flow times (when total flow is less than 200 cfs).

Current practice: The flow of water out of Landa Lake into the new channel is restricted by the Comal Canal Dam. This dam is maintained and inspected by the LCRA. The flow from the lake into the old channel is controlled by the spring-fed pool dam and new bypass culvert that was installed in 2000 with funding from FWS. The spring-fed pool dam is maintained by the City. The only maintenance activity for the bypass culvert is the removal of debris that collects on the trash rack in front of the culvert intake.

The new culvert to the old channel allows more ability to regulate flows to the old and new channels. If the water surface elevation in Landa Lake falls to a low level, maintaining flows in the old channel for critical fountain darter habitat should now be possible by adjusting the valve on the gate. The inflow gate at the spring-fed pool dam (see Section II.A. Maintenance of Spring-Fed Swimming Pool) is normally closed only during cleaning and pool maintenance during the summer season. Partially or completely closing this gate could alter the quality of the spring-fed pool as a swimming area and would reduce the amount of water flowing into the old channel. The new bypass culvert allows *up to* more than 100 cfs to be diverted down the old channel. The new bypass culvert was constructed with an intake elevation to allow water into the old channel, even when Landa Lake is at very low levels.

Problems and concerns:

1) Lake levels and stream flows into the old and new channels - Landa Lake and the old channel support large numbers of fountain darters. It is therefore particularly important to maintain spring discharge in Landa Lake as well as sufficient flows through the old channel. While assuring adequate spring flows is beyond the scope of this document (and beyond the ability of the City to do by itself), managing flows to the old and new channels is within the City's purview.

2) Shutting off flow to the spring-fed pool for maintenance and other purposes - The decrease in flow to the old channel may impact fountain darter populations, especially during periods of decreased spring discharge.

Recommendations:

1) Maintenance of adequate flows to old channel - 1a) Hardy et al. (1999) recommends 40 cfs be maintained in the old channel anytime the total spring discharge exceeds 80 cfs. Flows up to 110 cfs provide additional habitat and do not cause downstream flooding. The proposed flow split is to partition flows equally between the two channels at total springflows below 220 cfs. Above that flow, 110 cfs would go down the old channel, and the remainder would be routed down the new channel. This recommendation is based on fountain darter habitat modeling, which indicates the need

to moderate water temperatures downstream in both the new and old channels as well as the Comal River proper below the confluence of the old and new channel.

1b) The trash rack on the new bypass culvert should be inspected at least once per week and cleaned as soon as excessive debris is noticed to prevent impeding flow.

1c) Narrow areas of the old channel are susceptible to restrictions in flow caused by the accumulation of debris or fallen trees and limbs. The portions of the old channel adjacent to city park or golf course land should be inspected at least twice a week by parks and golf course personnel and any obstructions should be removed.

1d) Modifications could be made to the Comal Canal Dam that would give greater control over the amount of water flowing through this structure. The addition of a gate or valve at this dam could help maintain lake levels and old channel flows in times of low spring discharge.

1e) An alternative to these modifications of the Comal Canal Dam is to totally replace the dam. The LCRA has expressed an interest in this idea. The best time to construct such a dam is during a period of low flow when water levels in the new channel would only have to be lowered a little or none at all. Some take of fountain darters may occur during the construction of a new dam (or during modification of the existing dam). If this alternative is pursued and design details and construction schedules are available, the Service will coordinate with the involved parties to make recommendations for avoiding and/or minimizing take. **[UPDATE W/ INFO FROM BO - NEED TO GET FROM PAT]**

Modifications to any of these control structures should be cleared with the TCEQ to ensure that they are in compliance with state water rights regulations. Also, a coordination plan between the Parks and Recreation Department, NBU, and LCRA should be established to outline how the control structures will be managed to maintain an optimum water surface elevation of the lake and/or flow down the old channel, based in part on results from Hardy et al. (1999). The plan should also set a schedule for periodic inspection of the control structures to ensure adequate functioning.

2) Shutting off flow to the spring-fed pool for maintenance and other purposes - Flows through the new bypass culvert should be adjusted upward to account for flows not passing through the spring-fed pool to avoid or minimize any impacts from the loss of spring-fed pool flow.

D. MAINTENANCE OF COMAL RIVER DAMS

Objective: Keep public dams on the Comal River below Landa Lake in good repair for public safety and to maintain flow regimes.

Current practice: There are six dams on the Comal River downstream of the Landa Lake control structures. However, clear public ownership has been established for only two of these dams and only they are considered to be within the scope of this management plan *check on USGS dam - city proposal to repair*. See Section I.B.8. - Artificial Structures, for discussions of all dams; and Figure 1, for the location of the dams.

The reservoir dam is located at the NBU hydroelectric plant on the new channel. This dam serves to pool water in the plant's forebay for plant operations (see Section II. B. Reopening of the NBU Hydroelectric Plant, for more details on this dam). This dam is owned by the LCRA.

The tube chute dam (Clemen's dam) is located on the Comal River below the confluence of the old and new channels. This dam is maintained by the City. The TCEQ has no record of inspection for this dam.

Problems and concerns:

1) The current availability of fountain darter habitat in some areas of the Comal River is shaped in large part by the presence of these dams. Fountain darters have been collected in areas of the river influenced by these dams. Altering the dams may alter

the quantity and quality of fountain darter habitat, though it is unclear if the changes would be positive or negative.

Recommendations:

1) The City and LCRA should schedule periodic inspections (about every 5 years) for their dams and ensure that these dams are repaired as needed. The dam safety unit of the TCEQ can be contacted for information on dam inspection (Appendix C). Each dam could have different influences (back-water effects, width and depth of pool, etc.) on the river. Changes in these dams may not necessarily result in negative impacts. However, any changes should be carefully planned and evaluated for impacts. It is also important to avoid changes in the dimensions of the dams, including the height of a dam, without first evaluating the consequences.

E. FISHING DERBY IN OLYMPIC AND SPRING-FED SWIMMING POOLS

Objective: Provide a fun, safe fishing experience for children.

Current practice: The fishing derby ("Troutfest") is held once a year during the winter in either the Olympic or, primarily, spring-fed swimming pool, and the fishes are in place for about 10 days. The Parks and Recreation Department uses rainbow trout measuring 8 to 10 inches (20 to 25 cm) long, provided by the A.E. Wood State Fish Hatchery (TPWD), and channel catfish weighing 1 to 5 lbs. (0.5 to 2.3 kg) obtained from a private fish farm. About 1000 rainbow trout and 1000 to 1200 lbs. of channel catfish are stocked. Precautions are used in the spring-fed pool to prevent the escape of fishes. A barrier net of galvanized wire is extended across the outflow gate and over the spillway. It is in place before fish are added to the pool and is not removed until the pool is drained and left over fish are removed. Although the Parks and Recreation Department staff keeps a tally sheet for fish removed by guests during the derby, due to predation by birds, this tally probably does not reflect the actual number of fish remaining in the pool. Catfish remaining at the end of the fishing derby are donated to a local food bank.

Both locations, the spring-fed pool and the Olympic pool, have advantages and disadvantages for management of the fishing derby. In the spring-fed pool, cormorants (a fish-eating bird) consume a large number of the trout, and so much natural food is available for catfish that they are not eager to take the bait during the derby. The Olympic pool does not have these problems, but it does not hold as many fish, so fewer people can participate. We will address precautions to be taken for the derby in both locations.

Problems and concerns:

The following are concerns for both the Olympic and spring-fed pools:
1) Fish escapement - Accidental release of trout (which are not native to this area) into the Comal ecosystem is a problem because of potential impacts on native fishes (McDowall 1976) and invertebrates (Fish 1966) (see Section I.C.3. - Problematic Organisms). The introduction of a large number of channel catfish, though probably native to the river, could also impact fountain darters through impacts on habitat and competition for food resources.

2) Disease and parasite concerns - Stocked fish may carry parasites or diseases that are transmittable to other fishes. In the spring-fed pool, any disease carried by the derby fish can spread downstream even if none of the fish escape. In the Olympic pool, water drains into the Comal River, also giving disease a pathway to the river.

Recommendations:
1) Prevent fish escapement - We recommend that when the spring-fed pool is used, the Parks and Recreation Department continue their current practice for preventing escapement of derby fish. (Even with these precautions, derby fish are much more likely to escape into the Comal River from the spring-fed pool than the Olympic pool).

Weather forecasts should be monitored so derby fish can be removed from the spring-fed pool prior to any possible flooding. Otherwise fish could be washed out of the pool

into the river. In the Olympic pool, fish should be removed before draining the pool, or nets of a mesh size small enough to contain the derby fish, should be placed over drains, and fish removed after draining the pool.

2) Parasite and disease control - The Parks and Recreations Department should obtain their derby fishes from a reputable supplier with a good reputation for supplying parasite and disease-free fishes. The A.E. Wood State Fish Hatchery (TPWD) supplies trout that have been certified disease-free. However, there is no certification procedure for the suppliers of the catfish. A TPWD biologist may be available to perform a cursory, external examination of a small number (10 to 15) of the catfish prior to stocking them into the derby pool (see Appendix E for information). Such an inspection by TPWD personnel would serve only to provide information, not advice, to the City. The responsibility for deciding to stock or not to stock, and the consequences of that decision, would still belong solely to the City. Before and during the event, the City should work to educate the public to discourage people from releasing any trout caught during the derby into the wild.

F. MAINTENANCE OF THE OLYMPIC SWIMMING POOL

Objective: Provide a fun, safe swimming environment for the public.

Current practice: The Olympic pool is open on weekends beginning in early May and open daily from 11:00 a.m. to 7:00 p.m. from mid-May through the Labor Day weekend. City water is used to fill the pool and more water is added as needed throughout the season. The pool's filter is cleaned by **backwashing** into the old channel about once a week. The end result is about a 10,850 gallon slug of turbid, chlorinated (about 1 ppm) water, heated about 10°F higher than the river, discharged into the old channel. The backwashing process takes about 7 minutes. If the filter is backwashed less often than once a week during the pool season, it may require 15 minutes of backwash to clean the filter, which doubles the discharge (Tim Dean, Parks and Recreation Department, personal communication, 1995).

At the end of the season, the pool is closed and the water is allowed to sit until February. It is then drained into the old channel and the pool is cleaned. It is not a problem to drain the water into the old channel, because by this time the chlorine has dissipated.

Problems and concerns:

1) Filter cleaning - The discharge of the backwash water might have negative impacts on fountain darters in the old channel.

Recommendations:

1) Filter cleaning.

1a) Prior to deciding on a management option, additional information on the significance of the impact should be collected. In particular, the water quality should be checked 1 meter out from the point of discharge and 2 meters downstream, and again 5 meters out and downstream to help determine if any significant changes in water quality occur as result of discharge. Temperature and chlorine residuals are the primary concerns (the temporary increase in turbidity probably poses only minor impacts to fountain darters). The EPA (1984) recommends that residual chlorine levels in freshwater should not exceed an average of 0.019 mg\L for an hour during any 3 year period. Water quality in the area of the effluent should be tested to determine if this criteria is being met. This test should be conducted at low flows as well as normal flows. The short period of discharge, in combination with the diluting factor of the river, at normal and high flows, may reduce the temperature and chlorine concentrations to inconsequential levels. However, the dilution capability of the old channel will be reduced at low flows.

If, after analyzing water samples collected as described above, it is determined that a change in procedure is warranted, there are several options to explore:

1b) A method of delivering a steady supply of a dechlorinating chemical (such as sodium thiosulfate) to a discharge of chlorinated water is being used at some facilities. In the case of the Olympic pool, a portable device could be placed near the cistern when the pool is backwashed and set to deliver a steady supply of a known

concentration of dechlorinating agent for the duration of the discharge. The use of this method would necessitate the standardization of the backwash procedure in terms of duration and amount of water discharged so that dechlorination is consistently achieved. Backwashing should be done in the morning when the pool water temperature and river temperature are most similar.

1c) Construction of a small, concrete-lined retention pond located close to the filter area would allow the chlorine to **volatilize** and the sediment to settle before the pool water enters the Comal River. The volume capacity would not need to be larger than about 12,000 gallons if the filter were backwashed on a weekly basis during the pool season. The captured water should be tested daily with a chlorine test kit and released when the chlorine concentration is below 0.019 ppm. The water should be discharged in the early morning when its temperature is most similar to the river temperature. Storm events would cause a diluted overflow that would travel about 40 feet (10 meters) before reaching the river, and should therefore contain very little chlorine. The disadvantages to a retention pond include safety concerns, sediment removal, algal blooms, and mosquito problems. Most of these could be avoided if the pond were fenced and emptied 24 hours after filling. An outflow gate or release valve would need to be included in the design of the pond. See the Urban Drainage and Flood Control District (1992) manual for more information. This may be the method that best addresses chlorine, temperature, and turbidity.

1d) The backwash could be run into the sewer system, so it is transported to the wastewater treatment plant or to the golf course to be used for irrigation.

G. LANDA PARK GOLF COURSE MANAGEMENT PRACTICES

Objective: To maintain a high quality golf course for its users.

Current practice: The Landa Park Golf Course runs along Landa Lake and the old channel (Figure 1). It is open to golfers year round and is a popular course.

Management practices that are pertinent to this plan include: 1) the use of pesticides and fertilizers to maintain the grounds, 2) removal of aquatic vegetation in the waterways to make golf balls more visible and for aesthetics, and 3) retrieval of golf balls from the waterways for resale in the golf shop.

All areas of the course are treated with chemicals, including the **roughs**. Pesticides, colorants, defoamers, and iron supplements are sprayed on the **greens** from about October through February. The entire course is sprayed March through September, with the greens and **fairways** sprayed at least twice a month. Fertilizers are applied about once a month for the entire year to the greens and **tees**.

Aquatic vegetation is removed from the canal that runs between the golf course and Pecan Island (Figure 1) *does figure need work?*. A rake, secured with a rope, is thrown out into the canal, and dragged back to pull up vegetation. In the past, floating vegetation has been chopped with the propeller of a boat and pushed out of the canal to float downstream (Fernando Gutierrez, golf course greenskeeper, personal communication, 1995).

Golf balls are retrieved from the bottom of the canal alongside Pecan Island in Landa Lake and in areas of the old channel that run along the golf course. Golf course employees wade and snorkel through these areas collecting golf balls as often as twice a week during the summer (Fernando Gutierrez, personal communication, 1995).

<u>Problems and concerns</u>:

1) Chemical use - The primary area of concern is the impact of herbicides, fungicides, fertilizers, and insecticides on the Comal ecosystem. These chemicals are useful in controlling pests, but they may also present a hazard to species not considered to be pests in the surrounding environment. For example, runoff of pesticides used on the golf course into Landa Lake may reduce populations of aquatic insects, which are important food sources for many freshwater fish. Runoff of methoxychlor (a pesticide used on the Landa Park Golf Course) into a stream has been shown to greatly reduce stream invertebrate populations (Eisele and Hartung 1976 *not in lit cited*).

Methoxychlor also interferes with fetal development and can cause sterility in mammals. Fish can also be directly affected by pesticides. Dursban *is it still applied?*, another chemical applied on the golf course, has immediate, highly toxic, and long-term effects upon all forms of aquatic life, as well as mammals (Briggs 1992).

Once in the water, pesticide residues can become attached to suspended material, deposited on bottom sediments, and absorbed by organisms. They may be transported through the aquatic system by water currents or in the bodies of aquatic organisms. Impacts that some chemicals have on some forms of aquatic life include behavioral changes (such as swimming and predator avoidance), physiological changes (such as growth and reproduction), biochemical changes (such as blood enzyme and ion levels), and death. These effects can be acute (happening relatively soon after exposure) or chronic (happening some time after a single exposure or after repeated or long-term exposure) (Rand and Petrocelli 1985).

Fertilizers can be a problem because of their nutrient-enrichment effect on receiving aquatic systems. An excess of phosphorus and nitrogen (fertilizer nutrients) will promote algal growth and can lead to "algal blooms" (a rapid increase in the algal population). These "blooms" can cause a depletion of dissolved oxygen in the water, particularly at night. In the Comal River, this could be a problem during very low or no flow times.

2) Vegetation harvesting - The harvesting of aquatic vegetation from the canal along Pecan Island could result in some destruction of fountain darter habitat and direct mortality to fountain darters. Fountain darters have been found in this area and aquatic plants are essential components of their habitat in the Comal River (see Section II.H. Management of Aquatic Vegetation).

3) Golf ball retrieval - Wading and snorkeling to retrieve golf balls can damage the aquatic plants. Fountain darters have been found in the areas from which golf balls are collected.

Recommendations:

1) Chemical usage - A good approach for addressing chemical usage at Landa Park Golf Course is to develop and implement an integrated pest management plan (IPMP), incorporating appropriate information from the Service and other sources, that is specific for the local environment and concerns. IPMPs are being developed and used by many U.S. golf courses to keep management practices as ecologically sound as possible. For example, Barton Creek golf course in Austin, Texas, developed an IPMP plan using information obtained from the LCRA, EPA, City of Austin, Texas Agricultural Extension Service, the Golf Course Superintendent Association of America, and the U.S. Golf Association. As part of the plan, the Barton Creek golf course staff is using no chemicals on the roughs, they are mowed only, and the weeds on the greens are managed strictly by physical/mechanical methods. Also, a greater abundance of insect pests are tolerated on the roughs than on the greens. Practices such as these allow an important reduction in chemical use, while still maintaining an attractive course. Pesticides and fertilizers are expensive, using them as efficiently as possible will also reduce expenditures. Lost Pines golf course in Bastrop also uses IPM and as a result has dramatically reduced their use of chemicals.

Landa Park Golf Course runs along the Comal River with tees on Pecan Island. Because the golf course extends to the river bank, we recommend that golf course personnel explore alternative pesticides to reduce impacts on aquatic life. Because Pecan Island is surrounded by water, it is particularly difficult to prevent runoff of chemicals into the water. It is important that the smallest possible amount of pesticides and fertilizers be applied to the island. The manufacturer's recommendation is not necessarily the minimum. For the rest of the golf course, a 100 feet buffer of untreated land with increased vegetation between the course and the river is recommended. A healthy **riparian** zone would dramatically reduce runoff of chemicals. However, because it is not a large course, it might be more feasible to emphasize the elimination of surface runoff.

The rate, method, and timing of pesticide and fertilizer application are important in minimizing transport by surface runoff, as well as optimizing the intended purpose of

pesticides and fertilizers in landscape maintenance. For controlling runoff, irrigation is the most critical, but it is a difficult practice to control. Overwatering can provide the vehicle for transport of chemicals into the river. Limits on irrigation could be set so no part of the course is overwatered. At Barton Creek Golf Course, for example, a watering schedule is used that minimizes percolation below the root zone, which reduces the likelihood of runoff into Barton Creek as well as reduces fungal problems. Also, weather reports should be monitored to avoid irrigating or applying pesticides before a storm, and to change required water amounts in response to changes in humidity, soil moisture, and air temperature. TCEQ can provide information on determining application rates for irrigation (Appendix C).

The Audubon Cooperative Sanctuary System, is a program for golf courses designed to promote protection of wildlife and other natural resources. Monitoring wildlife on and around golf courses, setting up nest boxes and feeders, protecting endangered species, and creating natural buffer zones along stream edges are just a few of their recommended activities. They want to encourage golf courses to take a leadership role in conservation projects. They will provide information to assist the golf course superintendent and course officials through publications, telephone consultations, and specially arranged on-site visits. Further information on this program can be obtained from the Audubon Society (Appendix C).

2) Vegetation removal - A large amount of clipped vegetation is probably coming from areas upstream of Pecan Island. Preventing the entrance of this vegetation into the canal should reduce the amount of floating vegetation in the canal and the harvesting effort. One method of doing this is to establish a barrier upstream of the canal that maintains the present flow of water into the canal, but prevents floating vegetation from entering. The barrier should be checked regularly and any accumulated vegetation removed. Vegetation could be removed by hand from a non-motorized boat. The removed vegetation should be shaken over the water's surface to dislodge entangled fountain darters.

When it is necessary to remove floating vegetation from the canal, it is essential to do so with minimal disturbance to the plants that are rooted in the canal. Rooted aquatic plants are an important part of fountain darter habitat. Uprooting these plants will likely negatively impact fountain darters in the canal. Operating from a non-motorized boat, personnel could use pitch forks to remove floating vegetation from the surface of the water. The spacing of the pitch fork tines should allow fish trapped in the vegetation to escape. Alternatively, a seine, pulled along the water surface by two people wading in the water, would collect the floating vegetation from the canal without uprooting plants. Once collected, the vegetation should be shaken over the water's surface to dislodge any trapped fountain darters (see Section II.H). Vegetation removed from the canal and the upstream barrier could be used in a compost program for the golf course and the city parks.

3) Golf ball retrieval - Limiting golf ball retrieval to two golf course staff members and two days a week is a good practice as it reduces the number of personnel involved and the frequency of activity. Optimally, golf balls could be retrieved using a non-motorized boat and a tool made to retrieve golf balls. If there are areas in which vegetation is too thick to see the golf balls, golf course personnel could snorkel. Snorkeling would allow them to sort through the vegetation without standing on or walking through aquatic habitat. Prior to snorkeling, the personnel involved should be informed of the presence of fountain darters and reminded to keep habitat disturbances (for example, uprooting vegetation and stirring-up sediments) to a minimum.

H. MANAGEMENT OF AQUATIC VEGETATION

Objective: Maintain an attractive park for recreational users, as well as preserve the submerged plant stands that are needed for the healthy functioning of the ecosystem and minimize the amount of floating vegetation that is transported downstream into other recreational areas of the river.

Current practice: Landa Lake usually has abundant vegetation, which can become quite thick. While this provides excellent habitat for aquatic animals, it is considered a

nuisance and unattractive by some residents and park visitors. Prior to the increase in non-native giant ramshorn snail populations in 1989-90, the Parks and Recreation Department used a cutter boat to cut submerged vegetation in Landa Lake. In recent years, this has not been needed because the giant ramshorn snail and tilapia have reduced, and in some areas eliminated, stands of submerged vegetation in the lake *is this still true?*. The New Braunfels Parks and Recreation Department no longer manages the submerged vegetation because it has remained below the level where its management is desirable for recreational use of the lake.

During the summer the amount of floating, dead vegetation transported downstream into the river can be a nuisance to people using the river downstream. The vegetation apparently originates from private individuals cutting vegetation in the upper part of the lake, vegetation management by the golf course, and primarily from natural uprooting and fragmentation of plants. During the summer of 2000, the City contracted the use of the existing conveyor belt upstream of the reservoir dam to remove floating vegetation.

Problems and concerns:

1) Dense, submerged aquatic plant communities were found by Barnett and Schneider (1974) to support higher numbers of animals than most other aquatic habitats. Aquatic vegetation provides food and/or refuge for many aquatic animals, and plays an important role in the health of the river system (Wetzel 1983). Many studies recognize the importance of aquatic vegetation and state that management efforts should be focused on control rather than elimination of plant life (Terrell and Terrell 1975, Addor and Theriot 1977).

Care must be taken when managing aquatic vegetation because it is used by the fountain darter as a refuge from predators and as a place to deposit their eggs. It also provides habitat for many of the darter's invertebrate prey (see Section I.C.2. - Target Organisms), as well as other species of fish. Strawn (1956) *in captivity?* observed that fountain darters grew to maturity only when dense vegetation was available for cover from predation.

Recommendations:

1) The current practice of not cutting vegetation is the best practice for the Comal ecosystem.

2) Limited vegetation cutting - The Parks and Recreation Department may decide to begin cutting the vegetation if it becomes more abundant and starts emerging above the water surface. Any cutting using a cutting boat should be limited to no more frequently than once a week and a maximum of 2 feet below the water surface. If water depths are 2 feet or less (such as the canal running between Pecan Island and the golf course), plants could be cut at the surface by hand from a boat, and the clipped plant material could be skimmed from the surface of the water. Surveys by the Service have found fountain darters in plant material on the water surface, so clippings need to be shaken to dislodge any darters before being removed from the water. Removed vegetation could be used in a compost program for the golf course and the city parks. Practices that uproot vegetation from the bottom, such as dredging or raking, should be avoided.

The use of herbicides to control submerged aquatic vegetation in this system is an undesirable management practice because of possible unintended impacts to the habitat. Even if the herbicide is selective and not toxic to the fountain darter or its prey species, there could still be impacts from loss of habitat and other secondary impacts from vegetation control (such as increased decomposition and subsequent decreased dissolved oxygen levels). There are also other unique organisms in the Comal River that could be impacted by chemical methods of vegetation control.

3) The City should provide qualified personnel on site as a biological monitor during vegetation removal using the conveyor belt. This person will sort through the vegetation as it is removed and search for fountain darters.

I. NUISANCE SPECIES

Objective: Control introduced species that have direct or indirect negative effects on native populations and habitat.

Current practice: Attempts have been made to control only two nuisance species in Landa Lake (nutria and elephant ear). The Parks and Recreation Department calls a Wildlife Damage Control Specialist at the U.S. Department of Agriculture if nutria populations seem to be increasing, such as when the normally nocturnal nutria are noticed coming out during the day in increased numbers. In the past, elephant ears were sprayed with Rodeo(R), an herbicide with low toxicity for aquatic organisms (Briggs 1992). The Parks and Recreation Department no longer sprays the elephant ears. No other management practices have been established for control of nuisance species.

Problems and concerns:

1) Some of the problems associated with non-native species are outlined in Section I.C.3. - Problematic Organisms. As water levels and flows decrease with decreasing spring discharge, physical and chemical conditions in the Comal River could change (see Section I.B.4. - Water Quality). In a system that exhibits relatively constant water quality parameters, changing conditions could give a competitive advantage to different species. Some non-native species that may not be causing a problem at average flows could become a problem as flows decrease and some that do have an impact at high and medium flows could have a larger impact under the stress of low flows. Under low flows, competition for remaining resources may increase; predation due to increased accessibility to prey may also increase.

The species discussed in this section are either presently a nuisance in the river, or there are concerns that they could have significant negative impacts in the future. For these reasons they should be controlled. The specific problems posed by these species are identified in Section I. C.3. - Problematic Species *are they? Check*.

Recommendations: The following recommendations are organized by species. See Section I. C. (Problematic Species) for the scientific name and native range of each species.

1) Tilapia - Tilapia are abundant in Landa Lake (Patrick Connor, USFWS, personal communication, 1996) and have an extremely high reproductive potential (Courtenay and Stauffer 1984). One method to help control tilapia would be to host an annual "Tilapia Round-up". This type of event could also serve to educate people about negative impacts of non-native species. Bag seines or gill nets could be used to block-off an area with an abundance of tilapia, such as the channel between Pecan Island and the golf course or the Blieder's Creek area, and the tilapia could be herded into the nets. Such events should be carefully planned and supervised to minimize impact to other aquatic life. Such precautions include limiting the number of people in the water at any given time and specifying how the fish are captured to avoid harming aquatic vegetation. Local food banks may be willing to take the removed tilapia. If done in the area near the golf course, additional safety considerations may be necessary and the event should be coordinated with golf course personnel.

2) Giant Ramshorn Snail - As spring flows decrease, current velocity in many areas of the Comal ecosystem will also decrease. This will likely make more areas accessible to the giant ramshorn snail and increase their populations in the river, especially in Landa Lake. Arsuffi et al. (1993) discuss three possible ways to control or eliminate the snail from Landa Lake: 1) introducing a predator; 2) using a **molluscicide**; and 3) manual harvest. They concluded that introducing a predator is unacceptable because the impacts on the ecosystem cannot be predicted, and using a molluscicide is unacceptable because it could eliminate native snail species. The manual harvest method may not eliminate the giant ramshorn snail, but it may control populations without seriously impacting the ecosystem. A seasonal harvest of the snails may keep populations under control and avoid a significant increase in their numbers as water levels drop. The best time of year to harvest the snails is probably from March through July. The snail population is composed primarily of adults at this time, and it is a peak reproductive period (Badough 1992). Studies to determine the most effective harvesting method should be undertaken. The numbers of the snails have declined since the flood of 1998 *update*.

3) Elephant Ear - Small stands of elephant ear along the river banks could be safely controlled with certain herbicides by wicking when there is no chance of rain in the forecast. Wicking allows the application of the herbicide to specific plants and thus helps reduce the risk of exposing the herbicide to desirable plants. Wicking also reduces the risk of the herbicide entering the river. The herbicide that the Parks and Recreation Department previously used (Rodeo®) is acceptable if wicked on carefully. It may take repeated application s to kill elephant ear plants because of their large colms. Because the roots of the elephant ear hold soil in place and prevent erosion of soil into the river, removing stands of elephant ear from the bank of the river could necessitate the re-establishment of native plants. After an elephant ear stand has died, native plants should be planted. Once a stand of elephant ears has died and their above ground stalks have been removed, the remaining colms will stabilize the bank until the native plants can take hold. A list of native plant species, some of which would be suitable for planting in the place of elephant ear, is provided in Table 7. Plants for reestablishment should come from a source free of undesirable species.

4) Hydrilla - Hydrilla has been found in the new channel of the Comal River below the hydroelectric plant (Linam et al. 1993). It could be eliminated from the river more easily at this point than if allowed to spread. Manual harvesting is the recommended method of removal. Depending on the depth of the river, snorkelers or scuba divers could gather the plants into mesh bags, being careful not to allow fragments of the plant, which can re-root, to float downstream. The use of herbicides to control plant populations is not advisable in this situation. Herbicides are often broad spectrum and could affect native plant populations. Also, in deep, flowing water they are ineffective.

5) Nutria - Nutria destabilize stream banks through digging and consumption of vegetation. If the Parks and Recreation Department decide nutria populations need to be controlled, the current practice, which does not involve the wide-spread introduction of harmful chemicals to the lake or the destruction of habitat, is acceptable.

6) Domesticated waterfowl - Domesticated waterfowl concentrated in an area can cause numerous problems, including bank destabilization from uprooting vegetation and

increased nutrient input into waterways. There have been as many as 200 or more waterfowl seen in Landa Park at any one given time (Nathan Allan and Patrick Connor, USFWS, personal communication, 2000). While migratory waterfowl are a natural part of the Comal ecosystem and not a problem, the non-migratory, domesticated waterfowl are problematic. These domesticated waterfowl could be controlled through live trapping and relocation or by lethal means.

7) Monitor for “watch list” of species to control if they show up.

8) Educate public about not dumping bait buckets or aquaria.

9) Work with TPWD to control use of live fish for bait in Landa Lake?*

J. RECREATIONAL ACTIVITIES

Objective: Provide safe and fun recreational activities on the Comal River for the public.

Current practice: The use of motorized boats for recreational purposes is not allowed on the Comal River (including Landa Lake). Motorized boats are only used for search and rescue emergency operations. Paddle boating, glass-bottom boat tours, and fishing are the only recreational activities that occur in the public section of Landa Lake. Swimming is allowed in the spring-fed pool and children's wading pool in Landa Lake. Public swimming, canoeing, snorkeling, scuba diving, fishing, and tubing occur from the reservoir dam downstream to the Union Street takeout (see Section I.B. - Public Recreation).

Problems and concerns:
Habitat alteration can occur from some recreational activities through either direct or indirect impacts. Examples of direct impacts are stream bottom disturbance and aquatic vegetation removal. Indirect impacts are things such as the introduction of non-native bait fish through fishing, or streamside influences such as increased compaction, erosion, litter, pollution and runoff from parking areas and support facilities.

The areas of the river most susceptible to impacts from recreational use are shallow spots with abundant vegetation. Vegetation provides good fountain darter habitat and shallow areas are convenient places for people to stand, walk, and enter or exit the river. Generally, the deeper areas of the river are less likely to be directly impacted by human activities. Swimming, snorkeling, scuba diving, and tubing are the types of recreation most likely to have impacts in shallow areas. Swimming, snorkeling, and scuba diving are usually done in Prince Solms Park and Hinman Island Park *check to see if in figure* and thus are confined to a smaller area than tubing. At the current level of activity and normal to high flows, additional damage is not likely to occur to areas already impacted. However, at below normal flows the impacts of recreation could be greater.

Recommendations:

Recommendations for some of the concerns identified above are covered in other parts of Section II. For bait fish recommendations see Section II.M. - Human Activity in Spring Runs, for recommendations on bank compaction and erosion see Section II.N. - Bank Stabilization, and for recommendations on litter, pollution, and runoff see Section II.K. - Stormwater Runoff.

1) Not allowing motorized boats on the river is good for public safety, and also eliminates the many negative impacts of motorized boats on aquatic life. We recommend this ban be continued. We also recommend the continuance of current policies on recreational activities in public sections of Landa Lake, which have no more than minimal habitat disturbance.

2) Fountain darters have been collected throughout the river. To reduce the potential for impacts from the existing activities, signs could be set up requesting that people avoid the edges and that tubers not get out of their tubes until they are ready to exit the river.

3) As flows decrease, the amount of shallow area in the river will increase, making more area susceptible to impact from recreational activities. It would be helpful to develop a plan that looks at recreational use and its potential impacts as flows decrease. The plan could establish a flow level at which signs would be set up along the river asking guests to avoid specific areas. While this does not restrict recreationists from the river, it may help reduce their impact on fountain darter habitat during times of reduced flow.

4) We also recommend coordination with resource agencies (such as the Service and TPWD) if plans are made to increase or expand recreational activities. The planning of new or expanded activities should include an analysis of their impacts on fountain darter habitat during times of low flow (a "worst case scenario"). The plans could identify a critical level of flow at which steps are taken to minimize impacts.

K. STORM WATER RUNOFF

Objective: Prevent or reduce degradation of Comal River water quality from pollutants and sediment in storm water runoff.

Current practice: Runoff can enter the Comal River through point and non-point sources. Point source discharges are from storm water culverts located at various places in the river. These culverts drain runoff from large areas into specific locations in the river. Non-point sources include runoff from construction sites, roads, parking lots, and other facilities built along the river. The City does have regulations dealing with runoff from construction sites and runoff from materials stored in the floodplain.

Problems and concerns:

Most of the Comal River's banks have been developed. Parks, roads, parking lots, buildings, recreational facilities, and other structures are located along the river. Runoff from these urban areas may contain many types and forms of pollutants. It may include pesticides and herbicides, fertilizers, litter, hydrocarbon and inorganic/metal compounds from vehicles and machinery, and household solvents and paints (Urban Drainage and Flood Control District 1992). Runoff from the developed areas along the Comal River

could contain some of these pollutants. **Sediment** runoff is most often associated with construction activities.

Pollutants and sediment do become diluted and dispersed to some extent when they enter the Comal River. During normal and high spring flows this may be enough to minimize the impacts associated with the current level of activity. However, if the level of pollution and **sedimentation** increases or the level of spring flow and current velocities decrease, the dilution effect of the river will be reduced. Negative impacts to the river will then be more likely or more severe.

Recommendations:

There is currently no data to suggest that the current level of runoff is causing significant degradation of habitats in the Comal River, however, this issue has not been evaluated *check*. However, in the event of a reduction of spring flow this could change. The discussion that follows will therefore concentrate on preventative measures and not address specific current practices.

Prevention is often a more cost effective management practice than cleanup. The Urban Drainage and Flood Control District (1992) manual and the City of Austin Public Works Department (1982) manual outline many preventative measures for controlling stormwater runoff. A few of these measures are discussed below.

1) Methods for preventing pollutants from reaching the river include: (a) establishing a year-round hazardous disposal site(s) for household wastes; (b) installing trash racks in the storm drains (see Appendix E for more information); and (c) minimizing directly connected impervious areas (DCIA). An example of DCIA is storm water flowing from a roof to a parking lot to the street. This concentrates runoff quickly. Instead storm water should be directed over landscaped areas or grass buffer strips. This reduces the rate and volume of storm water runoff entering the river, encourages filtering and infiltration of storm water, and improves water quality. For specific guidance on minimizing DCIA, reference the Urban Drainage and Flood Control District's (1992) manual.

2) There are numerous structural methods that can be used to prevent or reduce sedimentation. For details on these techniques, refer to the Urban Drainage and Flood Control District (1992) manual and the City of Austin Public Works Department (1982) manual. The EPA and the Corps of Engineers can also be contacted for further management practices (see Appendix F).

3) Public education of runoff reduction techniques can be accomplished in a number of ways. Education is an effective tool for increasing the public's willingness to use these techniques. One possible educational forum is a "Clean River Festival". A festival can be a fun way of providing information to the public. In Austin, the LCRA has an annual festival for this purpose that includes free music, informational booths, food booths, water quality testing demonstrations, riverboat rides, and a children's stage. Several agencies, such as LCRA, TCEQ, GBRA, TPWD, and EUWD, have public outreach and educational programs designed to support this type of activity. The City could also contact the Water Oriented Recreation District (WORD) and Friends for Rivers (see Appendix C) who have a large volunteer base for river cleanup activities. Local businesses and large corporations in the area could be contacted for financial support. Plant nurseries could set up booths with organic gardening and xeriscape information. The festival would be most beneficial for local residents, so holding it during the non-tourist season may be optimal. It could possibly be held in conjunction with an established festival, such as Wurstfest.

Another educational tool could be integrated into the interpretive trail in Landa Park. The City could put a kiosk on the trail that details how pollutants end up in the river, what the impacts are, and how to reduce the input. However, keeping visuals to a minimum is important to maintain a more natural-appearing environment.

L. TRASH FEST AND LANDA LAKE CLEANUP

Objective: Remove litter that has accumulated in Landa Lake and downstream to the confluence with the Guadalupe River to maintain a clean, attractive environment.

Current practice: The Parks and Recreation Department periodically removes trash from Landa Lake. Parks personnel patrol the lake by boat and snorkel to recover litter. This practice takes place once or twice a week during the summer season (May to September) and less often during the off-season.

An annual cleanup (TrashFest) is held during the fall, usually the first Saturday in October. SCUBA divers, sponsored by the Houston Gulf Coast Council of Divers, pick up trash from the river bottom. They cover the Comal River from the hydroelectric plant downstream to the Guadalupe River, excluding the old channel. Their coverage area includes both public and private areas of the river. About 20 to 60 divers usually participate.

Problems and concerns:

1) Excessive disturbances (like sediment disturbance or plant damage) during trash removal in some parts of Landa Lake may have negative impacts on fountain darter habitat.

2) The high number of SCUBA divers and snorkelers in the river simultaneously during Trash Fest could cause habitat impacts. If the SCUBA divers are unaware of habitat concerns, beds of aquatic plants might be torn apart and bottom sediments stirred up. However, many of the SCUBA divers are experienced and are involved in the Trash Fest every year.

Recommendations:

1) Landa Lake, on average, contains only a minimal amount of litter and its removal using the current procedures probably has no impact on fountain darter habitat. It is important to keep the number of people involved to a minimum and inform them of potential impacts to fountain darter habitat.

2) The Trash Fest, as currently conducted, is a beneficial activity for the ecosystem, and as an annual event it probably does not result in substantial impact to fountain darter

habitat. However, large scale cleanup activities should be monitored, and SCUBA divers asked to help avoid habitat destruction.

M. HUMAN ACTIVITY IN SPRING RUNS

Objective: Encourage enjoyment by visitors to Landa Park and discourage activities that impact spring run habitat.

Current practice: Park rules prohibit people from entering the spring runs, with the exception of the wading pool. However, park visitors have been frequently observed wading in the restricted areas of the spring runs. In the past, occasional observations (*by whom*)have been made of some park visitors building dams to create small ponds, collecting plants, collecting bait fish with cast nets, shampooing their hair, brushing their teeth, and depositing bodily waste in the spring runs. These activities are against park policy and violators can be fined.

Problems and concerns:
The spring runs not only contain fountain darter habitat, but are the most common location in the Comal ecosystem for the Comal Springs salamander (*update*), and the only location in the Comal ecosystem for the Comal Springs riffle beetle and aquifer-dwelling invertebrates (see Section I.B. - Target Organisms). The vegetation in these shallow areas can be easily disturbed by human activities such as wading and swimming. Vegetation is an important habitat component for many of the aquatic animals. The practice of casting a net to capture baitfish is also a problem because of the potential for catching fountain darters.

Recommendations:
1) The Parks and Recreation Department is not able to maintain a continuous presence in the spring run area, so they could organize volunteer groups to monitor the spring runs. The Parks and Recreation Department could also encourage park rangers to consistently enforce the regulations when they are in the spring run area and use fines for repeat violators. If these methods are not effective, then adding barriers, such as a

simple bar across the upstream side of the wading pool and a railing along the side of the spring runs, may help to remind visitors of the boundaries of the wading area. Railings along the spring runs could be designed so as to not detract from the natural setting. For instance, two-rail cedar or rough hewn lumber fence might appear very attractive and still allow for easy observation of the spring runs by visitors. It may also help if signs that delineate restricted areas are printed in both English and Spanish.

2) While enforcement is necessary and should continue, park rangers cannot always be on the scene when a violation occurs. Education, therefore, plays an important role. The uniqueness of the spring runs and the impacts of activities previously discussed could be explained through the use of educational tools such as kiosks or interpretive activities using volunteers.

3) The preferred alternative to eliminate the capture of bait from the spring runs is banning the use of live fish for fishing in Landa Lake. This would also eliminate the risk of introducing non-natives to the ecosystem through bait release. An alternative could be an on-site bait shop selling crickets and worms. The boat dock might be a good location for a bait stand.

N. BANK STABILIZATION

Objective: Provide bank stability to slow down the erosional processes by maintaining existing retaining walls, while maximizing opportunities to protect and restore natural near shore habitats.

Current practice: Banks can be destabilized through the process of erosion. Stacked concrete bags or rocks, and vertical retaining walls are methods often used in the Comal River to slow down the erosion process where bank stabilization has become a problem. Some areas along the river have enough riparian vegetation to prevent excessive erosion.

Problems and concerns:

There are numerous techniques available for stabilizing stream banks. These techniques vary in their effectiveness and in the amount of impact they have on the bank and adjacent shallow water habitat. Retaining walls, for instance, cause the loss of shallow water and riparian habitat bank. They also have a less "natural" appearance than banks stabilized by some other methods. The method chosen for a bank stabilization project should be one that will minimize habitat impacts and loss while still resulting in a stable bank. The usage of a section of stream bank should be considered in selecting a stabilization technique. Areas with high public access may require a different method than areas of low public access.

Recommendations:

The following discussion is intended to highlight some of the various methods available for bank stabilization. The method chosen for a specific project will depend on factors such as land usage, habitat type present, and stream characteristics (for instance, stream flow).

1) Banks that need erosion control measures are often those that are subjected to high human activity (for example, in Prince Solms Park). Bank impacts can be reduced by providing access to the river, such as stairways, and vegetating the banks between access points in a way that encourages people to use only the designated entrance. Banks that are steeper than a 2:1 ratio (that is, bank height is twice the slope) are also highly susceptible to erosion (City of Austin Public Works Dept. 1982). Even banks with a 1:1 ratio can become an erosion problem. The Austin Public Works Department recommends that the City of Austin stabilize critical areas with native trees, shrubs and grasses. Table 7 lists plants native to the Comal area that could be used for erosion control.

2) Riparian vegetation plays an extremely important role in controlling erosion and stabilizing banks and is the preferred method of bank stabilization. Roots bind particles together and the underbrush reduces raindrop impact forces on the soil. Riparian vegetation increases infiltration and reduces runoff velocity. Vegetation also reduces wind velocity at the ground surface and provides a rougher surface, which traps

particles moving along the ground (Urban Drainage and Flood Control District 1992). Below the waterline, the root system helps to hold the soil together and exposed stalks and stems slow the stream flow which reduces erosion and does not remove shallow water habitat. Riparian vegetation is relatively easy to establish and maintain, appears more natural than many other bank stabilization structures, and is the only bank protection method that can repair itself after some types of damage. See Appendix C for sources of information on using plants for bank stabilization and erosion control.

3) Criblock could also be used to stabilize banks. These are cellular blocks that are cast with openings to provide for drainage and to allow vegetation to grow through the blocks thus permitting the root structure to strengthen the bank (U.S. Army Engineers Waterways Experiment Station 1983). This method, in contrast to a vertical concrete wall, provides some surface for habitat.

4) The current method of overlapping concrete bags is also better than vertical walls, because it can provide shallow habitat. However, unlike criblock, soil does not fill in and it is more difficult for plants to establish themselves on concrete bags.

5) Another technique to stabilize banks that is especially useful until vegetation becomes established, is using large tree trunks and boulders placed at the water's edge (Briggs et. al. 1994). This also improves fish habitat by providing cover for fish as well as a habitat for their prey. However, erosion can continue to occur underneath and between the trunks and boulders. Little pools can also form, which provide good habitat for pests such as mosquitos.

O. BASKING HABITAT FOR TURTLES

Objective: Preserve turtle **basking** habitat in the Comal River, while considering public safety.

Current practice: Turtle basking habitat often includes trees and branches that have fallen into the river. These are removed by the Parks and Recreation Department if deemed unsafe for the public or at the request of local citizens.

Problems and concerns:

Turtle populations have been decreasing at an alarming rate in North America (Ernst et al. 1994). Two major factors causing their rapid decline are habitat destruction and over-collection for pet trade (Ernst et al. 1994).

Recommendations:

1) Habitat for aquatic turtles is generally characterized by slow to moderate current, soft bottoms, and easy access to basking areas. Wide areas of water that receive at least some daylight are typical (Ernst et al. 1994). Flavius Killebrew (West Texas State Univ., personal communication, 1995) suggested that the most significant activity the City could do for some turtle species in the Comal ecosystem is provide basking areas by

(1) not mowing or clearing bank riparian zones and

(2) letting trees fall into the water, except where public safety is compromised. Another advantage of allowing fallen logs to remain in the water is they serve as good habitat for fish and aquatic invertebrates.

2) Certain areas could be set aside for turtle habitat and possibly used as part of the nature walk in Landa Park and tourist attractions (turtle viewing areas) in parts of the river where safety is not a concern. Creating and maintaining habitat in the heavy-traffic areas like Prince Solms Park above and below the tube chute might not be successful because of interference from the public and safety concerns. However, many portions of the old channel and Landa Lake are good sites.

3) Pathway signs could provide species identification and life history information for turtles that are found in each area.

P. RIPARIAN VEGETATION

Objective: Maintenance or restoration of native vegetation as a way of repairing and maintaining riparian wildlife habitat, preventing bank erosion, and maintaining a pleasant aesthetic quality for humans.

Current practice: No specific preservation or restoration plans are in place for riparian zones.

Problems and concerns:

1) Maintaining riparian vegetation - Riparian communities have many values, including reducing downstream flooding by slowing down and reducing runoff from storm events; recharging aquifers; as a source of nutrition for stream residents; reducing erosion; storing sediments, heavy metals, and toxins which may otherwise reach the river and adversely affect water quality; recreation; and aesthetics (Malanson 1993). Woody-deciduous riparian zones are also important in supporting wildlife diversity, especially migratory songbirds (Maser et al. 1984).

Riparian zones in the U.S. have been greatly altered in the last 200 years. The dominant factor has been hydrologic alteration (such as reservoirs), but timber clearing, overgrazing by livestock, agricultural conversion, and urban growth are other important causes of change in riparian habitat (Malanson 1993). The Comal River has experienced severe alterations in its riparian zones primarily due to urban growth. Only a thin border (if any) of riparian vegetation remains along the banks of the Comal River.

2) Safety - A specific city management concern in public areas is the use of wooded areas along the bank for hiding stolen goods.

Recommendations:

1) Maintaining vegetation - Based on the benefits provided by maintaining a riparian zone, we recommend that the City

(1) maintain existing riparian communities, and

(2) restore impacted riparian areas where possible. Briggs (1994) discusses several restoration projects and provides clear directions for beginning such a project. Native plants should be used in these projects. Table 7 lists many plants native to this area.

2) We recommend that riparian areas being used to hide stolen items not be totally cleared, but rather just clear the underbrush so it is more difficult to hide stolen items. Care should be taken to not clear the next generation of trees, as they are essential for the continuance of the riparian zone.

Q. GAME FISH ENHANCEMENT

Objective: To enhance fishing in the Comal River.

Current practice: The New Braunfels Parks and Recreation Department currently does not stock game fish in the Comal River.

Problems/concerns:
Stocked fish (both native and non-native) can reduce fish populations already in the river through crowding, competition, predation, and habitat modification or destruction (see Section I.C.3. - Problematic Organisms). Many of the desirable game fish, such as largemouth bass, are predators on smaller fish, such as fountain darters. Also, there is the possibility of introducing fish diseases and parasites to the river when introducing native or non-native fish.

Recommendations: The current status of game fish populations in the Comal River, including Landa Lake, is not known. It is possible that the population levels are at or near optimum for this system based on the food and habitat available. Stocking should be considered only when the target species have been identified, their current populations have been assessed, and the impact of adding more individuals to the system has been estimated.

1) We recommend that a fish community study be done on the Comal River, including Landa Lake. This study should determine the present population levels of desirable game fish and tilapia, as well as the amount of resources available to them. The Service should be allowed to review and comment on the study design early, and throughout, the development process. Some important resources to identify are spawning habitat, nursery areas, prey availability, and competition with other species. The role of game fish as predators of fountain darters should also be determined. This data should be used to answer some basic questions considering the feasibility of stocking additional fishes: (a) Are there enough resources available to support more fishes than presently occur here; (b) Will the introduction of additional fishes negatively impact fountain darters; and (c) Can higher populations of game fishes be attained using a management practice, other than stocking, that does not negatively impact fountain darters (for instance, removing tilapia and giant ramshorn snails might increase the habitat available for game fishes and fountain darters). Negative impacts to fountain darters can be direct, such as predation, and indirect, such as loss of habitat or competition for food with young game fishes. Possibly, such a study could be done in cooperation with a university as part of a graduate degree project.

2) If, after completing a study as described above, it is determined that fish stocking is feasible, only native fish species should be considered. The approach should be one that develops the native fish populations for fishing and not one that introduces non-native species or subspecies or fish with parasites or diseases. Possible acceptable activities should be discussed with the Service after an accurate assessment has been completed.

Table 1. Monthly statistics of historical daily spring flow at Comal Springs for 1929-1992 (USGS records **NEED DATE**). The readings are independent of storm events.

Month	Minimum (cfs)	Maximum (cfs)	Mean (cfs)
January	34	478	269.9
February	39	514	300.0
March	55	500	298.2
April	32	506	294.1
May	19	506	294.4
June	0	503	288.0
July	0	495	271.3
August	0	476	257.5
September	0	468	262.8
October	0	534	272.3
November	0	462	282.2
December	18	483	291.2
TOTAL	0	534	284.0

[WILL BE UPDATED FOR 1929-2000 FIGURES - WAITING FOR PAT]

Table 2. Water quality readings for the Comal River at Hinman Island from November 1994 to May 1995 (GBRA 1995 records).

Parameter	11/94	12/94	1/95	2/95	3/95	4/95	5/95
Fecal coliform (org/100ml)	108	64	88	44	78	6	23.3
Suspended solids (mg/l)	1.6	3.6	4.3	4	1.2	2	10.2
Turbidity	0.9	1.6	2.3	2.5	1.5	1.2	7
pH	7.4	7.5	7.4	7.5	7.8	7.6	7.5
Temperature (°C)	22	22	21	21.6	22.8	23	23.2
Dissolved Oxygen (mg/l)	9.42	8.8	8.7	9.6	8.9	9.1	9.7
Conductivity (umhos/cm)	560	558	563	631	560	590	520
Total Phosphorus (mg/l)	.04	.04	.09	.03	.08	.08	.09
Nitrate (mg/l as N)	1.5	1.1	1.7	2.7	1.8	1.5	1.9

[WILL BE UPDATED WITH BETTER DATA - WAITING FOR PAT]

Table 3. Fishes collected from the Comal River (Hubbs et al. 1991, Whiteside 1974-1990)

FAMILY	COMMON NAME	SCIENTIFIC NAME
MINNOWS - CYPRINIDAE	central stoneroller	*Campostoma anomalum*
	gold fish*	*Carassius auratus*
	red shiner	*Cyprinella (=Notropis) lutrenis*
	blacktail shiner	*Cyprinella (=Notropis) venusta*
	common carp*	*Cyprinus carpio*
	roundnose minnow	*Dionda episcopa*
	golden shiner*	*Notemigonus crysoleucas*
	Texas shiner	*Notropis amabilis*
	pallid shine*	*Notropis (=Hybopsis) amnis*
	fathead minnow*	*Pimephales promelas*
	bullhead minnow*	*Pimephales vigilax*
SUCKERS - CATOSTOMIDAE	gray redhorse	*Moxostoma congestum*
CHARACINS - CHARACIDAE	mexican tetra*	*Astyanax mexicanus*
BULLHEAD CATFISHES - ICTALUIDAE	black bullhead	*Ameiurus (=Ictalurus) melas*
	yellow bullhead*	*Ameiurus (=Ictalurus) natalis*
	channel catfish	*Ictalurus punctatus*
	tadpole madtom	*Noturus gyrinus*
	flathead catfish	*Pylodictis olivaris*
SUCKERMOUTH CATFISHES -LORICARIIDAE	suckermouth catfish*	*Hypostomus spp.*
KILLIFISHES - CYPRINODONTIDAE	blackstripe topminnow	*Fundulus notatus*
LIVEBEARERS - POECILIIDAE	largespring gambusia	*Gambusia geiseri*
	amazon molly*	*Poecilia formosa*
	sailfin molly*	*Poecilia latipinna*
SUNFISHES - CENTRARCHIDAE	rock bass*	*Ambloplites rupestris*
	redbreast sunfish*	*Lepomis auritis*
	green sunfish*	*Lepomis cyanellus*

Table 3 continued.

	warmouth*	*Lepomis gulosus*
	bluegill	*Lepomis macrochirus*
	longear sunfish*	*Lepomis megalotis*
	redear sunfish	*Lepomis microlophus*
	spotted sunfish*	*Lepomis punctatus*
	smallmouth bass*	*Micropterus dolomieui*
	largemouth bass	*Micropterus salmoides*
	guadalupe bass	*Micropterus treculi*
	white crappie	*Pomoxis annularis*
PERCHES - PERCIDAE	fountain darter	*Etheostoma fonticola*
	greenthroat darter	*Etheostoma lepidum*
	orangethroat darter	*Etheostoma spectabile*
	texas logperch	*Percina carbonaria (caprodes)*
	dusky darter	*Percina sciera*
	river darter	*Percina shumardi*
CICHLIDS - CICHLIDAE	Rio Grande perch*	*Cichlasoma cyanoguttatum*
	blue tilapia*	*Oreochromis aurea*
	Mozambique tilapia*	*Oreochromis) mossambica*

* species not considered native to the Comal River

Table 4. Amphibians and reptiles observed/documented or potentially found in the Comal ecosystem (Dixon 1987; Andy Price, TPWD, personal communication, 1995).

FAMILY	COMMON NAME	SCIENTIFIC NAME
TREEFROGS - HYLIDAE	Blanchard's cricket frog	*Acris crepitans blanchardi*
	Gray treefrog	*Hyla versicolor*
	Green treefrog	*Hyla cinerea*
	Strecker's chorus frog	*Pseudacris streckeri*
TRUE FROGS - RANIDAE		
	Rio Grande leopard frog	*Rana berlandieri*
	bullfrog*	*Rana pipiens*
WATER TURTLES AND BOX TURTLES - EMYDIDAE		
	Texas river cooter*	*Pseudemys texana*
	Red-eared slider*	*Trachemys scripta elegans*
MUD AND MUSK TURTLES - KINOSTERNIDAE		
	Yellow mud turtle	*Kinosternon flavescens flavescens*
	Mississippi mud turtle	*Kinosternon subrubrum hippocrepis*
SOFTSHELL TURTLES - RANIDAE		
	Guadalupe spiny softshell*	*Trionys spiniferus guadalupensis* (also observed by Roemer in 1847)
AQUATIC SNAKES - COLUBRIDAE		
	Blotched watersnake*	*Nerodia erythrogaster transversa*
	Diamondback watersnake*	*Nerodia rhombifera rhombifera*
MOCCASINS - VIPERIDAE		
	Western cottonmouth	*Agkistrodon piscivorus leucostoma* (also observed by Roemer in 1847)

* Species documented in the Comal ecosystem

Table 5. Invertebrates sampled from the Comal ecosystem (Espey, Huston & Assoc. 1975, Bosse 1988, Barr 1992-1994).

LOCATION	ORDER	SPECIES (years collected)
1	Decapoda	*Palaemonetes sp.* (1975)
	Macrobrachium carcinus	
mphipoda	*Hyallela azteca* (1991)	
phemeroptera	*Centroptilium sp.* (1975)	
		Tricorythodes sp. (1975, 1991)
	Caenis sp. (1990)	
astropoda	*Amnicola comalensis* (1975)	
		Heliosoma trivolvis (1975)
		Marisa cornuarietis (1990)
		Thiara granifera (1975)
		Elimia comalensis (1990)
		Cincinattia comalensis (1990)
		Gyraulus parvus (1990)
donata	*Nehalennia sp.*	
		Argia sp. (1990)
iptera	Chironomidae (1990)	
2	Amphipoda	*Hyallela azteca* (1990, 1991)
iptera	Chironomidae (1990, 1991)	
phemeroptera	*Hexagenia sp.* (1990, 1991)	
		Tricorythodes (1990, 1991)
donata	*Argia sp.* (1991)	
astropoda	*Marisa cornuarietis*(1990,1991)	
		Thiara granifera (1990,1991)
		Thiara tuberculata (1990,1991)
		C. comalensis (1990,1991)
		Gyraulus parvus (1990)
		Elimia comalensis (1990,1991)

A E G O D D E O G

		Physa virgata (1990)
		Heliosoma anceps (1990)
ecapoda	*Palaemonetes sp.* (1990)	
		Macrobrachium carcinus
3	Amphipoda	*Hyallela azteca*

Table 5 continued.

LOCATION	ORDER	SPECIES (years collected)
ecapoda	*Procambarus sp.* (1975,1990-91)	
		Macrobrachium carcinus
		Palaemonetes sp. (1975,90-91)
phemeroptera	*Centroptilium sp.*	
		Tricorythodes sp.
3	Gastropoda	*Amnicola comalensis*
		Goniobasis comalensis
		Thiara granifera (1975,90-91)
		Marisa cornuarietis (1990-91)
		Thiara tuberculata (1990-91)
		Cincinattia comalensis (90-91)
		Gyraulus parvus (1990-91)
		Elimia comalensis (1990-91)
		Physa virgata (1990-91)
		Heliosoma anceps (1990-91)
donata	*Argia sedula*	
iptera	Chironomidae (1990)	
		Oligochaeta (1990-91)
4	Diptera	Oligochaeta (1990-91)
		Hirudinea (1990)
astropoda	*Marisa cornuarietis* (1990-91)	
		Thiara granifera (1990-91)
		Thiara tuberculata (1990-91)
		Elimia comalensis (1990-91)
		Heliosoma anceps (1990-91)

		Cincinattia comalensis (90-91) *Gyraulus parvus* (1990-91)
5	Oligochaeta (1990-91)	
iptera	Chironomidae (1990-91)	
donata	*Argia sp.* (1990)	
astropoda	*Marisa cornuarietis* (1990-91)	*Thiara granifera* (1990-91) *Thiara tuberculata* (1990-91) *Cincinattia comalensis* (90-91)

Table 5.continued.

LOCATION	ORDER	SPECIES (years collected)
		Gyraulus parvus (1990-91) *Elimia comalensis* (1990-91) *Physa virgata* (1990-91) *Heliosoma anceps* (1990-91)
ecapoda	*Palaemonetes sp.* (1990-91)	*Macrobrachium carcinus*
6	Amphipoda	*Hyallela azteca* (1975, 1990) *Stygobromus pecki* (1992-94) *Stygobromus russelli* (1992-94) *Mexiweckelia hardeni* (1992-94) *Seborgia relicta* (1992-94)
7	Coleoptera	*Psephenus texanus* (1975,90,92-94) Elmidae (1990, 92-94) *Microcylloepus pusillus* (92-94) *Heterelmis comalensis* (92-94) *Stygoparnus comalensis* (92-94) *Phanocerus clavicornis* (92-94) *Neoelmis sp.* (1992-94) *Haideoporus texanus* (92-94) Bessinae (1992-94) *Hydroporus rufilabris* (92-94) *Neoclypeodytes discretus* (1992-94)
emiptera	*Rhagovelia sp.* (1992-94)	

		Gerridae (1992-94)
		Hydrometridae (1992-94)
astropoda	*Thiara granifera*	
egaloptera	*Sialis sp.*	
donata	*Argia sedula*	
		Argia translata
		Argia sp. (1990)
		Brechmorrhoga mendax
		Hetearicana sp.
		Nehalennia sp.
	Diptera	*Prosimulium sp.*
		Chironomidae (1990)
phemeroptera	*Baetis sp.* (1975, 1990)	
		Centroptilium sp.
		Psuedocleon sp.
		Tricorythodes sp. (1975, 1990)
ricladida	triclad flatworms	

Table 5.continued.

LOCATION	ORDER	SPECIES (years collected)
8	Ephemeroptera	*Tricorythodes sp.*

* Locations:
1 = LL near confluence of Bleider's Creek
2 = LL just above Spring Island
3 = north side and below Spring Island
4 = LL between gazebo and bird island
5 = LL across from boat dock
6 = spring runs
7 = Comal River between LL and final reach (USFWS-not available)
8 = final reach before Guadalupe River

Table 6. Caddisflies (Trichoptera) sampled by Dr. David Bowles (TPWD) in 1993 & 1994 at five sites in the Comal springs and river.

FAMILY	SPECIES	Collection Sites*	Abundance
Glossosomatidae	*Protoptila alexanderi*	1,2,3,4,5	Common
Helicopsychidae	*Helicopsyche borealis*	1,2,3,4,5	Common
	H. piroa	1,2,3,4,5	Common
Hydrobiosidae	*Atopsyche erigia*	2,3,4	Common
Hydropsychidae	*Cheumatopsyche pettiti*	3,4	Uncommon
	Smicridea fasciatella	1,2,3,4,5	Common
Hydroptilidae	*Hydroptila ajax*	1,2,3,4,5	Common
	H. waubesiana	2,4,5	Uncommon
	Leucotrichia sarita	1,2,3,4,5	Common
	Neotrichia edalis	4	Rare
	Ochrotrichia nigritta	1,2,3,4,5	Common
	O. tarsalis	1,2,3,4,5	Common
	Oxyethira azteca	3,5	Rare
	O. pallida	2,3,4,5	Common
	O. ulmeri	2,3,4,5	Common
Family Leptoceridae	*Nectopsyche gracilis*	1,2,3,4,5	Common
	Oecetis inconspicua	2,3,4,5	Common
	O. persimilis	4	Uncommon
	Triaenodes ignitus	4	Uncommon
Family Philopotarridae		*Chimarrra feria*	1,2,3,4,5Common
	C. obscura	2,3,5	Uncommon
	C. texana	1,2,3,4,5	Common
Family Polycentropodidae			
	Cemotina astera	4	Uncommon
	C. calcea	3	Rare
	Nyctiophylax affinis	1,4	Uncommon
	Polyplectropus santiago	4	Rare

*Collection Sites

1. near head of spring run 3
2. at confluence of spring run 3 and Landa Lake
3. at new channel near park pavillion across from Parks and Recreation office
4. at spillway between Landa Lake and the golf course west of Golf Course Rd bridge
5. halfway between the head of spring run 1 and California Boulevard bridge

Table 7. Partial list of plants native to the Comal River area (Soil Conservation Service 1984, Cox and Leslie 1988, Hatch et al. 1990).

Type	Common name	Scientific name
ferns	Southern maidenhair	*Adiantum capillus-veneris*
grasses	bearded sprangle-top	*Leptochloa fascicularis*
	fall panic grass	*Panicum dichotomiflorum*
sedges	awned flatsedge	*Cyperus aristatus*
	creeping spikerush	*Eleocharis macrostachya*
	saltmarsh bulrush	*Scirpus maritimus*
	three-square bulrush	*Scirpus pungens*
herbs/shrubs	spiny water-starwort	*Callitriche verna*
	dotted smartweed	*Polygonum punctatum*
	Nuttall's poverty weed	*Monolepis nuttalliana*
	mexican summer cypress	*Kochia scoparia*
	seaside heliotrope	*Heliotropium curassavicum*
	buttonbush	*Cephalanthus occidentalis*
	beautyberry	*Callicarpa americana*
	snowberry	*Symphoricarpos orbiculatus*
trees	bald cypress	*Taxodium distichum*
	black willow	*Salix nigra*
	eastern cottonwood	*Populus deltoides*
	Texas oak	*Quercus buckleyi*
	Shumard oak	*Quercus shumardii*
	Bur oak	*Quercus macrocarpa*
	post oak	*Quercus stellata*
	live oak	*Quercus virginiana*
	American elm	*Ulmus americana*
	cedar elm	*Ulmus crassifolia*
	sugar hackberry	*Celtis laevigata*
	Lindheimer hackberry	*Celtis lindheimeri*
	osage-orange	*Maclura pomifera*
	red mulberry	*Morus rubra*
	American sycamore	*Platanus occidentalis*
	yaupon holly	*Ilex vomitoria*

possumhaw	*Ilex decidua*
Eastern redbud	*Cercis canadensis*
Texas redbud	*Cercis canadensis texensis*
Texas mountain laurel	*Sophora secundiflora*
Eve's necklace	*Sophora affinis*
huisache	*Acacia farnesiana*
pecan	*Carya illinoensis*

Table 7 continued

western soapberry	*Sapindus drummondii*
Mexican buckeye	*Ungnadia speciosa*
box elder	*Acer negundo*
red buckeye	*Aesculus pavia*
yellow buckeye	*Aesculus pavia flavescens*
Texas buckeye	*Aesculus arguta*
Texas ash	*Fraxinus texensis*
elderberry	*Sambucus canadenis*

Table 8. Surface Water Rights in the Comal River (TNRCC records, 1994).
C = consumptive; NC = nonconsumptive; NB = New Braunfels

TNRCC Permit No.	Ownership	Use	Amount (ac-ft/yr)
3823	City of NB	municipal (C)	1,289
3826	City of NB	irrigation (C)	100
3827	City of NB	recreation (NC)	N/A
3824(400)	NB Utilities	irrigation (C)	200
3824(401)	NB Utilities	industry (NC)*	139,198
3824(402)	NB Utilities	hydro (NC)	124,870
3824(403)	NB Utilities	municipal (C)	**2,240
3828	Bad Schloess Inc.	irrigation (C)	3
3818A	Bad Schloess Inc.	recreation (NC)	5,000

* 3,418 ac-ft of the 139,198 ac-ft authorized can be consumptively used annually.

** NBU transferred this amount of water from Comal River to Guadalupe River. NBU's diversion point is now on the Guadalupe River.

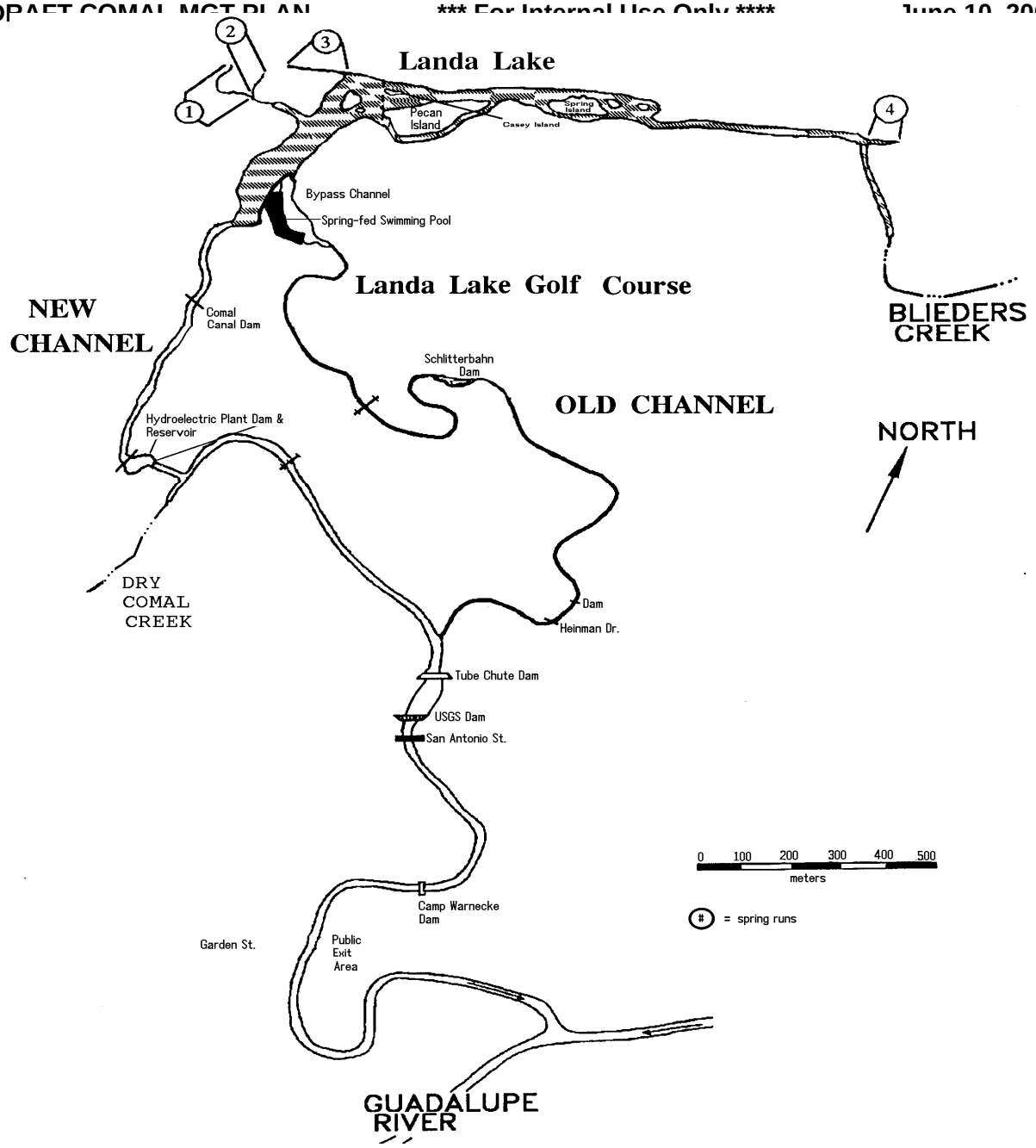


Figure 1. Comal Springs and River

Figure 1. Map of Comal Springs and River (USFWS 1996).

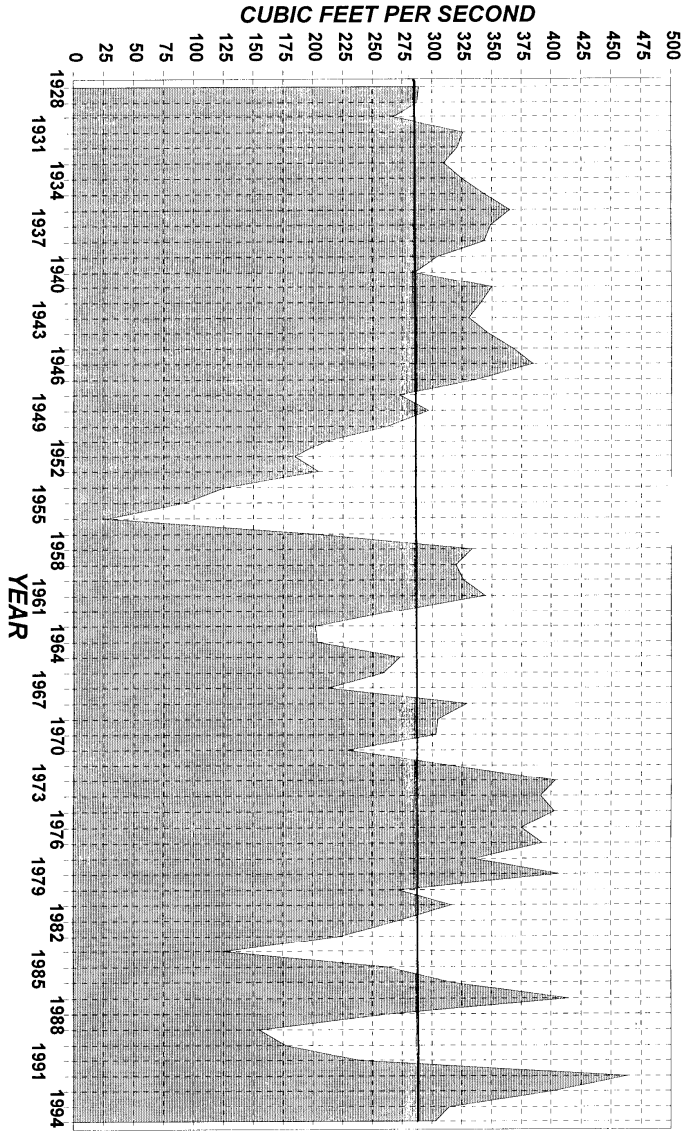
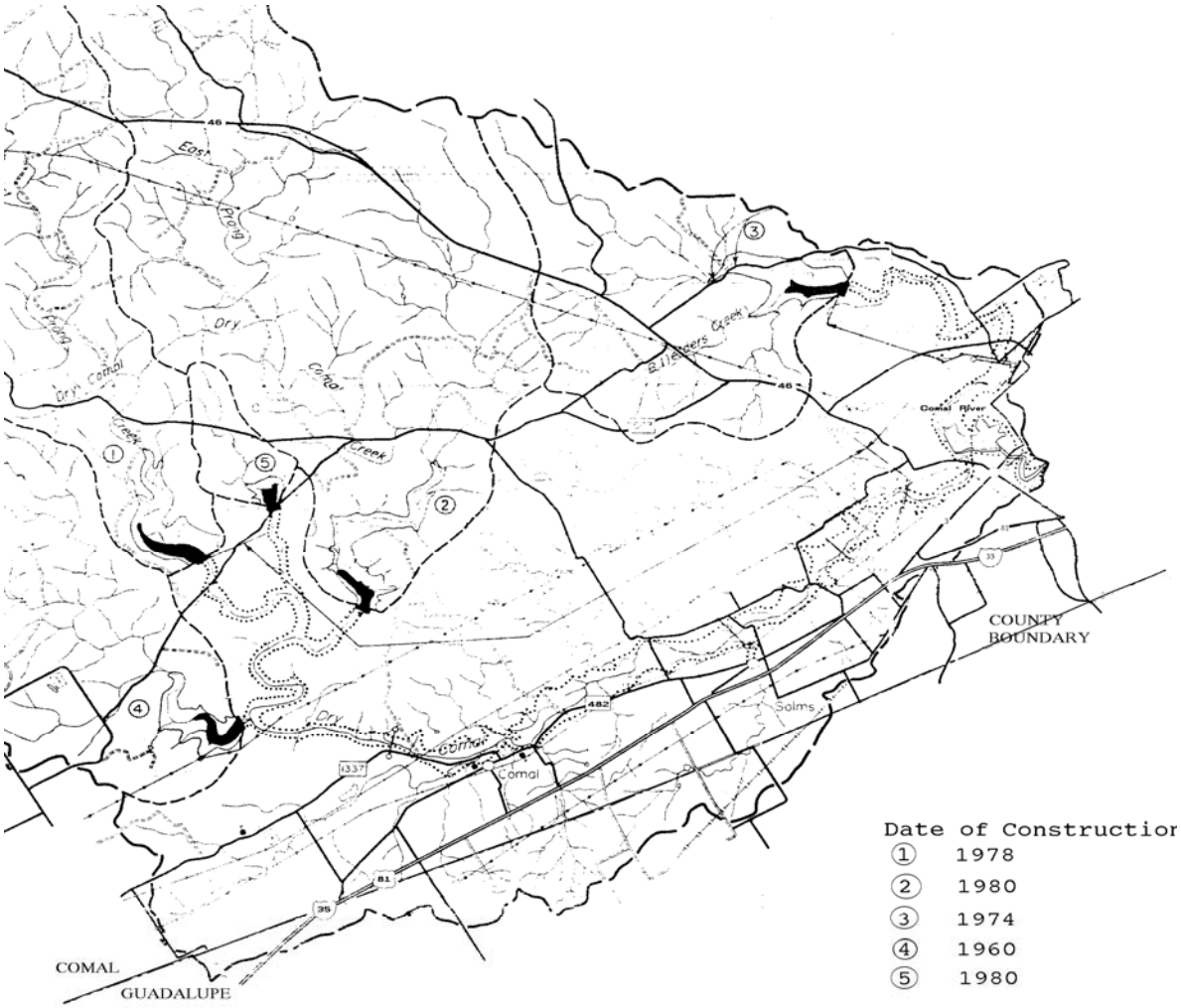


Figure 2. Comal River 1928 - 1995 Yearly Median Flow (cfs)

Figure 2. Annual median flows on the Comal River, 1928-1995.
[UPDATE W/MONTHLY FLOWS - WAITING FOR PAT]

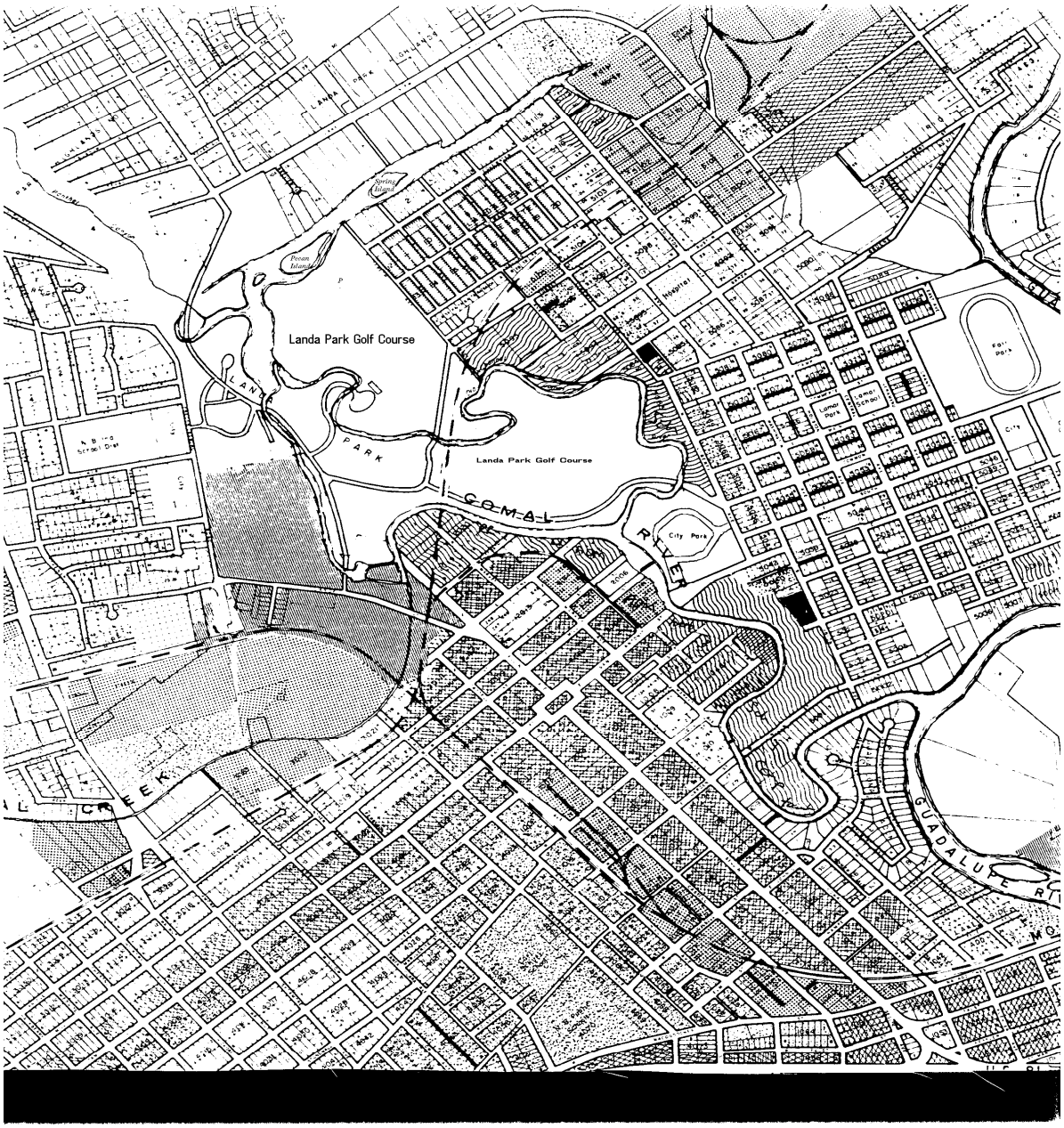
Figure 3. **[LOCATION OF SPRINGS & SEEPS - WAITING FOR PAT]**



COMAL AND GUADALUPE COUNTIES
USDA SCS TEMPLE, TEXAS

0 1 2 3 4
AFFROXIMATE SCALE IN MILES

Figure 5. Flood control structures in the Comal River watershed.


Landa Park Golf Course
Landa Park Golf Course
LANDA PARK
COMAL RIVER
City Park
Lamar Park
Lamar School
Fair Park
Hospital
Spring Island
Pecan Island
N B Ind School Dist
GUADALUPE RI
CREEK

80%

Figure 6. Land use in the Comal River Watershed, City of New Braunfels.

[GET UP DATE/CLEARER PICTURE OF LAND USE PATTERNS FROM CITY ENGINEER]

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Appendix A

ACRONYMS AND MONIKERS USED IN THE COMAL ECOSYSTEM MANAGEMENT PLAN

ADM	Archer Daniels Midland
cfs	cubic feet per second
City	City of New Braunfels
Comal Plan	Comal Springs Ecosystem Management Plan
DCIA	directly connected impervious areas
EPA	Environmental Protection Agency
ESA	Endangered Species Act
EUWD	Edwards Underground Water District
fps	feet per second
GBRA	Guadalupe-Blanco River Authority
IPM	integrated pest management
LCRA	Lower Colorado River Authority
NBS	National Biological Service
NBU	New Braunfels Utilities
NRCS	Natural Resources Conservation Service
Parks and Recreation Department	New Braunfels Parks and Recreation Department
ppm	parts per million (equal to milligrams per liter, mg/L)
Recovery Plan	San Marcos/Comal Springs and Associated Aquatic Ecosystems (Revised) Recovery Plan - 1996
Service	United States Fish and Wildlife Service
TCEQ	Texas Commission on Environmental Quality
TNRCC	Texas Natural Resource Conservation Commission
TPWD	Texas Parks and Wildlife Department
TWDB	Texas Water Development Board
USDA	United State Department of Agriculture

USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WORD	Water Oriented Recreation District

Appendix B

GLOSSARY OF TERMS APPEARING IN BOLDFACE TYPE

allele - the two individual members of a gene pair

allozyme electrophoresis - a method of determining genetic differences between organisms

amphipods - a type of small crustacean

backwashing - a method of filter cleaning that uses a reverse flow of water

backwater effect - a reversal in streamflow direction and subsequent buildup of water that occurs as a result of a downstream barrier, such as a dam

basking - as related to turtles, the act of leaving the water to sun themselves

brackish - water that is saline, but less so than sea water

cavitation - the formation of partial vacuums in a liquid by a swiftly moving solid body (i.e. a propeller)

cubic feet / second (cfs) - a measurement of the rate of flowing water (1 cfs = 0.0283 cubic meters / second)

***Dionda episcopa* complex** - a group of closely related species of fish that occupy the Colorado and Guadalupe River basins

down drop - a section of land that drops below surrounding areas as a result of geological activity

emboli - accumulation of internal bubbles in the cardiovascular system

entrainment - being drawn in and transported by the flow of a fluid

estuary - a coastal body of water that has a connection with the open ocean, and where fresh water derived from land drainage is mixed with sea water

fairway - on a golf course, the mowed part of the course between a tee and a green

flow type - the physical characteristics of the flow in a body of water which can include riffles, pools, and runs

forebay - the enlarged part of the river adjacent to the hydroelectric plant intake

green - on a golf course, a smooth grassy area at the end of a fairway that contains the hole

habitat - the living place of an organism, or community, characterized by its physical and biological properties

intermittent stream - a stream that ceases to flow on the surface during dry periods

larvae - an early form of some animals that is unlike the parent; in insects, the first stage after leaving the egg, preceding the pupa

low volume spring -

macrophyte - as used in the text, non-algae plants

molluscicide - a chemical used for killing molluscs

non-native species - plants or animals that did not naturally occur in the Comal River

prawn - a freshwater decapod (having five sets of appendages) crustacean

ribosomal RNA - these are the strands of RNA that are assembled into ribosomes. They are extracted to supply genetic data on a particular organism or species.

riparian - the strict definition of riparian is "streambank". In a broader sense, the riparian zone is an area of transition from riverine to upland vegetation.

rough - on a golf course, the grounds bordering a fairway

runoff - that portion of the precipitation on a drainage area that is discharged from the area in stream channels

run-of-river hydroelectric plant - a hydroelectric plant whose power is dependent upon natural daily, weekly, or seasonal flow patterns and on upstream regulation. The river runs through the facility and over an associated dam

sediment - solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice, and has come to rest at a new location.

sedimentation - deposition of detached soil particles

spring run - a stream fed directly by a spring

substrate - sediments, rocks, etc. at the bottom of a body of water

tee - on a golf course, the area from which a golf ball is struck at the beginning of play on a hole

turbidity - a measure of water clarity. Turbid waters contain suspended particles and have low clarity

volatilize - to pass off in vapor.

Appendix C

Contacts for more information on selected topics in the Comal Springs Ecosystem Management Plan. The contacts are listed by section and topic.

Section B. Reopening the NBU Hydroelectric Plant

Supersaturation and its effects on fountain darters:

r. Tom Brandt U.S. Fish and Wildlife Service
San Marcos National Fish Hatchery and Technology Center
500 E. McCarty Ln.
San Marcos, TX 78666
(512) 353-0011
tom_brandt@fws.gov

Section D. Maintenance of Dams on the Comal River Below Landa Lake

Dam safety and inspection:

exas Commission on Environmental Quality (TCEQ) Dam Safety Unit
(512) 239-4763

Section E. Fishing Derby in Olympic and Spring-fed Pools

Availability of Texas Parks and Wildlife (TPWD) biologist to examine catfish:

A. E. Wood Fish Hatchery
507 Staples Road
San Marcos, TX 78666
(512) 353-0572

Section G. Landa Lake Golf Course Management Practices

L
ost Pines Golf Course (Bastrop, TX):

ike McCracken
Course Integrated Pest Management information
(512) 321-2327

Information on irrigation rates:

ettye Urban
Texas Commission on Environmental Quality (TCEQ)
(512) 239-6659

A
udubon Cooperative Sanctuary System:

udubon Society of New York State
46 Rarick Road
Selkirk, NY 12158
(518) 767-9051

Section K. Stormwater Runoff

Information on river clean-up activities:

im Inman
Water Oriented Recreation District
(210) 907-2300

Information on river clean-up activities:

avid Davenport
Friends for Rivers
(210) 609-0543

Information on the use of trash racks on storm drains:

ecilia Martinez
City of Austin
(512) 499-7188

Information on sediment control techniques:

iane Evans
U.S. Environmental Protection Agency
(214) 665-6677

Information on sediment control techniques:

ary Landen
U. S. Army Corps of Engineers
(601) 634-2942

Section N. Bank Stabilization

Information on plants for erosion control:

ames Alderson
Natural Resources Conservation Service
(817) 774-1291

Information on a native grass mix for bank stabilization:

ennis Markwardt

Texas Department of Transportation
(512) 416-3090

Appendix D

PHOTOS (FIGURES D1-D8) OF THE DAMS ON THE COMAL RIVER

APPENDIX O:

DOCUMENTS PERTAINING TO THE VISPP PROGRAM, 2010-2011

AgriLIFE RESEARCH & EXTENSION
Texas A&M System

TEXAS A&M UNIVERSITY
COLLEGE OF AGRICULTURE AND LIFE SCIENCES
INSTITUTE OF RENEWABLE NATURAL RESOURCES

November 16, 2010

Dear Irrigator:

In 2007, the Texas Legislature created the Edwards Aquifer Recovery Implementation Program ("EARIP"). The Legislature directed the Edwards Aquifer Authority (Authority), Texas Department of Agriculture, Texas Commission on Environmental Quality, Texas Water Development Board and Texas Parks and Wildlife Department to work with other stakeholders to develop a plan for protecting the federally listed threatened and endangered species at the Comal and San Marcos springs.

The EARIP is considering an innovative voluntary program, called the ***Voluntary Irrigation Suspension Program Option,*** or ***VISPO,*** to compensate irrigators with permits to withdraw water from the Edwards Aquifer for reducing or suspending irrigation when the aquifer is at specified low levels. The VISPO would be ONE of the means to help meet the state and federal mandate to resolve the longstanding dispute over the use of the Edwards Aquifer by ensuring sufficient flows at the Comal and San Marcos.

The EARIP wants to inform you and other interested persons about the proposed VISPO. We include with this letter an Information Sheet that provides an explanation of the proposed optional program as well as background on the EARIP.

We encourage you to learn more about the VISPO program by attending one of the informational meetings scheduled as follows---

6:00 p.m. Monday, December 6, 2010
Location: Texas AgriLife Research and Extension Center, 1619 Garner Field Road, Uvalde, Texas, 78801

6:00 p.m. Tuesday, December 7, 2010
Location: Braden Keller Community Center, 1410 Amelia St., Castroville, Texas, 78009

Thank you for your consideration of this important program.

Sincerely,

Robert L. Gulley
Program Manager
Edwards Aquifer Recovery Implementation Program

RLG/mb

Enclosure

AgriLIFE RESEARCH
EXTENSION
Texas A&M System

TEXAS A&M UNIVERSITY

COLLEGE OF AGRICULTURE
AND LIFE SCIENCES
INSTITUTE OF RENEWABLE NATURAL RESOURCES

January 4, 2011

Dear Irrigator:

This is a follow-up letter to our November letter and the purpose of this letter is to determine interest in an innovative voluntary program being considered by the Edwards Aquifer Recovery Implementation Program (EARIP), the ***Voluntary Irrigation Suspension Program Option,*** or ***VISPO,*** to compensate irrigators with permits to withdraw water from the Edwards Aquifer for reducing or suspending irrigation when the aquifer is at specified low levels. Two meetings were held in early December with excellent comments and questions from the approximately 150 persons in attendance. In response, we have attached a Frequently Asked Questions sheet to represent the questions and the answers.

At this point, the EARIP needs to gage interest by irrigators in the VISPO. Please remember the VISPO is one piece of a multi-layered approach; however, we want to understand participation in the program so we can continue with the development of the larger program to sustain the federally protected species and habitats in the Comal and San Marcos springs ecosystems. Please understand -- your indication of interest is not a contractual commitment, rather an expression of your intent that is quite important in assisting the EARIP in putting together the program.

We have attached a sheet for you to use to indicate your interest that includes a table showing that annual payment schedule for both options as a reminder. If you are interested, please indicate the amount of water you would consider enrolling in the program, the respective permit number and if the water is base or unrestricted. Regardless of your interest, we would appreciate your comments on the program. When finished, tear the bottom portion off and return it to Mr. Rick Illgner at the Edwards Aquifer Authority by January 14, 2011. The address is indicated at the bottom of the sheet.

Thank you for your consideration of this important program.

Sincerely,

Robert L. Gulley
Program Manager
Edwards Aquifer Recovery Implementation Program

RLG/mb

Enclosure

Voluntary Irrigation Suspension Program Option (VISPO) Information Sheet

PROGRAM DESCRIPTION

The VISPO is a voluntary program that would provide financial compensation to permitted irrigators that are willing to enter into a 5-year or 10-year commitment to reduce or suspend their authorized withdrawals for the calendar year if the elevation of aquifer levels in the J-17 index well in San Antonio is at or below 650 feet above mean sea level (msl) on September 1 of the previous year.

TARGET VOLUME

The volume goal for the VISPO program is 40,000 acre-feet and any Edwards Aquifer irrigation permitted water rights within the Edwards Aquifer Authority (EAA) boundaries are eligible for enrollment in the program. Both base and unrestricted irrigation righs will be accepted in the program. Also, a portion of an irrigation right can be enrolled rather than the entire right.

VOLUNTARY PARTICIPATION

It should be clearly understood that VISPO program participation would be completely voluntary. Currently, all Edwards Aquifer water right holders are required to reduce their permitted withdrawals intermittently by 40% under the most severe drought restrictions. Accordingly, we believe the financial incentive offered to enrollees in the program should encourage participation. We recognize that a significant amount of irrigated acreage is rented or leased land. Therefore, any situation in which the landowner is not the operator, authorization and payment instructions must be received from both parties.

PROGRAM TRIGGER AND ESTIMATED IMPLEMENTATION FREQUENCY

The program, as currently envisioned, will be triggered if the level in the J-17 index well in San Antonio is at or below 650 feet msl on September 1. The J-17 well and trigger level applies to all participants in the program, including those in Uvalde County. The September 1 date was chosen to provide irrigators with ample time to make cropping decisions. According to historical water level records dating back to 1934, J-17 was at or below 650 feet msl approximately 37% of the time; however, J-17 was at or below 650 feet msl every year during the drought of record (1947-1956). Exact implementation frequency in the future is difficult to accurately predict.

PROGRAM TERM AND PAYMENTS TO ENROLLEES

The EARIP proposes to offer two programs, a five-year and a ten-year program to increase flexibility of potential enrollees. However, the ten-year program will have additional financial incentives to encourage enrollment in the longer-term program.

- Five-year program
  - initial standby fee of $50/acre-foot that increases 1.5% per year (this amount is paid to the enrollee every year of the term, regardless of aquifer conditions)
  - initial implementation fee of $150/acre-foot that also increases 1.5% per year.
- Ten-year program
  - initial standby fee of $57.50/acre-foot for years 1-5 and $70.20/acre-foot for years 6-10 (this amount is paid to the enrollee every year of the term, regardless of aquifer conditions)
  - initial implementation fee of $172.50/acre-foot for years 1-5 and $210.60 for years 6-10.

Frequently Asked Questions:

Edwards Aquifer Recovery Implementation Program's (EARIP) Voluntary Irrigation Suspension Program Option (VISPO)

The purpose of this sheet is to provide responses to **all** Edwards Aquifer Authority (EAA) irrigation permit-holders for questions that were asked at one of the informational meetings held December 6th & 7th, 2010 regarding the VISPO.

1. *"Can I enroll Base Irrigation Groundwater (base) into the VISPO?"*

   Yes, this program is designed to provide compensation to those interested in participating in this voluntary program. No one else can use the water enrolled in the program – it will remain in the aquifer to benefit aquifer levels, springflows, the protected species and their habitats.

2. *"What about other sources of water for irrigation?"*

   The VISPO is intended to enroll **Edwards Aquifer** pumping permits. Water rights from another source, such as other aquifers or surface water [e.g. canals], are not eligible to be enrolled. An EAA permit-holder can enroll their EAA permit and continue to irrigate from these other sources, recognizing that all of the legal conditions affecting those other water sources remain in force.

3. *"How will this program be paid for? What is the funding source?"*

   The VISPO is **one part** of a **multi-layered** approach to aquifer management to ensure the beneficial economic use of the Edwards Aquifer can continue while at the same time accomplishing endangered species protection during periodic droughts. The EARIP is now considering various options for funding the implementation of the approach. Even though specific funding mechanisms have not been identified at this time, some combination of financial resources is expected to be available to meet the funding needs of **each part** of this **multi-layered** approach including the VISPO prior to September 1, 2012.

4. *"When would the first trigger date be? What year?"*

   Some or all of the components to the multi-layered approach may not be implemented until the United States Fish & Wildlife Service formally approves the Habitat Conservation Plan. The goal is to have this approval by September 1, 2012. If the EARIP is successful in achieving this goal, the first time VISPO would be triggered is in September 1, 2012. If not, the first time the VISPO could be triggered would be September 1, 2013.

5 *"What happens if the trigger is implemented on September 1st, but then aquifer levels improve?"*

   If the trigger is reached (650 feet or lower as measured at the Index Well J-17 in San Antonio, Stage 2) on or before September 1st, those who choose to enroll in the program will be required to suspend their irrigation the following calendar year regardless of improved conditions. Irrigation of fall crops can continue until January 1, subject to Critical Period reductions, if the suspension trigger is reached on September 1. If the aquifer level improves after September 1st, but the VISPO has been triggered, participants will still be paid to suspend irrigation the following year.

6. *"Can a portion of a permit be enrolled?"*

   Yes. If a permit-holder wishes, a portion of the pumping rights **can** be enrolled in the VISPO. This preserves the enrollee's flexibility to irrigate a portion of the farm. Enrollees who desire to enroll less than their entire permit

will be required to have a real-time meter installed by the EAA on their well(s) at no cost to the well-owner. This is intended to ensure the pledged portion of the permit is suspended.

7. *"What does this mean to businesses that supply and equip irrigators?"*

Seed, fertilizer, equipment, fuel, and crop storage companies have expressed concern that they will be adversely affected by the VISPO. Several components of this program have been designed to **lessen** any impacts to these businesses. First, enrollees and agribusinesses will have what is thought to be enough time to adjust their operations in preparation for an upcoming suspension-season. Second, irrigated agriculture can continue on the acres of land not affected by the program. Third, enrollees can choose to pledge only a portion of their pumping permits and still irrigate on a portion of their acreage. Fourth, dry-land farming remains an option for enrollees; it is believed that a September 1st trigger date will provide adequate notice for agribusinesses to accommodate these practices. A similar program was enacted by the EAA in 1997, as documented by agricultural economists at Texas A&M University (http://repository.tamu.edu/bitstream/handle/1969.1/6153/tr175.pdf?sequence=1). Also see Frequently Asked Question #9 below).

8. *'What will this do to aquifer levels?"*

Aquifer levels depend on many factors; however, current analysis indicates that the VISPO provides a significant improvement in springflows at Comal Springs and some benefit at San Marcos Springs during a repeat of the drought of record compared to a baseline condition of withdrawing water from the aquifer at permitted amounts with drought restrictions.

9 *"How has agriculture been represented in this process, and how can I get involved?"*

The EARIP is overseen by a Steering Committee and almost 100 other participant stakeholders give their input to the Steering Committee through various working groups and subcommittees.

Agriculture has multiple seats ("votes") on the Steering Committee. An Edwards Aquifer irrigator and EAA permit-holder is one of the voting members. The alternate for that voting member has been actively involved in numerous other EARIP working groups and is also an EAA permit holder. The Texas Department of Agriculture has been involved in this process from its inception. The Department of Agriculture must be satisfied with the entirety of the plan, since it is required to be a signatory of the final document by State law. The EAA itself is a voting member of the Steering Committee and is overseen by a Board of elected Directors, four of whom represent irrigated-agriculture communities of Medina or Uvalde counties. The Guadalupe County Farm Bureau is represented on the Steering Committee, representing irrigators who receive their water partly from springflow in the surface rivers downstream. The South Texas Farm and Ranch Club and the Texas Wildlife Association are also involved stakeholders in the process. The Texas farm Bureau is an important, active stakeholder in the EARIP. The EARIP is administered by Texas AgriLife Extension at Texas A&M University.

All EARIP meetings adhere to the spirit of required public notice and are held in public buildings in the aquifer region. Anyone interested in the EARIP process can be involved in a number of ways:.

- The EARIP's website: http://earip.org/
- Join the EARIP mailing list to receive updates, reports, and notices of upcoming work group, subcommittee, and Steering Committee meetings (EARIP@listserv.tamu.edu)
    - The next meeting of the Steering Committee will be held on January 13-14, 2011 from 10AM-4PM at the San Marcos Activity Center in San Marcos.

Program Payment Schedule and Indication of Interest

Option	Fee	1	2	3	4	5	6	7	8	9	10
5-Year	Stand-by	50.00	50.50	51.01	51.52	52.03	N/A	N/A	N/A	N/A	N/A
	Implementation	150.00	151.50	153.02	154.55	156.09	N/A	N/A	N/A	N/A	N/A
10-year	Stand-by	57.50	57.50	57.50	57.50	57.50	70.20	70.20	70.20	70.20	70.20
	Implementation	172.50	172.50	172.50	172.50	172.50	210.60	210.60	210.60	210.60	210.60

Please tear off this portion and return it as indicated below the table

I would be interested in participating in the VISPO in the following manner:

5-year			10-year		
Permit #	Base (acre-feet)	Unrestricted (acre-feet)	Permit #	Base (acre-feet)	Unrestricted (acre-feet)
Total			Total		

Comments

Please return to Mr. Rick Illgner by January 14, 2011
Edwards Aquifer Authority
1615 N. St. Mary's
San Antonio, TX 78215

Voluntary Irrigation Suspension Program Option (VISPO) for the Edwards Aquifer Recovery Implementation Program (EARIP)

BACKGROUND

As the EARIP explores options to provide the necessary protection for the endangered species and respective habitats in the Comal and San Marcos ecosystems, it is apparent there is a relationship between the habitat of the endangered species and the management of the aquifer, especially during the most severe droughts. Consequently, the EARIP is considering a Voluntary Irrigation Suspension Program Option (VISPO) program to reduce aquifer pumping demands during specified critical periods in order to improve aquifer levels and protect spring flows, the protected species, and their habitats.

PROGRAM DESCRIPTION

The VISPO is a voluntary program open to participation to eligible holders of irrigation water rights from the Edwards Aquifer Authority (EAA) in Atascosa, Bexar, Comal, Hays, Medina and Uvalde counties who are willing to suspend exercising all or a portion of their authorized withdrawal rights in exchange for financial compensation. The program sponsor (Sponsor) will determine, by September 1, if the Aquifer level declines to a level at or below 645 feet above mean sea level (msl) in the J-17 index well in San Antonio (the trigger), indicating that the program participants (Participants) must suspend withdrawals in the next following calendar year. Each Participant will be paid a standby fee each year of the program term regardless of aquifer level or condition and will be paid an implementation fee equal to an additional three times the standby fee each year the program requires suspension of withdrawals.

PROGRAM ELEMENTS

Target Volume

The volume goal for the VISPO program is 40,000 acre-feet. The procedure for achieving the target volume is to initially pursue enrollment from Atascosa, Bexar, Comal and Hays counties first. Then the balance of the target volume goal will be divided between Medina and Uvalde counties, with a 15,000 acre-foot cap for each county. In review of enrollment applications for Medina and Uvalde counties, those choosing the 10-year option from both of these counties will be given first priority. S The intent of the VISPO program is to leave water in the aquifer for the benefit of springflow, withdrawals of enrolled water by another party will not be allowed. The financial offering for the program are clearly aimed at base irrigation groundwater rights; however, all permitted irrigation water rights (base and unrestricted) will be accepted in the program. Any permitted irrigation water rights are eligible for enrollment in the program (including municipal and industrial) since all modeling scenarios assume total permitted Edwards Aquifer withdrawal rights are pumped when aquifer or spring conditions allow. Further, permit holders whose withdrawals are monitored by real time automated meters will be allowed to enroll a portion of their water rights in the program.

Voluntary Participation

It should be clearly understood that VISPO program participation is completely voluntary and that electing not to participate or declining to enroll will not result in any consequences to an irrigation water right holder other than the required withdrawal reductions specified by the EAA Act. Nevertheless, the requirement that all Edwards Aquifer water right holders must reduce their permitted withdrawals intermittently by up to 40% currently under the most severe drought restrictions (44% under the proposed Stage V) and the financial incentives offered to enrollees in the program should encourage participation. In recognition of the fact that a significant amount of irrigated acreage is rented or leased land, the program will require that in any situation in which the landowner is not the operator, authorization and payment instructions must be received from both parties. Finally, in order that the VISPO program is credited as a component of the EARIP program document, there must be a determination by the U. S. Fish & Wildlife Service (Service) that the VISPO program is likely to occur.

Program Trigger and Estimated Implementation Frequency

The program will be triggered if the level in the J-17 index well in San Antonio is at or below 645 feet msl on the trigger date, September 1. In response to feedback received from the agricultural community, and maintain an level of protection for the VISPO program, the trigger was adjusted to 645 feet msl. That level will reduce its frequency of implementation (33% for the years 1947 - 2000 compared to a 38% implementation rate for 650 feet msl). However, during extreme droughts, the program trigger will still protect springflow and endangered species. The September 1 date was chosen to provide irrigators, and ancillary businesses affected by the decisions made by irrigators, with ample time to make cropping decisions. Announcing implementation of the program on that date will result in a complete suspension of withdrawals of the enrolled water for each program participant for the next following calendar year, beginning on January 1.

The calibration period for the EAA groundwater model is the period from 1947 – 2000. According to historical water level records for that period, J-17 was at or below 645 feet msl approximately 33% of the years in that calibration period; however, J-17 was at or below 645 feet msl every year during the drought of record, according to model outputs. Exact implementation frequency in the future is difficult to accurately predict and is dependent on multitudes of factors.

Estimated Program Benefits

Preliminary analysis by HDR Engineering, Inc. indicates that a VISPO with 40,000 acre-feet participation will significantly improve springflow at Comal Springs during severe drought. According to the modeled results, Comal Springs would have flow at or below 30 cubic feet per second 33% fewer months during the drought of record compared to a baseline condition with 572,000 acre-feet authorized withdrawals reduced up to 40% during the most restrictive stage of drought reductions*. Likewise, Comal Springs would have no flow 32% fewer months during the drought of record compared to a baseline condition with 572,000 acre-feet authorized withdrawals reduced up to 40% during the most restrictive stage of drought reductions.

* This was made at an October 21, 2010, EARIP meeting. Here is the link to the HDR presentation:

http://earip.org/EARIPMeetings/Oct2110/10-21-0%20EARIP_Tech%20Analyses_10-21-2010_v2.pdf

Program Term

The program should extend for a term of ten-years in order to provide maximum benefits in a repeat of the entire drought of record and to serve as a substantial component of in the Habitat Conservation Plan. Information available from agricultural interests suggests that most irrigators are more comfortable with a short-term arrangement. Therefore, the EARIP proposes to offer both a five-year program and a ten-year program. The ten-year program will have additional financial incentives to encourage enrollment in the longer-term program. It is the hope and intent of the EARIP that the program can be extended for longer than ten years, if that is necessary to cover the term of an Incidental Take Permit.

Estimated 10-year Program Costs

The VISPO Workgroup recommends that the EARIP consider a starting point with two programmatic offerings; a five-year a ten-year program. Both programs will have an annual standby fee and an implementation fee equal to three times the annual standby fee as follows:

- Five-year program
  - standby fee of $50/acre-foot that increases 1.5% per year
  - implementation fee of $150/acre-foot that also increases 1.5% per year.
- Ten-year program
  - standby fee of $57.50/acre-foot for years 1-5 and a step-up to $70.20/acre-foot for years 6-10
  - implementation fee of $172.50/acre-foot for years 1-5 and a step-up to $210.60/acre-foot for years 6-10.

Determining the cost of the program ahead of time is complicated because expenses are determined by the amount of water enrolled in the five and ten-year program options and the number of times the program is implemented. Assuming that all 40,000 acre-feet are enrolled in the ten-year program and an average implementation rate of 33%, a hypothetical average annual cost for a ten-year option is approximately $4,137,200. On the other hand, a conservative estimate of the program cost with all 40,000 acre-feet enrolled in the ten-year option and the program is implemented every year as it would during a repeat of the drought of record, the average annual cost is approximately $10,216,000

MEMORANDUM

FROM: **RICK ILLGNER, Chair of the VISPO Work Group**

TO: **EARIP**

DATE: **May 12, 2011**

SUBJECT: **RECOMMENDATIONS FOR VISPO**

The VISPO work group met on May 12 to discuss operational adjustments that would reduce the overall program costs without sacrificing the estimated benefits. Larry Land of HDR Engineering, Inc. participated by phone to provide technical analysis. The group considered the trigger date, the trigger level (at J-17), the target volume of the program and the possibility of using a staggered implementation (dividing the total amount enrolled into two groups and only calling for one of the groups each year or some variation on this theme).

After considerable discussion, and with the assistance of information provided by Larry Land, the work group would like to suggest the following recommendation for the VISPO program:

- The target volume remain at 40,000 acre-feet with our commitment to fill the volume the same as mentioned previously - aggressively pursue enrollment from Atascosa, Bexar, Comal and Hays counties first and divided the balance of the target volume goal between Medina and Uvalde counties, with a 15,000 acre-foot cap for each county. In review of enrollment applications for Medina and Uvalde counties, those choosing the 10-year option will be given first priority.
- Change the trigger date to October 1*.
- Change the trigger elevation at J-17 to 635 feet*.

It is the general understanding of the VISPO work group that these changes, if acceptable to the Steering Committee and EARIP participants, will still provide the springflow benefits at a substantially reduced overall program cost. Using the lower trigger level would reduce implementation rate for the model period (1947-2000) using the SB 3 baseline analysis from 69% at 645 feet to 33% at 635 feet. During the drought of record sequence, the implementation rate would only be reduced from 100% to 90%. The estimated program costs could be approximately 30-40% of the original estimate ($10,216,000 annually). More importantly, the estimated springflow benefit is the same during the worst part of the drought of record sequence. Therefore, the group felt comfortable with the recommendations.

A presentation will be made at the May 17 EARIP meeting.

* different from existing VISPO package paramaters

March 2011

VISPO Status Report Number 1

Dear Irrigator:

This Status Report follows our January 5, 2011 letter and the informational meetings held in December 2010.

The VISPO is a program being developed by the EARIP to compensate irrigators with permits to withdraw water from the Edwards Aquifer for reducing or suspending irrigation when the aquifer is at specified low levels.

First and foremost, the EARIP appreciates the interest shown by all persons who attended the VISPO informational meetings as well as those who followed-up with calls seeking clarification. We especially appreciate those who submitted responses indicating interest in participating in the VISPO.

The EARIP received responses from approximately 12% of the irrigators who were sent informational letters. Most of the responses indicated the amount and type of water and which program the responder was interested in enrolling. Some of the letters we received offered questions, comments and support for the program, although a few letters expressed opposition to the program. In total, slightly more than 17,000 acre-feet of water was submitted as an indication of interest.

The EARIP has determined that as a result of the amount of positive interest shown by irrigators for the VISPO, it is in the interest of all aquifer stakeholders to move forward. We are pursuing the development of funding mechanisms to implement the VISPO and other components of an appropriate environmental program to address statutory requirements to provide long-term protection for aquifer-dependent threatened and endangered species. In response to the comments received, we have made a few changes to the program and posted information on the EARIP web site. The most notable changes are the trigger level has been reduced from 650 feet to 645 feet at the J-17 index well. The lower level will reduce implementation frequency from 38% to 33%, based on historic records for the period 1947 - 2000. Also, we are going to put more emphasis in securing water in counties other than Uvalde and Medina to reach our goal. You can now follow the progress of the VISPO program at this link - http://earip.org/Article.aspx?ID=19.

If you have any questions, please call Rick Illgner at the Edwards Aquifer Authority, (210) 222-2204.

Thank you for your consideration of the VISPO.

Sincerely,

Robert L. Gulley
Program Manager
Edwards Aquifer Recovery Implementation Program

RLG/mb

APPENDIX P:

RESOLUTION 2011-21 ADOPTED BY THE SAN MARCOS CITY COUNCIL ON FEBRUARY 1, 2011

RESOLUTION 2011 - 21

A RESOLUTION OF THE CITY COUNCIL OF THE CITY OF SAN MARCOS, TEXAS, APPROVING RECREATION MITIGATION MEASURES FOR THE SAN MARCOS RIVER AND RECOMMENDING TO THE EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM THAT THESE MEASURES BE INCLUDED IN THE SAN MARCOS RIVER HABITAT CONSERVATION PLAN; AND DECLARING AN EFFECTIVE DATE.

BE IT RESOLVED BY THE CITY COUNCIL OF THE CITY OF SAN MARCOS, TEXAS:

PART 1. The San Marcos City Council hereby approves the Recreation Mitigation Measures attached to this resolution as Exhibit "A" and recommends to the Edwards Aquifer Implementation Program that these measures be included in Habitat Conservation Plan for the San Marcos River.

PART 2. This Resolution shall be in full force and effect immediately from and after its passage.

ADOPTED on February 1, 2011.

Daniel Guerrero
Mayor

Attest:

Jamie Lee Pettijohn
City Clerk

Recreation Measures

1. **Develop large and enhanced ingress/egress sites** that also act as bank stabilization structures at the following locations; Dog Beach (across from tube rental in City Park), tube rental, downstream of Hopkins RR trestle on river right, Bicentennial Park, upstream of Rio Vista Falls on river right along the row of cypress, Wildlife Annex and the Ramon Lucio pavilion bank. Access points need to be constructed downstream of Texas wild-rice stands. Recommend the construction of access points for fishing at locations to be determined. Site locations and design will be coordinated with community stakeholders and the U.S. Army Corps of Engineers.

2. **Create dense vegetation zones** between access points to prevent access which causes bank erosion and habitat damage. Plant selection will be coordinated with community stakeholders and U.S. Army Corps of Engineers.

Clear Springs Apartments. The river channel that runs alongside Clear Springs Apartments provides habitat for the San Marcos salamander, fountain darter and large stands of Texas wild-rice. Currently, it is open to public access and listed species habitat is damaged year after year. Recommend closing the walking path from the Clear Springs Apt parking lot to the river so anyone parking at this lot will not be able to directly access this portion of the San Marcos River. Additionally, steep walls and plantings could be constructed to minimize ongoing bank erosion and easy access to this portion of the river.

3. **Private Property.** The public is accessing the river via private property. This type of access is increasing resulting in litter and bank erosion. Recommend working with private owners to enforce trespassing laws on areas such as Cape's dam.

4. **Litter removal** from areas in and along the river is an important measure to enhance listed species' habitat. Additionally, controls on littering should be put into place and/or enhanced to decrease the level of cleanup that is occurring in the river. Cleanup in the river itself creates a disturbance to the listed species.

5. **Buffer.** Create a buffer to keep picnic tables, pop ups, shelters etc away from the river. Pushing these amenities further away from the river will reduce litter getting into the river, decrease bank compaction, and allow more space for access along the banks. The river trail could be used as the buffer boundary.

6. **Establish a state system of scientific study areas** for the protection of Texas wild-rice. Such areas have been created by Texas Parks & Wildlife Department to protect seagrass in Red Fish bay. One of the Texas wild-rice stands recommended for protection is below the spillway by Clear Springs Apts. The other is the large stand at Bicentennial Park. Scientific study areas should be located in the areas of the river that provide optimal habitat for Texas wild-rice even during extremely low flows (less than 60 cfs). Recommend using markers (i.e. flexible stakes) in the river that identify the area and notify users of the restricted access. Cordoning the area could cause safety problems for river users. The EARIP should talk to TPWD as soon as possible to explore the feasibility of this action.

Tying tubes together. Recommend limiting this activity to a maximum of two - four tubes to maintain integrity of scientific areas. It would be difficult for a caravan of tubes to avoid the sanctioned areas. Ensure dogs do not enter.

7. **Education** of the river user and the community is a critical component. Suggested ideas include:

a. Signage. Post signage at the City Park tube rental facility, Rio Vista Falls and at proposed hard access points along river. Signage should be simple, natural, and when possible use the existing sign locations (trying to avoid too many signs). Signs should have the same template and coloration so they are recognized up and down the river. Signs should cover the rules of the river and education and be bilingual.

b. Video Loop at City Park offering information about the river and safety rules while people are waiting on shuttle or tubes. Possibly also at Rio Vista Falls.

c. Posted maps showing trail, access points, fishing access and other amenities. Will include a map at Stokes Park to help inform about the San Marcos River / Blanco confluence.

d. Recreation information at hotels/restaurants, bed and breakfast facilities, Chamber of Commerce, Visitor's Center, City of San Marcos internet site, etc could include restrictions so river users are prepared prior to entering river.

e. Park Rangers. Include a section on river biology in the training of the park rangers so they can help disseminate the information.

f. School Outreach. Implement an outreach program for SMCISD so this information can be relayed to youth in San Marcos and indirectly to the parents.

g. Overall interpretation Plan. This would pull all the informational ideas together for conformity, continuity and implementation.

h. Lecture series at Texas State University.

i. Stencils on rented tubes

8. **Reduce turbidity and sedimentation** through the establishment of watershed management strategies, remove silt and accumulated sediment from designated areas within the San Marcos River, and increase density and width of vegetation along the river and the tributaries at least 100 feet where possible. This will decrease erosion and subsequent sedimentation and filter runoff to enhance water quality

9. **Enforcement** is a critical aspect in ensuring the success of all suggested measures. Recommend the development of a partnership between the City and the University to enforce suggested measures and educate river users. Also recommend using officers dedicated to the environmental regulations working both in and along the river. A TPWD game warden could possibly train the environmental officers.

Final Recreation Measures: 2-7-11

1. **Develop multiple large and small access sites** that also act as bank stabilization structures at eroded locations. Access points would be constructed away from Texas wild-rice stands.
Create dense vegetation zones between access points to prevent future bank erosion.

2. **Trespassing Enforcement.** The public is accessing the river via private property. Private property owners have requested City assistance through signage to enforce trespassing laws.

3. **Litter removal.** Continue/increase cleanup programs, such as underwater litter pickup. Add additional receptacles and collection services.

4. **Buffer Zone.** Create an appropriate buffer zone by location to keep picnic tables, pop up tents, shelters and portable grills away from the river. Pushing these amenities further away from the river will reduce litter getting into the river and decrease bank compaction/erosion.

5. **Establish a state system of scientific study areas.** Designated state scientific study areas allow for enforcement of restrictions in the river. An interlocal agreement between City and State allows local in-water enforcement. Access restrictions to preserve at least 1000 m2 would be delineated by for the protection of Texas wild-rice and markers and could be in place only during low flows as supported by scientific research.

6. **Education** of the river user and the community is a critical component. Suggested ideas include:

a. Signage. Post signage at the City Park tube rental facility, Rio Vista Falls and at proposed hard access points along river. Signage should be simple, natural, and when possible use the existing sign locations (trying to avoid too many signs). Signs should have the same template and coloration so they are recognized up and down the river. Signs should cover the rules of the river and education and be bilingual.

b. Video Loop at City Park offering information about the river and safety rules while people are waiting on shuttle or tubes. Possibly also at Rio Vista Falls.

c. Posted maps showing trail, access points, fishing access and other amenities. Will include a map at Stokes Park to help inform about the San Marcos River / Blanco confluence.

d. Recreation information at hotels/restaurants, bed and breakfast facilities, Chamber of Commerce, Visitor's Center, City of San Marcos internet site, etc could include restrictions so river users are prepared prior to entering river.

e. Park Rangers. Include a section on river biology in the training of the park rangers so they can help disseminate the information.

f. School Outreach. Implement an outreach program for SMCISD so this information can be relayed to youth in San Marcos and indirectly to the parents.

g. Overall interpretation Plan. This would pull all the informational ideas together for conformity, continuity and implementation.

h. Lecture series at Texas State University.

i. Stencils on rented tubes

7. **Reduce turbidity and sedimentation** through the establishment of watershed management strategies. This will decrease erosion and subsequent sedimentation and filter runoff to enhance water quality. Remove silt and accumulated sediment from designated areas within the river to more closely match historical conditions.

8. **Enforcement** is a critical aspect in ensuring the success of all suggested measures. Recommend the development of a partnership between the City and the University to enforce suggested measures and educate river users. Also recommend using officers dedicated to the environmental regulations working both in and along the river. A TPWD game warden could possibly train the environmental officers.

APPENDIX Q:

REPORT OF THE EDWARDS AQUIFER RECOVERY IMPLEMENTATION LOW IMPACT DEVELOPMENT / WATER QUALITY WORKGROUP, SEPTEMBER 3, 2010

9/03/10

REPORT OF EARIP LID/WATER QUALITY SUBGROUP

A. INTRODUCTION

The EARIP LID/Water Quality subgroup recognizes that the EARIP has a primary focus on water quantity impacts on the covered species, particularly as it relates to identifying specific minimization and mitigation measures for inclusion in the habitat conservation plan component of the Program Documents. However, as the Science Subcommittee, Ed Oborny, and Dr. Hardy have acknowledged, water quality is a relevant consideration. Various assumptions underlying the respective flow recommendations provided to the EARIP acknowledge the importance of maintaining good water quality.

The Expert Science Subcommittee, on page 22 of their December 28, 2009, report entitled Analysis of Species Requirements in Relation to Spring Discharge Rates and Associated Withdrawal Reductions and Stages for Critical Period Management of the Edwards Aquifer, states "[w]ater quality encompasses a range of variables that can potentially impact fountain darters and other aquatic life if altered too far from the historic range to which the stream inhabitants have become accustomed. Most potential water quality problems are linked to nonpoint source pollution such as fertilizer runoff and chemicals washed in from adjacent streets; however, spills and leaks from industrial and municipal infrastructure along the heavily developed shorelines of the Comal River also present hazards. The potential for accidents and nonpoint source pollution to affect the organisms in the Comal River may be exacerbated during below average flows since chemicals and nutrients would be less diluted when a lower volume of water is present." Although this specific discussion is directed at Comal Springs and the Comal River, similar concerns are noted elsewhere in that document related to San Marcos and the San Marcos River (see pp. 40-41, also noting additional concerns about sediment inputs) and aquifer-dwelling species (see, e.g., pp. 56-57).

Water quality impacts can be expressed in a variety of ways. For example, impacts, such as sedimentation, resulting from stormwater runoff directly into the spring or stream habitats used by covered species could actually reduce the extent of suitable habitat areas. Some of those direct impacts, particularly to the extent that they originate within the riparian areas adjacent to the habitat areas, are addressed in the report entitled "Restoration and Mitigation Actions for the Comal Springs Ecosystem"[1] produced by the Ecosystem Restoration Subcommittee and the document entitled "Report on Restoration Options for the San Marcos River."[2] Accordingly, in

[1] Available at http://earip.tamu.edu/EcoRest/12-11-09%20Ecosystem%20Restoration%20Subcommittee%20Report%20Final.pdf.

[2] Available at http://earip.tamu.edu/EcoRest/12-11-09%20San%20Marcos%20River%20Restoration%20Options%20Report.pdf.

order to build on those recommendations, while minimizing duplication, this document focuses on water quality impacts in a broader context.

As illustrated by the water quality data previously presented to the EARIP by George Rice,[3] runoff and spills originating even at long distances from the spring openings also can affect water quality at the springs. Fortunately, water quality in the Edwards Aquifer and at the spring openings remains very good. However, as levels of development continue to increase over the recharge zone, transition zone, and even the contributing zone, the threats to water quality will increase.

As a recovery implementation program, the EARIP Program Documents will address both specific actions to be included as provisions in any habitat conservation plan and other actions that are to be taken to benefit the covered species. Accordingly, the recommendations included in this document address both types of actions, as well as adaptive management. Except to the extent that the impacts would be captured in the recommended water quality monitoring at the spring openings, this document does not address water quality issues related to the various types of source water that might be used for recharge purposes. We have assumed that any such water quality issues will be addressed as part of the evaluation and design of those specific proposals.

B. RECOMMENDATIONS FOR ACTIONS TO BE INCLUDED IN THE HCP

1. Pursue implementation, if adequate support is indicated by individual local governments, the EAA, Texas State University, and/or TCEQ, of a ban on use of coal tar sealants within (a) areas draining to Landa Lake or to the Comal River above the confluence of the old and new channels; (b) areas draining to Spring Lake or to the San Marcos River above the wastewater treatment plant outfall for the City of San Marcos; and (c) the recharge, contributing, and transition zones of the Edwards Aquifer that are subject to the pollution control authority of the EAA.

***Discussion**: Asphalt streets, parking lots, and driveways are common in the urban landscape, with most of the parking lots and driveways periodically sealcoated with products containing refined coal tar. Coal tar sealants contain high levels of polycyclic aromatic hydrocarbons (PAHs), which are toxic to fish and other aquatic life and are a known carcinogen.[4] Pavement sealants containing coal tar are typically applied by commercial applicators on parking lots at apartment complexes, retail centers and office buildings. Generally, about 450 gallons of sealcoat are needed to apply a single coat to one acre of*

[3] Those data are contained in the presentation slides available at http://earip.tamu.edu/EARIPMeetings/Jul2710/07-27-10%20Urbanization%20and%20Degradation%20Presentation%20(Rice).pdf.

[4] U.S. Department of Health and Human Services. *Report On Carcinogens*, 10th ed.; National Toxicology Program, Public Health Service : Washington, DC, December 2002.

parking lot. Typically two coats are applied, and applicators suggest reapplication of sealcoat every two to three years.[5] Recent studies[6] show that coal tar sealcoat products used to protect asphalt pavement are a significant source of PAH contamination in our lakes and streams. The sealant is worn off by abrasive action of traffic and degraded by weathering and the resulting particulates are carried away by rainfall runoff. Particularly in areas without effective water quality control ponds, the particulates travel down-gradient to become entrained in sediments of nearby waterways. Studies in Austin[7] demonstrate that the PAH compounds reach streams and the waters of Barton Springs and that these compounds are toxic to fish. Similarly targeted studies focusing on runoff from asphalt surfaces have not been identified for the Comal and San Marcos spring systems.

Alternative products contain a far lower concentration of PAHs than coal-tar sealants. There are also newer sealants on the market that are represented as containing virtually no PAHs. Lowes, Home Depot, and other home improvement stores have discontinued the sale of coal tar sealants nationwide, greatly reducing use by individual homeowners. In 2005 the City of Austin, Texas passed an ordinance prohibiting the use and sale of Coal Tar Sealants.[8]

In order to implement this measure, it would be necessary to have ordinances adopted by individual municipalities and rules adopted by the Edwards Aquifer Authority and/or the Texas Commission on Environmental Quality. Accordingly, the EARIP should appoint a workgroup to approach these entities, in addition to Texas State University, at the earliest opportunity to provide information about this issue and to explore their willingness to take these actions. If adequate support exists, the measure should be included in the HCP. Costs to implement the program are expected to be limited, although the implementing entities would incur some expense in promulgating and enforcing the prohibition.

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[5] Water Resources Website, McHenry County, Illinois. Polycyclic Aromatic Hydrocarbon (PAHs) Quick Facts, Coal Tar Regulations, Page 2 http://www.co.mchenry.il.us/departments/waterresources/pdfDocs/CoalTarOrdinance.pdf.

[6] Van Metre, P.C.; Mahler, B.J.; Wilson, J.T.; *PAHs Underfoot: Contaminated Dust from Coal-Tar Sealcoated Pavement is Widespread in the United States*. 2008. Accessed November 19, 2008. <http://pubs.acs.org/doi/pdfplus/10.1021/es802119h>.

[7] City of Austin Watershed Protection and Development Review Department. *PAHs in Austin, Texas: Sediments and Coal-Tar Based Pavement Sealants Polycyclic Aromatic Hydrocarbons.* May 2005. Accessed August 3, 2010. <http://www.ci.austin.tx.us/watershed/downloads/coaltar_draft_pah_study.pdf>.

[8] City of Austin, Texas Municipal Code. *Chapter 6-6, Coal Tar Pavement Products.* Accessed August 3, 2010. <http://www.amlegal.com/nxt/gateway.dll/Texas/austin/thecodeofthecityofaustintexas?f=templates$fn=default.htm$3.0$vid=amlegal:austin_tx$anc=>. *Dane County, Wisconsin passed a similar ordinance in 2007.* Dane County, Wisconsin Code. *Chapter 80: Establishing Regulations for Lawn Fertilizer and Coal Tar Sealcoat Products Application and Sale.* Accessed August 3, 2010. <http://danedocs.countyofdane.com/webdocs/pdf/ordinances/ord080.pdf>.

2. Pursue implementation, if adequate support is indicated by individual local governments, the EAA, Texas State University, and/or TCEQ, of improved stormwater runoff controls, in the form of specific best management practices, applicable (a) in areas that contribute surface runoff to Landa Lake, to the old channel of the Comal River, or to the new channel of the Comal River above the confluence with Dry Comal Creek; (b) in areas that contribute surface runoff to Spring Lake or to the San Marcos River above the wastewater treatment plant outfall for the City of San Marcos; and (c) throughout the areas of the recharge zone, contributing zone, and transition zone that are subject to the pollution control authority of the EAA.

Discussion*: Stormwater runoff transports pollutants to nearby streams and recharge features where they can impact water quality. Nonpoint source pollutants include sediment, pesticides, herbicides, fertilizers, hydrocarbons, and bacteria from human and animal waste. Sources for these pollutants include streets, parking lots, urban lawns, golf courses, construction sites, hazardous materials, domestic pets and waterfowl, and streambank erosion. Many of these pollutants may be controlled by a stormwater management system that reduces pollutant load and/or concentration. High levels of impervious cover are known to exacerbate nonpoint source pollution impacts by increasing peak flows, channel degradation, and risks of flooding. Malfunctioning septic systems and leaking sewer lines also contribute pollutants. Specific recommended practices for addressing those sources are set out in Attachment A.*

Some best management practices appropriate for addressing stormwater runoff are set out in the two December, 2009 reports released by the Ecosystem Restoration Subcommittee and those practices, as more specifically identified in footnote 9, are hereby incorporated by reference.[9] *In addition, other best management practices that will be appropriate in various circumstances are set out on the City of Austin's website.*[10]

Storm water management systems may also control pollutants arising from illicit point source discharges and hazardous materials spills. These pollutants may include: dry cleaner

[9] Measures incorporated by reference are those listed in the Stormwater Management and Water Quality section of the December, 2009 "Restoration and Mitigation Actions for the Comal Springs Ecosystem" report, but with certain of those measures (relating to conversion of impervious to pervious cover, construction materials prohibition, prohibition on feeding of species, golf course SOPs, pool SOPs, Schlitterbahn parking lot, railroad trestles, and litter removal) understood to be limited to the areas near Comal Springs or the Comal River. Measures listed in the Stormwater Management section (Section 5) of the December, 2009 "Report on Restoration Options for the San Marcos River" also are incorporated by reference.

[10] http://austintech.amlegal.com/nxt/gateway.dll/Texas/environ/section1-waterqualitymanagement?f=templates$fn=altmain-nf.htm$3.0

solvents, mobile carpet cleaner waste, car wash discharge, boiler coolant discharge, chiller cleaning discharge, waste oil, gasoline (from a ruptured gas tank in the event of an accident), and other illicit or toxic substances. Managing potential impacts from hazardous material spills involves designing hazardous materials transportation routes to minimize travel over environmentally sensitive areas, including, where feasible, a specific prohibition on hazardous material transportation routes crossing the Comal and San Marcos Rivers or key tributaries in areas draining to habitats occupied by listed species, and installation of hazardous materials traps in the storm drain system along transportation routes within selected drainages. For all types of BMPs, monitoring is essential to ensure that the practices are achieving the intended results. In addition, monitoring of actual storm water discharges is needed to help detect illicit discharges so that action will be taken to eliminate those discharges at the earliest opportunity. Implementing entities should undertake reasonable monitoring in addition to monitoring to be undertaken by the EARIP.

Potential implementation mechanisms include stormwater permits required pursuant to the federal Clean Water Act, ordinances adopted by local governments, voluntary actions taken by Texas State University, and rules adopted by the EAA and TCEQ. However, these actions are outside the control of the EARIP. Accordingly, the EARIP should appoint a workgroup to approach these entities at the earliest opportunity to provide information about these issues and to explore their willingness to take these actions. If adequate support exists, specific measures should be included in the HCP.

C. RECOMMENDATIONS FOR MEASURES TO BE INCLUDED IN THE PROGRAM DOCUMENT BUT NOT IN THE HCP

1. <u>Encourage all entities regulating any aspect of development over the portions of the recharge zone of the Edwards Aquifer that are within areas subject to the pollution control authority of the EAA to implement, consistent with their authority, responsible limits on impervious cover. High levels of impervious cover result in degradation of water quality in surface water and in groundwater. Accordingly, the EARIP should approach these entities at the earliest opportunity to provide information about this issue and to explore ways to facilitate the implementation of appropriate measures. There is general, but not universal, recognition that 20% impervious cover may be the maximum amount that can responsibly be allowed over most areas of the recharge zone, but more data are needed to refine that value. In order to help define responsible limits on impervious cover, the EARIP, in coordination with the EAA and other participating entities, should develop and ensure implementation of targeted, long-term</u>

water quality monitoring of runoff from existing and future development and from control sites, as appropriate.

Discussion: *The most effective way to protect water quality is to limit impervious cover (i.e., urbanization) of the vulnerable portions of the Aquifer: the recharge zone, the near-by contributing zone (e.g., within five miles of the recharge zone) and the transition zone (including the portion of the contributing zone included within the transition zone).*[11] *The available data show that there is a strong relationship between the urbanization of these vulnerable areas and the degradation of surface water and groundwater.*

Water quality in the Edwards Region is currently monitored by a number of agencies including the USGS, TCEQ, EAA, GBRA, SARA, and SAWS. These monitoring programs have produced a large amount of useful data. However, these monitoring programs generally were not specifically designed to measure the effects of urbanization on water quality. A comprehensive program designed to measure these effects would include: 1) monitoring runoff from areas of varying levels of impervious cover; 2) monitoring streams both upstream of urbanized areas, and as they pass through those areas; 3) monitoring flows upstream and downstream of various water quality controls (BMPs); 4) monitoring flows entering recharge features; 5) monitoring recharge zone wells in urban areas; and 6) monitoring springflows, including immediately after storms.

Such a monitoring program could help to quantify the effects of urbanization on water quality, and might identify areas that are causing the most water quality degradation. It also would help to identify control strategies, including improved public education, that might best be employed to address that degradation. If such areas are identified, it may be possible to mitigate the degradation through some kind of corrective action (e.g., improved structural BMPs, education to reduce the use of hazardous materials such as pesticides). In addition, the monitoring program would help to inform future judgments about responsible levels of impervious cover.

A comprehensive water quality monitoring program could be expensive with the cost for of a full suite of analyses for individual samples running about $2000 per sample.[12] *This cost includes sample analysis (common ions, metals, VOCs, SVOCs, pesticides, bacteria), equipment, and personnel costs. Thus, a program that collected 500 samples of that type annually would cost approximately $1,000,000 per year. However, once baseline*

[11] The transition zone is that area where the rocks that form the Edwards Aquifer are not exposed at land surface, but geologic features such as fractures, faults, or sinkholes provide possible pathways for contaminants in surface water to reach the water table of the Aquifer.

[12] Based on a rough estimate of the EAA's sampling costs.

information has been collected, less comprehensive analyses of samples could be interspersed between comprehensive ones, resulting in reduced costs or increased sampling coverage. The EARIP should strive to work with other entities undertaking monitoring in order to accomplish mutual goals and further minimize costs. A monitoring budget of $1,000,000 per year is recommended for this purpose.

2. Encourage all entities regulating any aspect of development over the portions of the recharge and contributing zones of the Edwards Aquifer that are subject to the pollution control authority of the EAA to implement low impact development principles and measures for new development. Accordingly, the EARIP should approach these entities at the earliest opportunity to provide information about the benefits of low impact development and to explore ways to facilitate the implementation of those principles and measures. Specific LID principles and measures of particular importance for use in these areas include vegetated swales, bioretention, biofilters, vegetated buffers, curb planters, tree trenches and cisterns. These can be used as stand-alone measures or collectively as part of a stormwater treatment train.

Discussion*: LID, or low impact development, is an integrated approach to development that seeks to maintain the natural hydrologic character and functioning of a site or region. Put simply, LID techniques address water at its source, capturing rainwater and treating it or reusing it on a site before discharging it into streams and aquifers.*[13] *LID measures have been shown to be adequate to treat stormwater to regulatory standards, reducing the need for offsite treatment and conveyance. LID projects are typically planted with water-loving vegetation, increasing the beauty of the property while treating water quality.*

In order to help encourage the implementation of LID principles and measures, the EARIP, in coordination with the EAA, should seek state and federal funding to support pilot projects for implementation of LID.[14] *In addition, to help document the effectiveness of LID in protecting water quality in karst areas, the water quality monitoring undertaken pursuant to Recommendation 1, immediately above, shall, to the extent possible, include development projects implementing LID principles and measures. Attachment B provides*

[13] See for example, Low Impact Development: an integrated design approach, Prince George's County, Maryland June 1999, EPA 841-B-00-003.

[14] The US EPA is a primary funding source for LID implementation in communities through grants, loans and cost-sharing programs. Cities have also relied on impact fees levied on traditional development, stormwater fees for impervious pavement area and special fees for use of potable irrigation water. These and other fees that capture the true costs of stormwater "gray infrastructure" can be used to subsidize low impact development. A 2010 study by the Philadelphia Water Department Office of Watersheds calculates cost-benefits of low-impact stormwater management and recommends ways to offset costs. Philadelphia Combined Sewer Overflow Long Term Control Plan Update, www.phillywatersheds.org/ltcpu.

a general discussion of the value of LID concepts as applied in karst regions. Additional sources of information about LID are listed in Attachment C.

3. In recognition of the special vulnerability of recharge to, and of water quality in, the Edwards Aquifer as a result of development around significant recharge features, encourage all entities regulating any aspect of development over the portions of the recharge and transition zones of the Edwards Aquifer that are subject to the pollution control authority of the EAA to provide special protections, over and above those set out in Recommendations 1 and 2, immediately above, for significant recharge features. Accordingly, the EARIP should approach those entities at the earliest opportunity to provide information about the importance of protecting significant recharge features and to explore mechanisms for facilitating implementation of these protections. Significant recharge features include stream beds, sinkholes, faults, and fracture zones. Given the nature of recharge in the Edwards, pollution introduced at a significant recharge feature association with a rapid flow path to a spring opening can quickly cause adverse effects for listed species. Similarly, damage to such a recharge feature could result in reduced recharge and, ultimately, in reduced spring flows. Protection mechanisms to be considered should include buffer zone designations, conservation easements, transfers of development rights, clustering of development away from recharge features, and fee-simple acquisition for conservation purposes. In order to help identify significant recharge features in need of special protection, the EARIP, working with the EAA[15] in a leadership role if the EAA agrees to play that role and in coordination with affected local governments, will develop and ensure implementation of targeted studies, including, as determined to be appropriate, dye-tracer or equivalent studies designed to detect and characterize especially important recharge features.

Discussion*: Recharge occurs broadly across the recharge zone. Although some recharge features are easily identified (e.g., stream beds, exposed sinkholes), many recharge features are difficult to identify because they are hidden beneath the soil. Thus, while it is necessary to protect easily identified features, doing only that is not sufficient to protect water quality or to protect recharge quantity. Accordingly, in order to help ensure better informed decisions about protection of recharge features, the EARIP will work with*

[15] *The EAA has been performing dye tracing studies in the Edwards aquifer for a number of years.* For an example of a recent dye tracing study see the EAA publication: *Tracing Groundwater Flowpaths in the Edwards Aquifer Recharge Zone, Panther Springs Creek Basin, Northern Bexar County, Texas*; http://www.edwardsaquifer.org/files/Panther%20Springs%20Creek%20Traces%202010.pdf.

regulatory entities to facilitate protection of significant recharge features, including by providing funding for a limited amount of studies designed to identify flow paths and recharge features meriting special protection. If the EAA is agreeable, the EARIP should rely on the EAA to take a leadership role in study implementation.

The relationships between recharge features and flow paths may be determined through dye tracing. Dye tracing may also be used to define the distribution of recharge and to identify hidden recharge features. The cost of a typical dye tracing study is around $50,000. The budget should be adequate, when considered in combination with support from cooperating entities, to support at least 2 such studies per year, on average during the first 10 years of program implementation ($100,000 per year).

D. RECOMMENDATIONS FOR SPECIFIC ADAPTIVE MANAGEMENT PROVISIONS

Identifiable trends in degradation of water quality as measured at the springs, in areas of occupied habitat downstream of the springs, or in the aquifer would call into question assumptions underlying the determination of spring flow levels needed to protect the covered species. Accordingly, the EARIP will need to implement and fund the water quality monitoring programs set out above along with focused monitoring of water quality in the Comal and San Marcos rivers. If those monitoring programs reveal a trend toward significant degradation in water quality, as determined by an appropriate scientific body, the EARIP will develop and implement specific measures to address those changes in accordance with the adaptive management plan.

ATTACHMENT A

The LID/Water Quality group also recommends the following BMP's be adhered to regarding construction acceptance testing and maintenance of central wastewater collection systems pursuant to Recommendation B.2:

- All plans for systems must be submitted to TCEQ prior to construction for review and approval and clearly identify areas in the recharge, contributing within transition or contributing zones. TCEQ rules cover certain requirements unique to the Edwards formations.
- Excavation practices for working in the Edwards formation must be adhered to.
- Completed wastewater system piping and manholes must be pressure/vacuum tested, mandrel alignment tested, and video inspected prior to acceptance and placement into service.
- Piping and manholes over the Edwards recharge zone must be video inspected and smoke tested every five years. The films must be reviewed by a certified, registered Professional Engineer and sealed. The repairs specified as needed by the engineer must be completed within 60 days of review.
- In the event more stringent requirements are adopted in the future, the more stringent regulation should be followed.

ATTACHMENT B

"USING GREEN INFRASTRUCTURE IN KARST REGIONS"

ATTACHED SEPARATELY

ATTACHMENT C

Other LID resource material, consisting primarily of information about national programs and design standards, may be found at the links below:

Us Department of Housing and Urban Design (HUD)

The Practice of Low Impact Development

http://www.lowimpactdevelopment.org/lid%20articles/practLowImpctDevel_jul03.pdf

Environmental Protection Agency

http://water.epa.gov/polwaste/green/

Low Impact Development (LID) Center
A non-profit organization balancing growth and environmental integrity.

4600 Powder Mill Rd, Suite 200;
Beltsville, MD 20705 (USA)
301-982-5559;
301-937-3507 (fax)
info AT lowimpactdevelopment.org

http://www.lid-stormwater.net/background.htm

TCEQ Edwards Aquifer Technical Guidance Manual

http://www.tceq.state.tx.us/comm_exec/forms_pubs/pubs/rg/rg-348/rg-348.html/at_download/file

Natural Resources Defense Council

http://www.nrdc.org/water/pollution/storm/chap12.asp

Additional information from EPA regarding LID and related storm water best management practices is available at:
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=5

Additional documents are available through the Center for Watershed Protection. Free registration is required to access the documents: http://cwp.org/store/free-downloads.html

APPENDIX R:

FUNDING AND MANAGEMENT AGREEMENT TO FUND AND MANAGE THE HABITAT CONSERVATION PLAN FOR THE EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM, NOVEMBER 11, 2011

FUNDING AND MANAGEMENT AGREEMENT

by and among

The Edwards Aquifer Authority, The City of New Braunfels,
The City of San Marcos,
The City of San Antonio, acting by and through its
San Antonio Water System Board of Trustees, and
Texas State University – San Marcos

to fund and manage the Habitat Conservation Plan
for the Edwards Aquifer Recovery Implementation Program

Dated Effective January 01**, 201**2

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FUNDING AND MANAGEMENT AGREEMENT

by and among

The Edwards Aquifer Authority, The City of New Braunfels,
The City of San Marcos,
The City of San Antonio, acting by and through its
San Antonio Water System Board of Trustees, and
Texas State University – San Marcos

to fund and manage the Habitat Conservation Plan
for the Edwards Aquifer Recovery Implementation Program

This Funding and Management Agreement (Agreement), effective on the Effective Date provided in Section 8.1, is an interlocal cooperation contract made pursuant to Texas Government Code Chapter 791 by and among the Edwards Aquifer Authority ("EAA"), the City of New Braunfels ("New Braunfels"), the City of San Marcos ("San Marcos"), the City of San Antonio acting by and through its San Antonio Water System ("San Antonio"), and Texas State University – San Marcos ("University") (collectively, the "Parties," and individually, "Party").

Recitals

Recital A. Parties.

The Parties to this Agreement are the five Permittees under the incidental take permit (Permit) relating to certain threatened or endangered species covered by the Permit (Covered Species) which are associated with the Edwards Aquifer and protected under the federal Endangered Species Act of 1973 (ESA). The Parties, in their capacities as Permittees, have prepared their joint application (Application) for the Permit for submittal to the United States Fish and Wildlife Service (Service). The Application is supported by the Edwards Aquifer Recovery Implementation Program (EARIP) Habitat Conservation Plan (HCP) and the related agreement to implement the HCP by and among the Parties, as Permittees, the Texas Parks and Wildlife Department, and the Service, as Permit issuer (Implementing Agreement).

Recital B. Purpose.

The purposes of this Agreement are to: (1) provide the terms of the rights and duties agreed to by the Parties for managing and funding the Program for the implementation of the HCP as provided in the Implementing Agreement; and (2) provide the terms of the Program's Adaptive Management Process.

Recital C. Legislative Directives.

By the Act of May 28, 2007 (Senate Bill 3 or SB 3), the 80th Legislature of the State of Texas directed the EAA to cooperatively develop a recovery implementation program (RIP) for the Covered Species through a facilitated, consensus-based process that involves participation by the Service, other appropriate federal agencies, and interested Edwards Aquifer stakeholders (Stakeholders). The EAA and other RIP participants were further directed to jointly prepare, under the oversight and with the assistance of a Steering Committee of representatives of certain Stakeholders designated by SB 3, a program document that may be in the form of a habitat conservation plan as the basis for the issuance of an incidental take permit by the United States Secretary of the Interior, through the Service, under Section 10 of theESA.

Recital D. Cooperative Development.

The EAA and other Stakeholders, in compliance with the SB 3 directives, have worked cooperatively since 2007 to develop a RIP program document and have determined that, in the interest of protecting the Covered Species, the RIP program document requirement is met by the development of the HCP to be submitted jointly by the Parties to the Service to support the Application.

Recital E. Program Phases and Adaptive Management Process.

The Parties have approved the Program consisting of two phases for the 15-year Permit Term, as it may be extended. Phase I commences with the effective date of the Permit and continues for

seven years. Phase II commences on the seventh anniversary of the effective date of the Permit and continues for eight years and for any agreed extension. The Program provides for the AMP that requires the continuing cooperation of the Parties to monitor the results of the Conservation Measures and to consider and take needed adaptive management actions by the Parties throughout Phase I and Phase II.

Recital F. Independent Determinations by Each Party.

Each of the Parties has independently found and determined that:

(1) the Party is authorized under applicable law to individually seek an incidental take permit from the Service for the Covered Activities associated with the Edwards Aquifer;

(2) the Party's respective cooperative actions to jointly submit the Application for a single permit will increase the efficiency and effectiveness of the Party and will most effectively discharge the direction in SB 3 to the Parties and other Stakeholders to develop a RIP for the Covered Species;

(3) it is in that Party's interest to enter into each of the Program Documents;

(4) the Party is both individually and, along with the other Parties, collectively responsible to the Service for the successful implementation of the HCP pursuant to the terms of the Implementation Agreement; and

(5) the performance of the specific duties and responsibilities of the Party, as described in the HCP, this Agreement, and other Program Documents, is integrally related to the achievement of the Biological Goals and Biological Objectives for the Program.

Therefore, for the mutual consideration expressed in this Agreement, the Parties agree as follows:

Article One – Definitions and Other References

Section 1.1. Terms Defined in this Agreement.

The following terms as used in this Agreement have the meaning provided in this Article.

1.1.1 "Adaptive Management Process" or "AMP" means an iterative process designed to develop information through monitoring and research, and the review and use of the results to confirm the efficacy of or to adjust the Conservation Measures, all as described in Article Seven and in Chapter 6 of the HCP.

1.1.2 "Additional Conservation Measure" means a measure to minimize or mitigate impacts to one or more Covered Species that differs from the Conservation Measures and that is proposed by the Service in response to:

(a) an Unforeseen Circumstance; or

(b) a Changed Circumstances that is not planned for in Table 8-1 of the HCP, or that is planned for in that table but for which the Service proposes a measure different from those included in that table.

1.1.3 "Agreement" means this Funding and Management Agreement.

1.1.4 "Annual Funding Obligation" means the level of funding required to be provided by the EAA for the Annual Program Budget as established according to Section 3.2 and Subsection 5.2.1.

1.1.5. "Annual Program Budget" means the budget for Program Expenditures adopted by the Board of Directors of the EAA for each year of the Permit Term pursuant to the process described in Sections 4.4 through 4.7, subject to the limitations in Section 3.2 and

Subsection 5.2.1.

1.1.6. "Annual Party Work Plan and Cost Estimate" means the work plan and cost estimate prepared by a Party to describe the activities and schedules that are reasonable and necessary for the Party to perform in order to implement the Conservation Measures and other Program-related activities for which the Party has responsibility to undertake in the year following the year in which the plan and estimate are submitted to the Implementing Committee as provided in Sections 4.4 and 4.6.

1.1.7. "Application" means the application submitted by the Parties to the Service for the Permit.

1.1.8. "Biological Goals" means the long-term biological goals described for each Covered Species in Section 4.1 of the HCP.

1.1.9. "Biological Objectives" means the key management objectives and flow-related objectives described for each Covered Species in Section 4.1 of the HCP, as they may be changed through the AMP pursuant to Subsection 7.13.7.

1.1.10. "Certificate of Inclusion" means a certificate issued by a Party to a non-federal Person that has agreed to be bound by the terms of the HCP and the Permit pursuant to Section 9.2 of the Implementing Agreement.

1.1.11. "Changed Circumstances" means changes in circumstances affecting one or more Covered Species or the Permit Area that reasonably could have been anticipated by the Parties and the Service during the negotiation and development of the HCP and this Agreement and includes the circumstances that have been specifically planned for as provided in Table 8-1 of the HCP.

1.1.12. "Comprehensive Phase I Work Plan" means the work plan for Phase I Conservation Measures and other Program activities developed and approved by the

Implementing Committee as provided in Section 4.2.

1.1.13. "Conservation Measure" means a measure identified in Chapter 5 of the HCP, as such measure may be modified pursuant to the AMP, or a new measure developed and approved by the Parties through the AMP, to minimize or mitigate to the maximum extent practicable the impacts of the authorized taking of the Covered Species or contribute to the recovery of the Covered Species.

1.1.14. "Covered Activities" means those activities described in Chapter 2 of the HCP for which incidental take authorization of Covered Species is authorized pursuant to the Permit.

1.1.15. "Covered Species" means the species identified in Table 1-3 of the HCP, for which the HCP provides protection in a manner sufficient to meet all of the criteria for issuing the Permit.

1.1.16. "Days" means calendar days unless otherwise specified. If the date of any performance falls on a Saturday, Sunday, or observed state, federal or local holiday, the date of performance is the next business day following the calculated date of performance.

1.1.17. "Department" means the Texas Parks and Wildlife Department.

1.1.18. "EAA Act" means the Edwards Aquifer Authority Act, Act of May 30, 1993, 73rd Leg., R.S., ch. 626, 1993 Tex. Gen. Laws 2350, as amended.

1.1.19. "EARIP" means the Edwards Aquifer Recovery Implementation Program which was developed through the consensus-based process under Section 1.26A of the EAA Act.

1.1.20. "Edwards Aquifer" means the Southern (or San Antonio) Segment of the Edwards

Aquifer as defined in Section 1.03(1) of the EAA Act within the boundaries of the EAA.

1.1.21. "Effective Date" means the date on which this Agreement takes effect, as provided in Section 8.1.

1.1.22. "ESA" means the federal Endangered Species Act of 1973, as amended (16 U.S.C. §§ 1531-1544).

1.1.23. "Excess Fund Balance" means any amount of funds at the end of an EAA budget year that has accumulated in the HCP Program Account in excess of the Fund Balance Cap.

1.1.24. "Fund Balance" means the accumulation of the excess of Program Aquifer Management Fees and other funds deposited to the HCP Program Account over Program Expenditures.

1.1.25. "Fund Balance Cap" means the maximum Fund Balance that the EAA may plan to accumulate in the reserve fund of the HCP Program Account as provided in Subsection 5.5.4.

1.1.26. "HCP" means the conservation plan required by Section 10(a)(2)(A) of the ESA that has been prepared by the Parties and submitted to and approved by the Service as part of the Application of the Parties for the Permit.

1.1.27. "HCP Program Account" means the restricted account, composed of a reserve fund and an operations fund, created by the EAA in accordance with Section 5.4 to accumulate and disburse Program Aquifer Management Fees consistent with the Annual Program Budget for the implementation of the Program.

1.1.28. "Implementing Agreement" means the agreement entered into by the Parties to this Agreement and the Service to implement the Program.

1.1.29. "Implementing Committee" means the committee created pursuant to Section 7.7.

1.1.30. "Parties" means the EAA, New Braunfels, San Marcos, San Antonio, and the University. Any one of the Parties individually is referred to as a "Party." In the Implementing Agreement the Parties are defined as the "Permittees."

1.1.31. "Permit" means the incidental take permit to be issued by the Service to the Parties pursuant to Section 10(a) of the ESA.

1.1.32. "Permit Amendment" means an amendment of the Permit that does not meet the Service's criteria for a clarification, administrative change, or minor amendment to the Permit and is administered as described in Subsection 9.2.2 of the HCP.

1.1.33. "Permit Area" means the geographic jurisdictional area of the EAA as defined in Section 1.04 of the EAA Act in all of Uvalde, Medina, and Bexar Counties, and part of Atascosa, Guadalupe, Comal, Caldwell, and Hays Counties, all in the State of Texas, as depicted in Figure 1-2 of the HCP, which includes the Comal Springs, Landa Lake, and the portion of the Comal River and associated areas riparian thereto within the municipal boundaries of New Braunfels in Comal County, Texas, and the San Marcos Springs, Spring Lake, and the portion of San Marcos River and associated areas riparian thereto within the municipal boundaries of San Marcos in Hays County, Texas.

1.1.34. "Permit Term" means the initial 15-year term of the Permit and any extension thereof as may be approved by the Parties and the Service in accordance with Section 5.3 of the Implementing Agreement.

1.1.35. "Person" means an individual or any entity or organization, such as a business or a governmental unit, that has a legal identity apart from its members.

1.1.36. "Phase I Conservation Measure" means a Conservation Measure that will be

initiated in Phase One, as that measure may be modified or developed pursuant to the AMP.

1.1.37. "Phase II Conservation Measure" means a Conservation Measure that will be initiated in Phase II, as that measure may be modified or developed pursuant to the AMP.

1.1.38. "Presumptive Phase II Conservation Measure" means the Conservation Measure of the San Antonio Water System described in Subsection 5.5.2 of the HCP.

1.1.39. "Program" means all activities related to implementation of the Permit and HCP, as described in the Program Documents.

1.1.40. "Program Administration Costs" means costs of the EAA necessary to manage the Program as described in Table 7-1 of the HCP.

1.1.41. "Program Aquifer Management Fees" means aquifer management fees collected by the EAA under Section 1.29 of the EAA Act from the holders of Edwards Aquifer groundwater withdrawal permits issued by the EAA and deposited in the HCP Program Fund to fund the costs of the Program.

1.1.42. "Program Documents" means the Permit, the Application, the HCP, the Implementing Agreement, and this Agreement.

1.1.43. "Program Expenditures" means the costs authorized by Section 5.6 and included in the Annual Program Budget.

1.1.44. "Program Funding" means funds provided by the EAA from the HCP Program Account to reimburse the Parties for costs associated with the Program, consistent with the Annual Program Budget and the program funding contracts provided for in Subsection 6.1.8.

1.1.45. “Program Funding Application” means an application submitted to the EAA by a Party for funding to implement a Conservation Measure or other Program-related activity, as provided in Section 6.1.

1.1.46. “Program Manager” means the employee of the EAA as described in Section 2.3 whose responsibility it is to administer the Program pursuant to the provisions of the Program Documents.

1.1.47. “Science Committee” means the committee created pursuant to Section 7.9.

1.1.48. “Science Review Panel” or “SRP” means the panel created pursuant to Section 7.10.

1.1.49. “Scientific Record” means a compilation of all the best scientific and commercial data currently available used to develop the Program, as supplemented by the results of new research and data made available during the Permit Term in accordance with Section 7.13.

1.1.50. “Service” means the United States Fish and Wildlife Service.

1.1.51. “Stakeholder Committee” means the committee created pursuant to Section 7.8.

1.1.52. “Unforeseen Circumstances” means changes in circumstances affecting one or more Covered Species or the Permit Area that could not reasonably have been anticipated by the Parties and the Service at the time of the negotiation and development of the HCP, the Implementing Agreement, and this Agreement, and that result in a substantial and adverse change in the status of one or more of the Covered Species. The term Unforeseen Circumstances as defined in this Agreement is intended to have the same meaning as “extraordinary circumstances” as used in the No Surprises policy described in Subsection 8.7.1 of the Implementing Agreement.

1.1.53. "Year" means calendar year (January 1 through December 31), unless the context clearly indicates otherwise.

Section 1.2. Terms Defined in the Implementing Agreement.

Each capitalized and other special term not expressly defined in this Agreement has the meaning assigned in the Implementing Agreement, unless the context specifically indicates otherwise.

Section 1.3. References to Sections.

References to any article, section, or subsection refer to the corresponding subdivision of this Agreement unless another document is specified.

Section 1.4. References to Other Program Documents.

This Agreement at times refers to provisions in one or more of the other Program Documents executed by the Parties and other persons in connection with, and related to, the HCP. Any such reference refers to the applicable provision in the executed document, as it may have been amended.

Article Two – Permit Application and Program Management

Section 2.1. Application for Permit.

On or before December 31, 2011, the Parties will jointly submit to the Service the following Program Documents:

(1) the Application;

(2) the HCP;

(3) the proposed Implementing Agreement; and

(4) this Agreement, executed by the Parties.

Section 2.2. General Program Management by EAA.

The EAA has responsibility for the general management and oversight of the Program, subject to the duties and responsibilities held solely or jointly by the other Parties, in accordance with the terms of the Program Documents.

Section 2.3. Program Manager.

The EAA will employ a Program Manager whose job responsibility will be to direct, under the supervision of the General Manager of the EAA, the management of the Program consistent with the Program Documents. The Program Manager will be employed, and the Program Manager's job performance will be reviewed, as provided in this Section.

2.3.1. Job Description.

The EAA will develop the job description, job title, responsibilities, accountability, and salary that it determines is appropriate for the Program Manager, provided that the EAA will confer with the Implementing Committee in: (a) the development of the job description; (b) the conduct of candidate interviews; (c) the review of candidate qualifications; and (d) the selection of the preferred candidate. The EAA will make reasonable efforts to accommodate the views and comments of the Implementing Committee in making the final hiring decision and will also solicit and consider the comments of the Implementing Committee when reviewing the performance of the Program Manager.

2.3.2. Program Manager Duties.

In addition to any duties and responsibilities the Program Manager will have as an employee of the EAA, the Program Manager will have the following duties:

a. to serve as the primary point of contact between the Parties and the Service;

b. to cooperate with, coordinate, and generally support the activities and decision-making processes of the Implementing Committee, Stakeholder Committee, Science Committee, and the Science Review Panel;

c. to use reasonable efforts to seek to secure unanimous action by the Implementing Committee, and consensus action by the Stakeholder Committee and the Science Committee, for matters brought before each of these committees pursuant to the Program Documents;

d. to cooperate with and coordinate with the Service;

e. to monitor compliance by the Parties with the Permit and other Program Documents;

f. to prepare and provide all reports as may be directed by the Implementing Committee or the Program Documents;

g. to compile and maintain the Scientific Record as described in this Agreement and as may be directed by the Implementing Committee;

h. to timely prepare work plans and cost estimates for the activities to be performed by the Program Manager during Phase I and Phase II for inclusion in the Comprehensive Phase I Work Plan and Comprehensive Phase II Work Plan,

respectively, as described in Sections 4.2 and 4.3;

i. to timely prepare for each year during the Permit Term a work plan and cost estimate for activities to be performed by the Program Manager for inclusion in the Annual Party Work Plan and Cost Estimate of the EAA;

j. to assist the Implementing Committee with developing and, if required, amending the Comprehensive Phase I Work Plan and Comprehensive Phase II Work Plan, each of which plans will include the activities to be performed by the Program Manager;

k. to assist the EAA with timely preparing the EAA's Annual Party Work Plan and Cost Estimate, which will incorporate descriptions and costs for the activities to be performed by the Program Manager, and will be submitted for approval in the same manner as the Party Annual Party Work Plan and Cost Estimate submitted by the other Parties;

l. to supervise all activities associated with the applied research facility described in Subsection 6.3.4 of the HCP, and the continuing reliance on the best available science and the continuing involvement of the Stakeholders in making certain AMP decisions, as provided in Article Seven;

m. to ensure that the EAA's website reflects all current science and research reports, and reports and activities of the Implementing Committee, Stakeholder Committee, Science Committee, and the Science Review Panel;

n. to perform other duties as may be assigned from time to time by the Implementing Committee, in consultation with the EAA General Manager; and

n. to perform any other duties and responsibilities as may be described in the job description developed by the EAA General Manager with the participation of

the Implementing Committee.

2.3.3. Acting Program Manager.

The EAA General Manager may from time to time designate a qualified member of the EAA staff to serve as the Acting Program Manager for temporary periods which may occur either pending the hiring of the initial or any successor Program Manager, or in the event of the Program Manager's unavailability or incapacity. Any duties or acts assigned to the Program Manager will be undertaken during the temporary period by the acting person thus appointed.

Article Three – Duties and Responsibilities of the Parties

Section 3.1. Parties' Collective Duties and Responsibilities.

The collective Program duties and responsibilities of the Parties include: (a) implementing the Conservation Measures and the AMP; (b) collaborating on research and planning associated with the implementation of Conservation Measures and the AMP; and (c) participating in any federal program that may provide funding for the Program.

Section 3.2. Each Party's Individual Duties and Responsibilities.

Each Party has sole responsibility for: (a) undertaking and performing each of the specific Conservation Measures assigned to that Party in Chapter 5 of the HCP; (b) if the Party determines to issue Certificates of Inclusion as provided in Section 9.2 of the Implementing Agreement, taking action as may be appropriate for such issuance and monitoring and enforcing the terms of any Certificate of Inclusion issued; (c) undertaking and performing each additional duty and responsibility that may be assigned to that Party as a result of decisions made under the AMP; and (d) complying with the terms of this Agreement to implement the Program. Subject to the limitations to the 2% annual increase from the 2013 Annual Funding Obligation as provided in Subsection 5.2.1, the EAA has responsibility for fully funding implementation of the Program,

as the Program may be adjusted pursuant to the AMP.

Article Four – Program Work Plan and Budget Approvals

Section 4.1. Implementing Committee.

The Implementing Committee will, as soon as reasonably practicable after January 1, 2012, convene its initial organizational meeting, adopt procedures, and take other actions as may be necessary to comply with the schedule in this Article.

Section 4.2. Comprehensive Phase I Work Plan.

Not later than March 1, 2012, the Implementing Committee will develop and approve a Comprehensive Phase I Work Plan, which will include descriptions, schedules, and cost estimates for the Phase I Conservation Measures and all Program activities to be conducted or managed by the Parties and the Program Manager that are to be funded from the HCP Program Account for the Phase I period through December 31, 2019. The Comprehensive Phase I Work Plan may be amended from time to time by the Implementing Committee to accommodate new information and modifications in Conservation Measures as may be approved and authorized in compliance with the AMP established by Article Seven.

Section 4.3. Comprehensive Phase II Work Plan.

Not later than March 1, 2019, the Implementing Committee will develop and approve a Comprehensive Phase II Work Plan, which will include descriptions, schedules, and cost estimates for ongoing Phase I Conservation Measures, for the Phase II Conservation Measures, and for all Program activities to be conducted or managed by the Parties and Program Manager that are to be funded from the HCP Program Account for the Phase II period from January 1, 2020 until expiration of the Permit. The Implementing Committee may amend the Comprehensive Phase II Work Plan from time to time to accommodate new information and modifications in Conservation Measures as may be approved and authorized in compliance with

the AMP established by Article Seven.

Section 4.4. Initial Annual Party Work Plan and Cost Estimate Submittal.

Not later than April 15, 2012, each Party will submit to the Program Manager and Implementing Committee for the Implementing Committee's review and approval its Annual Party Work Plan and Cost Estimate for 2013. The EAA's Annual Party Work Plan and Cost Estimate will include all activities related to the Program to be conducted or managed by the Program Manager during 2013. Each Annual Party Work Plan and Cost Estimate will include descriptions and schedules of the tasks that are reasonable and necessary in order to perform each Party's respective Conservation Measures and other Program-related activities.

Section 4.5. Annual Program Budget Approval.

The Program Manager and Implementing Committee will review and recommend changes, if necessary, to each Annual Party Work Plan and Cost Estimate. Not later than June 30, 2012, the Implementing Committee will complete its review and approval of each Annual Party Work Plan and Cost Estimate for the 2013 budget year and will consolidate them into a proposed Annual Program Budget for 2013. Upon approval by the Implementing Committee, the proposed budget will be forwarded to the EAA for review and action of the EAA Board of Directors, and upon the approval by the Board of Directors, the proposed budget, as it may have been adjusted, will be the Annual Program Budget for 2013 and included in the EAA's 2013 budget.

Section 4.6. Subsequent Years.

For the 2014 budget year and each subsequent budget year during the Permit Term, each Party will prepare and submit its Annual Party Work Plan and Cost Estimate for inclusion into the Annual Program Budget, in accordance with the requirements in Sections 4.4 and 4.5 but reflecting the activities and costs for the relevant budget year. The schedule for the submittal of the Annual Party Work Plan and Cost Estimate and the development and approval by the Implementing Committee and the EAA Board of Directors of the Annual Program Budget will

be consistent with the schedule for the 2013 budget year, unless the Implementing Committee, with the approval of the EAA, establishes a different schedule.

Section 4.7. Limitation.

The EAA will promptly notify the Program Manager and Implementing Committee if the EAA Board is unable to grant final approval during any year to a proposed Annual Program Budge,t or any Program Funding Application submitted or proposed to be submitted by a Party as provided in Article Six, because funds available for the Program are or are likely to be insufficient. In that event, the Implementing Committee will collaborate in a timely manner to amend the proposed Annual Program Budget for that year to incorporate less costly measures, activities, or schedules that will still ensure compliance with the Program Documents, and each Party will amend its Program Funding Application consistent with the revised proposed Annual Program Budget. The Implementing Committee will not submit to the EAA for action by the EAA Board a proposed Annual Program Budget, or any amendment to such proposed budget, that provides for expenditures greater than the funds that the EAA expects to have available for that year, including any available Fund Balance as provided in Subsection 5.5.4.

Article Five – Program Costs and Funding

Section 5.1. Program Implementation Costs.

Subject to the terms and limitations described in this Agreement, the cost of implementing the Program as described in Subsections 3.2 and 5.2.1 and Table 7-1 of the HCP, including maintaining appropriate reserves by the EAA, will be funded by Program Aquifer Management Fees, and by other contributions, grants and funds received by the EAA for implementation of the Program, all as described in this Article.

Section 5.2. Annual Funding Obligation of the EAA.

5.2.1. Level of Funding.

The EAA will provide funding for the costs of implementing the Program during each year of Phase I and Phase II (Annual Funding Obligation) in accordance with each Annual Program Budget approved by the Implementing Committee and the EAA Board. As long as adequate to implement the Program, the Annual Funding Obligation for 2013 will be at the amount indicated for 2013 in Table 7-1 of the HCP. The Annual Funding Obligation for 2014, and each Program year thereafter, may be increased or decreased from the Annual Funding Obligation for 2013 based on the Annual Program Budget developed for the year in accordance with Article Four. The Annual Funding Obligation for any Program year will be limited to the 2013 Annual Funding Obligation, adjusted for a 2% increase, compounded annually for the years that have elapsed since 2013. The EAA will ensure that any funds collected or received for the Program that are in excess of Program Expenditures during any year and result in a Fund Balance, as provided in Subsection 5.5.4, will be applied to Program Expenditures in subsequent years, subject to the provisions of Subsection 5.5.4.

5.2.2. Assessment of Fees by EAA.

The EAA will assess Program Aquifer Management Fees annually sufficient to meet the Annual Funding Obligation in accordance with Subsection 5.2.1. The EAA Board of Directors may, at its sole discretion, assess Program Aquifer Management Fees in an amount that will generate more funds than the amount required by Subsection 5.2.1, subject to the provisions of Subsection 5.5.4. If the EAA determines that the funds collected through the Program Aquifer Management Fees are or will be insufficient to fund the proposed Annual Program Budget and the associated Program Funding Applications for any year, the EAA will promptly notify the Implementing Committee of the expected amount of the insufficiency. The Implementing Committee will collaborate in a timely manner to amend the proposed Annual Program Budget as set forth in Section

4.7, and each Party will amend its respective Application for Program Funding consistent with the revised proposed Annual Program budget.

5.2.3. Initial Fee Assessment.

The Parties acknowledge that the EAA is expected to impose and begin collecting Program Aquifer Management Fees prior to the submittal by the Implementing Committee to the EAA of the proposed Annual Program Budget for 2013 for EAA Board approval in order to ensure that sufficient funding will be available on January 1, 2013, to pay Program Expenditures during the initial year of the Comprehensive Phase I Work Plan.

Section 5.3. Funding Contributions by Other Persons and Entities.

The Parties acknowledge that other persons and entities, including but not limited to the Guadalupe Blanco River Authority, have committed to make, beginning in 2012, annual contributions of funds to the EAA to be used solely for the Program. The Parties will pursue applications for grants and funds for the Program from state and federal agencies and other potential funding sources.

Section 5.4. The HCP Program Account.

Not later than October 1, 2012, the EAA will take action to create the HCP Program Account. The EAA will deposit funds in either the reserve fund or operations fund of the HCP Program Account as appropriate, and will disburse funds from the operations fund of the HCP Program Account for costs and expenses approved by the EAA in the Annual Program Budget in accordance with this Article. The HCP Program Account will allow for the accumulation of a Fund Balance in the reserve fund of the HCP Program Account subject to the Fund Balance Cap as provided in Subsection 5.5.4.

Section 5.5. Sources of Funds in the HCP Program Account.

Amounts deposited in the HCP Program Account will include the funds described in this Section.

5.5.1. EAA Fees.

All funds collected by the EAA through the imposition of Program Aquifer Management Fees will be deposited in the HCP Program Account.

5.5.2. Contributions and Grants.

All funds from contributions, grants, and other sources of funds the EAA may receive to support the Program during the Permit Term will be deposited in the HCP Program Account.

5.5.3. Earnings on Investments.

All earnings on the investment of funds deposited to the HCP Program Account will be deposited in the HCP Program Account.

5.5.4. Fund Balance.

In recognition that Program Expenditures may be higher in years in which Edwards Aquifer levels are low or are anticipated to be low, the HCP Program Account will allow for the accumulation by the EAA of a Fund Balance. The accumulated Fund Balance will be capped at $46 million (Fund Balance Cap), unless amended by the Implementing Committee. Any Excess Fund Balance may be used to reduce the Annual Funding Obligation of the EAA as otherwise required under Section 5.2. The EAA will reduce the Program Aquifer Management Fees assessed for the next following year to fund the Annual Program Budget to reflect the use of the Excess Fund Balance in that year.

Section 5.6. Uses of Funds in the HCP Program Account.

Except as provided in Subsection 5.6.1 with regard to certain costs incurred by the EAA in 2012, funds deposited in the HCP Program Account may be used only for Program Expenditures as described in this Section that have been approved in the Annual Program Budget.

5.6.1. Use of Funds in 2012.

Funds may be used for Program Administration Costs incurred by the EAA from the Effective Date through December 31, 2012, up to the total amount of $375,000.

5.6.2. Costs of Conservation Measures.

Funds may be used for the costs of implementation of the Conservation Measures.

5.6.3. AMP Costs.

Funds may be used for the costs of the AMP described in Article Seven, including activities described in Chapter 6 of the HCP.

5.6.4. Federal Program Participation Costs.

Funds may be used for the costs of qualification for participation in any federal program that may provide funding for the Program.

5.6.5. Limitations on Use of Funds - Employees and Administrative Costs.

With the exception of Program Administration Costs of the EAA, funds may not be used for: (a) costs of any Party's employees; or (b) any Party's administrative costs, such as costs of overhead, management, administration, research, planning, engineering, or legal

services, or any other ancillary costs that are not directly required for the Program.

5.6.6. Limitations on Use of Funds – MS4 Permit Costs.

Funds may not be used for the cost of measures required to be undertaken by any Party in order to obtain a Small Municipal Separate Storm Sewer System (MS4) permit under the Texas Pollution Discharge Elimination System Program as required by the Texas Commission on Environmental Quality (TCEQ) or the laws of the State of Texas. However, funds may be used for the cost of measures and activities included in a MS4 program to the extent that they implement Conservation Measures which exceed minimum requirements for obtaining the MS4 permit.

Article Six – Applications for Program Funding

Section 6.1. Applications from a Party for Program Funding.

A Program Funding Application from a Party to the EAA to implement a Conservation Measure or other Program activity which it is the duty of the Party to implement may be made and will be considered for approval by the EAA only as provided in this Article.

6.1.1. Required Contents.

The Program Funding Application will be filed in writing in affidavit form and include the following information:

a. the name and contact information of the applicant and its principal offices;

b. a resolution of the applicant representing that the filing of the application has been duly authorized by the governing body or other appropriate official of the applicant;

c. a description of the purposes for which Program Funding is sought;

d. a statement that the Implementing Agreement, HCP, the Permit or other appropriate regulatory document authorizes the proposed Conservation Measure or other Program activity to be performed;

e. citations to all appropriate Program Documents demonstrating that the proposed Conservation Measure or other Program activity is authorized to be performed;

f. the approved Annual Party Work Plan and Cost Estimate for the period for which Program Funding is sought, including the project schedule, budget, and contractors or subcontractors who will be performing the work;

g. a description of the procurement process utilized by the applicant to secure bids or proposals and a demonstration that the bid or proposal selected is lawful and reasonable;

h. the amount of Program Funding requested; and

i. the proposed schedule of payments.

6.1.2. Application Deadline.

Except under extenuating circumstances as approved by the Implementing Committee, a Program Funding Application will be filed with the EAA not later than October 1 of the year preceding the year for which Program Funding is sought.

6.1.3. Application Approval Criteria.

No later than 30 days after the EAA Board of Directors approves the Annual Program

Budget for the next year, the EAA will approve a party's Program Funding Application if the applicant demonstrates the following considerations:

a. the applicant is a Permittee under the Implementing Agreement;

b. the applicant is authorized to file the application;

c. each proposed Conservation Measure or other Program-related activity is authorized for Program Funding pursuant to Article Five and Chapters 5 and 6 of the HCP;

d. each proposed Conservation Measure or other Program-related activity is identified by the Implementing Agreement, this Agreement, the HCP, or other Program Document, to be performed by the applicant, or, the applicant, as authorized by the Implementing Committee, is acting to cure the failure of another Party to perform one or more Conservation Measures or other Program-related activities;

e. the approved Comprehensive Phase I Work Plan or Phase II Work Plan and Annual Program Budget include each proposed Conservation Measure or other Program-related activity for the period for which Program Funding is sought;

f. the approved applicable Comprehensive Phase I Work Plan or Phase II Work Plan and Annual Program Budget state the estimated total costs of each proposed Conservation Measure or other Program-related activity and the amount anticipated to be expended for the period for which Program Funding is sought;

g. The applicant's Annual Party Work Plan and Cost Estimate suitably describes each proposed Conservation Measure or other Program-related activity to be performed, the project schedule, and the proposed project cost; and

h. The recommended project cost based on the procurement process used by the applicant is reasonable.

6.1.4. Withholding Action on Application.

The EAA may withhold action on a Program Funding Application if the funds in the HCP Program Account are insufficient to provide Program Funding in the requested amount or if the EAA identifies a consideration in Subsection 6.1.3 that is deficient and allows reasonable time for the filing of additional information before the application is reconsidered for final action. If the reason for withholding action is the insufficiency of money in the HCP Program Account, the EAA will advise all applicants and withhold action on all applications until sufficient money is available. The EAA will promptly notify the Program Manager, and the Implementing Committee and Parties will take action in accordance with Section 4.7 and Subsection 5.2.2, and submit revised applications for EAA review and approval

6.1.5. Notice of Decision on Application.

The EAA will notify the applicant in writing of its decision on the application.

6.1.6. EAA Delegation of Action on Applications.

The EAA Board of Directors may delegate to the EAA General Manager or his designee its authority to take action on an application under this Section.

6.1.7. Amendments to Application.

A Program Funding Application may be amended in writing with a request to the EAA to take action on the application as amended. The EAA will take action on the amended application in the same manner as provided for the original application.

6.1.8. Program Funding Contracts.

Funds may be disbursed by the EAA from the HCP Program Account only in the form of a Program Funding contract for the work to be performed by the applicant. If the EAA approves a Program Funding Application, it will make reasonable efforts to enter into a contract not later than 30 days after it takes final action on the application and make available to the applicant the amount of the approved Program Funding according to the terms and conditions in the contract.

Section 6.2. Program Payments.

6.2.1. Submission of Invoices.

Each Party will submit invoices to the Program Manager monthly for Program Funding for work to be performed or overseen by that Party in accordance with the Annual Program Budget and that Party's applicable Program Funding contract and associated, approved Program Funding Application. Each invoice will be accompanied by appropriate documentation reflecting all costs to be incurred or paid by the Party and such other documentation as may be required by the EAA as a condition of the Program Funding. The EAA will not make any payment to any Party for any work that is not included in the Annual Program Budget, as it may be amended from time to time, and a Party's applicable Program Funding contract and associated, approved Program Funding Application. The Program Manager will coordinate with the EAA and each Party submitting an invoice to ensure that each invoice, if approved, is paid to the Party submitting the invoice within 30 days of invoice submission.

6.2.2. Documenting Expenditures.

Each Party will submit to the Program Manager receipts or other appropriate documentation reflecting actual expenditures in accordance with the Party's applicable

Program Funding contract.

6.2.3. Actual Costs at Variance with Budget.

In the event actual expenditures for an action item are less than the line-item amount for that action in the Annual Program Budget, the funds committed to that action item may be used for other authorized purposes approved in accordance with the Annual Program Budget. In the event actual expenditures for an action item in the Annual Program Budget exceed the line-item amount in the Annual Program Budget, the Party responsible for that action item will provide written notice to the Program Manager of the cost overrun with substantiation for the additional expenses. The Program Manager will review the notice and provide a recommendation to the Implementing Committee, after which the Implementing Committee members will consider recommending to EAA a line-item amendment to the Annual Program Budget. The Implementing Committee may recommend an amendment to the Annual Program Budget only if adequate funds are available in the Program Account and only with the approval of the Implementing Committee and the EAA.

Section 6.3. Reduction or Termination of Funding Obligations.

The Annual Funding Obligation of the EAA under this Agreement will be in effect only during the Permit Term and is subject to reduction or termination as provided in Subsection 6.4.1.

Section 6.4. Alternative Funding.

The Program Manager and the Implementing Committee will pursue cooperative and grant funding to the extent available from all state, federal, and other private sources for eligible activities included in the Program. The Parties acknowledge that action by the Texas Legislature or other efforts subsequent to the Effective Date may result in adoption of a regional sales tax or other alternative source to fund the Program.

6.4.1. Reduction or Termination of Funding Obligations.

In the event that a regional sales tax or other alternative funding source to fund Program costs is created or secured, the Annual Funding Obligation of the EAA will be reduced or terminated on the date, and to the extent, that the proceeds from the tax or other alternative funding source is determined to be remitted to the EAA in amounts sufficient to reduce or displace the Annual Funding Obligation of the EAA, or the need for the EAA to assess Program Aquifer Management Fees to fund all or a part of the Program Expenditures. Thereafter, funding responsibilities for the Program described in this Agreement, to the extent of funds available from any such alternative new funding source, will be the responsibility of the administrator of the tax as provided by the legislation establishing such a tax, or the terms of any agreement establishing the alternative funding source.

6.4.2. Use of Alternative Funding.

To the maximum extent possible, funds collected from a sales tax or other alternative funding source will be used to provide funding for Program Expenditures, including without limitation, the implementation of Phase I Conservation Measures and any Phase II Conservation Measures.

6.4.3. Use of Additional Funds.

To the extent that additional funds, greater than the amount required to comply with ongoing Program obligations, are available in the HCP Program Account upon reduction or termination of the Annual Funding Obligation of the EAA, the funds will be used only for approved purposes in accordance with the Program Documents.

Section 6.5. Refund Upon Termination of this Agreement.

Upon termination of this Agreement, any available Fund Balance held by the EAA will be

refunded pro rata to the permit holders and other funding parties from whom Program Aquifer Management Fees or funding contributions were collected during the immediate prior year, unless the Implementing Committee and EAA Board of Directors take action to transfer all or a portion of the Fund Balance to a successor program.

Article Seven – Adaptive Management Process

Section 7.1. Purpose.

The Parties will follow the AMP, as described in this Article, during the Permit Term to ensure the full implementation of species protection provided by the Program. This Article provides the procedural steps and responsibilities of the Parties for making AMP decisions, the respective roles of the Implementing Committee, the Stakeholder Committee, the Science Committee, and the Science Review Panel in relation to AMP decisions, and the actions that will be taken as a result of such decisions.

Section 7.2. EAA Responsibilities.

7.2.1. Management Responsibilities.

Management of the implementation of the AMP in accordance with the terms and conditions of the Program Documents is the overall responsibility of the EAA, except to the extent of the duties and responsibilities held solely or jointly by one or more Parties, or of the roles of the Department or the Service, as specifically provided in the Program Documents. The EAA will also:

a. provide necessary staff support to the Implementing Committee, the Stakeholder Committee, the Science Committee, the Science Review Panel, and to the Program Manager;

b. cooperate and coordinate its management and implementation activities

for the Program with the Service, the Implementing Committee, the Stakeholder Committee, and the Science Committee;

c. coordinate with and facilitate meetings of the Science Review Panel; and

d. to the extent required under the Program Documents, consult with and obtain recommendations or approval for its management and implementation activities from the Implementing Committee or the Service.

7.2.2. Procurement.

Any procurement related to the Program, unless relating to the duties and responsibilities of another Party, will be made in compliance with the EAA budgeting, procurement, and disbursement policies and procedures.

Section 7.3. Adaptive Management in Program Phases.

The Parties will engage in the AMP during the Permit Term, as more fully described in this Agreement and the Program Documents. The AMP related to Phase I Conservation Measures will begin on the Effective Date and continue as long as any of those Conservation Measures are ongoing. The AMP related to Phase II Conservation Measures will begin no later than January 31, 2019, and continue for the duration of the Permit Term. The AMP described in this Article provides procedures for three levels of adaptive management decisions by the Parties: (1) routine (2) nonroutine and (3) strategic. Each Phase I Conservation Measure will be undertaken as soon as reasonably practicable after the effective date of the Permit, and, subject to any modification made by the Parties through the AMP, will continue during Phase I and Phase II unless the Conservation Measure is discontinued as a result of an AMP decision. Each Phase II Conservation Measure that is implemented in addition to any continuing Phase I Conservation Measures will be undertaken as soon as reasonably practicable after the commencement of Phase II.

Section 7.4. Biological Goals, Biological Objectives, and Adaptive Management.

The Parties recognize and affirm that the Biological Goals and Biological Objectives are central to the consensus developed by Stakeholders during the EARIP and that those goals and objectives will not be changed except to the extent that the best available scientific and commercial information developed after the Effective Date demonstrates that such changes are appropriate in accordance with the Scientific Record as provided in Subsection 7.13.7. The Parties also recognize that effective adaptive management is critical to the success of the Program.

Section 7.5. Monitoring.

As more fully described in Section 6.2 of the HCP, the Parties, with input from the Science Committee, Stakeholder Committee, and the Department, will develop and implement a monitoring program approved by the Service to meet the goals of the AMP. The monitoring program will provide information for the Service and the Parties to: (a) evaluate compliance with the Permit and the HCP; (b) determine if the Biological Goals and Biological Objectives are being met; and (c) provide scientific data and feedback information for the AMP.

7.5.1. Compliance Monitoring.

The Parties will include compliance monitoring in the monitoring program to verify that the Parties are carrying out the terms of the Program Documents.

7.5.2. Effects and Effectiveness Monitoring.

The Parties will include effects and effectiveness monitoring in the monitoring program to evaluate the success of the Program in meeting the Biological Goals and Biological Objectives. The Parties will design and implement targeted studies to evaluate, at a minimum, each of the issues listed in Section 6.3 of the HCP. Utilizing the staff resources of the Parties to the extent appropriate and available, the Science Committee, the Science

Review Panel, and other appropriate persons, the Program Manager will regularly evaluate the data developed through the monitoring program, the results of the studies in the applied research facility as described in Subsection 6.3.4 of the HCP, other studies and modeling results, and other information as appropriate.

7.5.3. Monitoring Reports.

As part of the annual report to be submitted to the Service pursuant to Subsection 7.1.3 of the Implementing Agreement and Sections 6.2 and 9.3 of the HCP, the Parties will prepare and submit a monitoring report.

a. In addition to any other information deemed appropriate by the Program Manager or requested by the Service, the monitoring report will include the information required by Subsection 9.3.1 of the HCP.

b. The Program Manager will prepare and submit a draft of the monitoring report to the Implementing Committee, the Stakeholder Committee and the Science Committee at least 60 days prior to the submittal to the Service of the annual report. The first monitoring report, for the year 2013, will be submitted for inclusion in the annual report in 2014. The monitoring report will also be made available to the Stakeholder Committee contemporaneously with its submission to the Service.

7.5.4. Technical Assistance.

The Program Manager may engage technical assistance and consult with individual Parties, the Service, and the Department as necessary to ensure effective monitoring on a timely basis. Costs incurred under this Subsection are subject to approval pursuant to the provisions in this Agreement governing the Comprehensive Phase I Work Plan, the Comprehensive Phase II Work Plan, Annual Party Work Plans and Cost Estimates, and Annual Program Budgets.

Section 7.6. AMP Decisions.

The Parties will consider and make three types of AMP Decisions during the Permit Term as provided in this Section.

7.6.1. Routine AMP Decisions.

Routine AMP Decisions are decisions involving ongoing, day-to-day matters related to the management and administration of Phase I Conservation Measures, and Phase II Conservation Measures implemented through the Strategic AMP Decision Process. Routine AMP Decisions also include any modifications to a Phase I Conservation Measure and to a Phase II Conservation Measure implemented through the Strategic AMP Decision Process that do not require a Permit Amendment.

7.6.2. Nonroutine AMP Decisions.

Nonroutine AMP Decisions are those decisions relating to Conservation Measures which are not Routine AMP Decisions or Strategic AMP Decisions. Nonroutine AMP Decisions include, but are not limited to, decisions to: (a) make modifications to any Phase I Conservation Measure or to any Phase II Conservation Measure implemented through the Strategic AMP Decision Process that require a Permit Amendment; (b) discontinue any Phase I Conservation Measure regardless of whether the decision requires a Permit Amendment; (c) discontinue any Phase II Conservation Measure regardless of whether the decision requires a Permit Amendment; (d) make any substantial alteration of the Biological Goals or Biological Objectives; and (e) implement or decline to implement an Additional Conservation Measure proposed by the Service.

7.6.3. Strategic AMP Decisions.

Strategic AMP Decisions are those decisions that relate to the selection of Phase II

Conservation Measures to be undertaken by the Parties during Phase II.

Section 7.7. Implementing Committee.

The Parties will establish and designate members of an Implementing Committee to supervise implementation of the HCP in accordance with the provisions of this Agreement. The Implementing Committee will be comprised, operate, and have the duties, rights, and obligations as provided in this Article and other provisions of this Agreement.

7.7.1. Membership on the Implementing Committee.

a. Voting Members of the Implementing Committee.

The Implementing Committee will have five voting members, each appointed by and representing a Party. Each Party will take such actions as it finds appropriate to duly appoint the member, to authorize the appointed member to represent the interests of the appointing Party in deliberations, and to authorize the appointed member to cast votes for Implementing Committee actions by which the Party agrees to be bound. Within 60 days of the effective date of the Permit, and from time to time thereafter as necessary, each Party will advise the Program Manager in writing of the name and contact information of the person it has appointed to represent that Party on the Implementing Committee.

b. Nonvoting Members of the Implementing Committee.

The Implementing Committee will also include as nonvoting members a representative appointed by each person or group of persons, other than a Party, who contributes to the HCP Program Account, under a written agreement with the EAA, an amount not less than $400,000 for each year of the Permit Term, as such amount may be adjusted under the terms of the written agreement. Within 60 days of the effective date of an agreement with the EAA, and from time to time

thereafter as necessary, each person or group of persons entitled to nonvoting representation on the Implementing Committee will advise the Program Manager in writing of the name and contact information of the person appointed to represent that person or group as a nonvoting member of the Implementing Committee.

c. Alternate Members.

Each voting and nonvoting member of the Implementing Committee may appoint, by advising the Program Manager in writing, one or more alternates to act as its representative in the absence of its regular representative.

7.7.2. Organizational Meeting of the Implementing Committee.

The members of the Implementing Committee will, as soon as reasonably practicable after January 1, 2012, convene their initial organizational meeting, elect a Committee chair and other officers as they may determine are necessary for Committee business, and adopt procedures to govern its activities. The Committee may take other actions as may be necessary to comply with the schedule of Program activities in this Agreement.

7.7.3. Duties of Implementing Committee.

The Implementing Committee will have the duties and obligations provided in this Subsection as follows:

a. consult with and advise the Program Manager on Routine AMP Decisions proposed by the Program Manager, the Implementing Committee, or the Stakeholder Committee;

b. consult with and advise the Program Manager on research and the

development of models as necessary to support and inform AMP decision-making;

c. ensure that the governing bodies of the Parties are kept informed of and, as appropriate, engaged in, through consultation with their respective representatives on the Committee or otherwise, Nonroutine AMP Decisions proposed by or to the Program Manager;

d. ensure that the governing bodies of the Parties are kept informed of and engaged in, through consultation with their respective representatives on the Committee or otherwise, Strategic AMP Decisions proposed by or to the Program Manager; and

e. make recommendations or decisions as required by the Program Documents.

7.7.4. Meetings of the Implementing Committee.

The Implementing Committee will meet once each calendar quarter and at any other time upon the request of the Program Manager or any two Parties. Meetings will be conducted at the official offices of the EAA or at any other location agreed upon by the Implementing Committee. The Program Manager will provide reasonable advance notice of the meetings to the Parties and Stakeholder Committee, and will post notice of any meeting on the EAA website. Meetings will be generally open to the public, but, with good cause, may be closed to the public at the request of the Program Manager or any two Parties. Meetings of the Implementing Committee are not subject to the Texas Open Meetings Act, Chapter 551 of the Texas Government Code, but the Committee and Program Manager will make reasonable efforts to provide notice of its meetings and conduct them open to the public as though they were subject to the Texas Open Meetings Act.

7.7.5. Implementing Committee Voting.

Except as otherwise provided in this Article for resolution of specific issues, a decision of the Implementing Committee will be made only by unanimous vote of the five voting members of the Committee, and any vote less than unanimous will result in disapproval of the proposed decision. Nonvoting members of the Implementing Committee will not be considered as members of the Committee for determining quorum or for decisions involving consensus or voting.

Section 7.8. Stakeholder Committee.

The Parties, through the Implementing Committee, will establish, and invite Stakeholders to designate members of, an Adaptive Management Stakeholder Committee (Stakeholder Committee). The Stakeholder Committee will be comprised and operate as provided in this Section.

7.8.1. Membership on the Stakeholder Committee.

The Stakeholder Committee will be comprised of one representative from each of the Parties and, to the extent possible, one representative from each of the following:

a. Texas Commission on Environmental Quality;

b. Texas Parks and Wildlife Department;

c. Texas Department of Agriculture;

d. Texas Water Development Board;

e. Guadalupe-Blanco River Authority;

f. San Antonio River Authority;

g. South Central Texas Water Advisory Committee;

h. Bexar County;

i. CPS Energy;

j. Bexar Metropolitan Water District or its successor, if that successor entity is not already represented on the Stakeholder Committee;

k. A holder of an initial regular permit issued to a retail public utility located west of Bexar County, to be appointed by the EAA;

l. A holder of an initial regular permit issued by the EAA for industrial purposes, to be appointed by the EAA;

m. A holder of an industrial surface water right in the Guadalupe River Basin, to be appointed by the Texas Commission on Environmental Quality;

n. A holder of a municipal surface water right in the Guadalupe River Basin, to be appointed by the Texas Commission on Environmental Quality;

o. A retail public utility in whose service area the Comal Springs or San Marcos Springs is located;

p. A holder of an initial regular permit issued by the EAA for irrigation, to be appointed by the commissioner of agriculture;

q. An agricultural producer from the Edwards Aquifer region, to be appointed by the commissioner of agriculture;

r. Environmental interests from the Texas Living Waters project, to be appointed by the governing body of that project, or if that project is discontinued, jointly by the National Wildlife Federation and the Lone Star Chapter of the Sierra Club;

s. Recreational interests in the Guadalupe River Basin, to be appointed by the Texas Parks and Wildlife Commission;

t. A holder of an EAA initial regular permit issued to a small municipality (population under 50,000) located east of San Antonio to be appointed by the Stakeholder Committee;

u. Edwards Aquifer region municipal ratepayers/general public, to be appointed by the Stakeholder Committee;

v. Guadalupe River Basin municipal ratepayers/general public, to be appointed by the Stakeholder Committee;

w. A conservation organization, to be designated by the Stakeholder Committee; and

x. Nueces River Authority.

7.8.2. Representatives Serving on the Stakeholder Committee.

The Parties recognize that, with the exception of the Parties, participation on the Stakeholder Committee is voluntary and cannot be compelled by the Service or the Parties. Any entity or class listed above that does not have a designated representative to the Stakeholder Committee will not be considered as a member of the Committee for purposes of determining quorum, consensus, affirmative votes or unanimous votes.

a. Timely Acceptance.

Within 60 days of the effective date of the Permit, and from time to time thereafter as necessary, each designating entity described in Subsection 7.8.1 entitled to designate an entity representative or one or more class representatives to serve as members of the Stakeholder Committee will advise the Program Manager in writing of the name and contact information of each designated representative.

b. Later Acceptance.

A designating entity listed in Subsection 7.8.1 may, at any time after the 60-day period, elect to designate a qualified representative to serve as a member of the Stakeholder Committee by giving written notice to the Program Manager of its intent to designate a representative and by providing the name and contact information of the representative.

c. Authorization to Vote.

Each designated entity representative or class representative will become a member of the Stakeholder Committee on the date that the Program Manager receives the written notification from the designating entity of the designation and the designee's acceptance of the designation as a member. Each member will be authorized to vote on behalf of the entity or class the member represents. If an entity or class listed in Subsection 7.8.1 was represented on the EARIP Steering Committee created under Section 1.26A of the EAA Act, the representative of that entity or class will be presumed to continue as the voting representative of that entity or class on the Stakeholder Committee in the absence of a contrary designation or a written resignation.

d. Alternates.

Each designating entity may appoint one or more alternates to act as its representative Stakeholder Committee member in the absence of its regular designee.

7.8.3. Role of the Stakeholder Committee.

The Stakeholder Committee will have the role in the AMP and the Program as described as follows in this Subsection and as may be specifically provided in other sections of this Agreement:

a. at the request of the Program Manager or an individual Party, consult with, advise, and make recommendations to the Program Manager, the individual Party, or the Implementing Committee on Routine AMP Decisions;

b. consult with, advise, and make recommendations to the Implementing Committee on proposed Nonroutine AMP Decisions;

c. consult with, advise, and make recommendations to the Implementing Committee on proposed Strategic AMP Decisions;

d. consult with, advise, and make recommendations to the Program Manager or the Implementing Committee on the design of studies related to the Biological Goals or the Biological Objectives;

e. consult with, advise, and make recommendations to the Program Manager or the Implementing Committee on any other matter at the request of the Program Manager or Implementing Committee; and

f. make appointments of members to the Science Committee as provided in

Section 7.9.

7.8.4. Meetings of the Stakeholder Committee.

The Stakeholder Committee will meet twice each calendar year and at any other time upon the request of the Program Manager or of any two voting members of the Implementing Committee, or upon petition to the Program Manager by four members of the Stakeholder Committee. Meetings will be conducted at the official offices of the EAA or at another location agreed upon by the Stakeholder Committee. The Program Manager will provide reasonable advance notice of the meetings via email to each member of the Stakeholder Committee and will also post notice of any meeting on the EAA website. Meetings will generally be open to the public, but, with good cause, may be closed to the public at the request of the Program Manager or any two members of the Stakeholder Committee. Meetings of the Stakeholder Committee are not subject to the Texas Open Meetings Act, but the Committee and Program Manager will make reasonable efforts to provide notice of its meetings and conduct them open to the public as though they were subject to the Texas Open Meetings Act.

7.8.5. Stakeholder Committee Voting.

Each member of the Stakeholder Committee will have one vote until that member's participation is resigned, or forfeited by absence, without an authorized alternate, from three consecutive meetings.

7.8.6. Procedures of the Stakeholder Committee.

A quorum for any meeting of the Stakeholder Committee will be three-fourths of the total number of members. The Stakeholder Committee will operate on a consensus basis, to the maximum extent achievable. In the absence of consensus, an affirmative vote of at least three-fourths of the entire membership will be required to approve any recommendation to the Program Manager or the Implementing Committee. The

Stakeholder Committee will elect a chair person, along with any other officers, and adopt procedures to govern its activities.

Section 7.9. Science Committee.

The Parties, through the Implementing Committee, will establish and, in conjunction with the Stakeholder Committee, appoint an Adaptive Management Science Committee (Science Committee). To the extent possible, the Science Committee will be comprised of an odd number of not fewer than seven or more than eleven members, as determined by the Implementing Committee, who have technical expertise in one or more of the following areas: (a) the Edwards Aquifer or its management; (b) the Comal Springs and River as defined by Subsection 3.4.2 of the HCP; (c) the San Marcos Springs and River as defined by Subsection 3.4.3 of the HCP; or (d) the Covered Species.

7.9.1. Membership on the Science Committee.

The Implementing Committee and the Stakeholder Committee will each select an equal number of members of the Science Committee and will coordinate with one another in making selections in order to ensure balance and proper coverage of areas of expertise. The Implementing Committee and the Stakeholder Committee will jointly select one additional member of the Science Committee. In the case of a vacancy on the Science Committee, the committee, or committees, that made the initial appointment for that position will appoint a replacement member.

a. Invitations to Serve.

The Parties recognize that participation on the Science Committee is voluntary and cannot be compelled by the Service or the Parties. Any person to which the Implementing Committee or the Stakeholder Committee extends an invitation to be a member of the Science Committee will be requested to respond in writing to the Program Manager within 30 days of the date of the invitation advising of the

acceptance of the invitation and to provide the invitee's contact information. If an invitee does not timely respond with acceptance, that invitation will be considered declined and another qualified person will be invited to become a member of the Science Committee in the same manner as for the invitation that was declined.

b. Authorization to Vote.

Each member appointed to the Science Committee will be authorized to vote and such appointed member will become a member of the Committee on the date that the Program Manager receives the written acceptance of the appointment.

c. No Alternate.

No member of the Science Committee may designate an alternate to act for that member in the member's absence.

7.9.2. Role of the Science Committee.

The Science Committee will have the role in the AMP and the Program as described in this Subsection, as follows:

a. consult with, advise and make recommendations to the Program Manager, the Implementing Committee and the Stakeholder Committee on any AMP Decision upon request;

b. provide independent and unbiased advice based on their best scientific judgment so that all AMP Decisions will be made consistent with the best scientific and commercial data available; and

c. participate in the meetings of the Science Review Panel and provide to the Panel such information as requested by that Panel or the Implementing

Committee.

7.9.3. Operations of the Science Committee.

a. Meetings.

The Science Committee will meet at any time upon the request of the Program Manager, the Implementing Committee, or the Stakeholder Committee. Meetings will be conducted at the official offices of the EAA or at any other location agreed upon by the Science Committee. The Program Manager will provide reasonable advance notice of the meetings via email to each member of the Science Committee and will post notice of any meeting on the EAA website. Meetings will generally be open to the public, but, with good cause, may be closed to the public at the request of the Program Manager or any two members of the Science Committee. Meetings of the Science Committee are not subject to the Texas Open Meetings Act, but the Committee and Program Manager will make reasonable efforts to provide notice of its meetings and conduct them open to the public as though they were subject to the Texas Open Meetings Act.

b. Subcommittees.

The Science Committee may be organized into subcommittees as jointly determined by the Program Manager and Implementing Committee.

7.9.4. Requests for Science Committee Evaluations or Recommendations.

a. Requests on Proposed Routine AMP Decisions.

Requests by the Program Manager, the Implementing Committee, or the Stakeholder Committee for an evaluation or recommendation on a proposed Routine AMP Decision may be made to the entire Science Committee or the

appropriate subcommittee of the Science Committee. However, for any proposed Routine AMP Decision that has significant potential to affect the overall well-being of a Covered Species, the decision-maker (the Program Manager or the Implementing Committee, as appropriate) will, if time allows, consult the Science Committee for input prior to making a decision or, if that is not possible, as soon as possible after making the decision and will adjust the decision as appropriate.

b. Requests on Other AMP Decisions.

For any proposed Nonroutine or Strategic AMP Decision, the Implementing Committee will seek a recommendation from the entire Science Committee prior to taking action on the proposed decision.

c. Information Provided.

The Program Manager will regularly inform the Science Committee of plans related to the applied research activities described in the HCP, including, but not limited to, Subsections 6.3.4 (applied research facility), 6.3.5 (Texas wild-rice enhancement) and 6.3.6 (monitoring and reduction of gill parasites), and, unless exigent conditions require otherwise, seek comments and recommendations from the Science Committee with regard to the research plans before the plans are implemented. The Program Manager will also inform the Science Committee and the Science Review Panel of the findings and results of the research activities.

7.9.5. Procedures.

The Science Committee and its subcommittees will operate to the maximum extent achievable by a collaborative process designed to achieve consensus. In the absence of full consensus on any evaluation or recommendation, the Science Committee will provide a written summary of competing positions to the Program Manager or the Implementing or Stakeholder Committees, as may be appropriate. Each member of the Science

Committee will have one vote towards consensus until participation is resigned, or forfeited by absence from three consecutive meetings. A quorum for any meeting of the Science Committee will be three-fourths of the total number of members for whom the Program Manager has received the notification of acceptance described in Subsection 7.9.1.b. The Science Committee will elect a chair person and a vice chair and adopt procedures to govern its activities.

7.9.6. EAA Funding.

The EAA, after consulting with the Implementing Committee, may enter into contracts with members of the Science Committee as, in the judgment of the EAA, are necessary and reasonable to secure the members' services.

Section 7.10. Creation of the Science Review Panel.

Not later than December 31, 2013, the EAA will enter into a contract with the National Academies of the National Academy of Science to establish an independent Science Review Panel (SRP), select its members, and undertake the ongoing role of overseeing the SRP activities. If the National Academies declines to enter into a contract that is reasonable in the judgment of the Implementing Committee, the Program Manager will consult with the Implementing Committee and the Stakeholder Committee in order to develop a consensus recommendation to the EAA on another comparable organization to select, and contract to fulfill that role. The Implementing Committee, in its discretion and after receiving the recommendation of the Stakeholder Committee, may recommend to the EAA that it contract with one organization for selection of SRP members, and contract with another organization for the ongoing role of overseeing SRP activities.

7.10.1. Membership of the Science Review Panel.

The SRP will have five members, chosen on the basis of their expertise in the scientific areas most relevant to resolution of issues expected to arise in the AMP. The members

need not have specific knowledge about the Covered Species or the Edwards Aquifer and must not have pre-conceived positions on the appropriate resolution of the issues expected to be presented to the SRP.

7.10.2. Meetings of the Science Review Panel.

From the time that the SRP is established until determinations have been made under Subsection 7.13.7, the SRP will meet quarterly at various locations within the jurisdiction of the EAA. After determinations under Subsection 7.13.7 have been made, the Program Manager will request the SRP to meet on an as-needed basis for the remainder of the Permit Term. To the maximum extent practicable, such meetings will be open to the public and will be recorded, with the recordings included in the administrative record. As part of its meetings, the SRP is expected to tour various sites and facilities in order to obtain first-hand knowledge and insights about key issues and challenges to be addressed through the AMP. Such tours need not be recorded or open to the public.

7.10.3. Role of the Science Review Panel.

The SRP will serve as a formal review body as requested by the Program Manager to provide scientific advice to the Program Manager, Implementing Committee, Stakeholder Committee, and Science Committee on issues related to the AMP. The SRP will provide ongoing comments on the modeling, studies, and data collection and analyses performed pursuant to the HCP. The SRP will provide resolution of major scientific issues involved in the HCP and the AMP (including without limitation, changes to a Biological Goal or Biological Objective), and, upon request by the Project Manager, will definitively determine if the Scientific Record establishes each of the conclusions required in Subsection 7.13.7 and explain its determinations.

Section 7.11. Procedures for Routine AMP Decisions.

Routine AMP Decisions will be made in accordance with the procedures stated in this Section.

7.11.1. Program Manager Approval Authority.

Routine AMP Decisions that do not involve an adjustment to the Annual Program Budget in excess of $50,000.00, and that do not primarily affect an individual Party, will be made by the Program Manager, subject to Subsections 7.2.2 and 7.11.4.

7.11.2. Decisions Involving Substantial Budget Adjustments.

If a Routine AMP Decision involves an adjustment to the Annual Program Budget in excess of $50,000, the decision will be subject to approval by the Implementing Committee, subject to Subsections 7.2.2 and 7.11.4.

7.11.3. Decisions Affecting an Individual Party.

If a Routine AMP Decision will primarily affect an individual Party, the Program Manager will consult with that Party. Such a decision will not require the approval of the Implementing Committee unless it involves an adjustment to the Annual Program Budget in excess of $50,000, or an increase in the Annual Program Budget. If the Party and the Program Manager agree that such a decision does not require Implementing Committee approval, they will report it to the Implementing Committee. If the affected Party and the Program Manager cannot reach agreement on a decision that does not otherwise require Implementing Committee approval, the decision will be made by a majority vote of the voting members of the Implementing Committee.

7.11.4. Decisions Involving the Annual Program Budget.

Routine AMP Decisions involving an increase in the Annual Program Budget will require approval by the Implementing Committee and the EAA Board of Directors. Routine AMP Decisions that require amendments, transfers, or adjustments to the Annual Program Budget will be subject to applicable EAA budgeting, procurement, and

disbursement policies and procedures.

7.11.5. Use of Science in Decisions.

The Program Manager, individual Parties, and, if applicable, the Implementing Committee, will: (a) make Routine AMP Decisions on the basis of the best scientific and commercial data available; (b) consult with the Science Committee on any such decision that has significant potential to affect the overall well-being of a Covered Species for input prior to making a Routine AMP Decision or, if prior consultation is not possible, as soon as possible after making the decision; and (c) make appropriate adjustments in the decisions if the Science Committee input so advises. The Service will also be consulted on such decisions as a part of the AMP, as appropriate.

7.11.6. Voting on Decisions.

The Implementing Committee members may vote on a Routine AMP Decision by email or other electronic communication.

Section 7.12. Procedures for Nonroutine AMP Decisions.

Nonroutine AMP Decisions will be made on the basis of the best scientific and commercial data available, and in accordance with the procedures stated in this Section.

7.12.1. Submission of Proposals.

A draft proposal for a Nonroutine AMP Decision may be brought forward by the Program Manager, any Party, the Implementing Committee, or any three members of the Stakeholder Committee. A draft proposal for a Nonroutine AMP Decision will be forwarded in writing to the Program Manager. The Program Manager will promptly forward the draft proposal to the Implementing Committee and the Stakeholder Committee, as appropriate, and to the Science Committee.

7.12.2. Science Committee Review.

Upon receipt of a draft proposal for a Nonroutine AMP Decision, the Program Manager will convene a meeting of the Science Committee as soon as practicable to discuss the draft proposal and to develop a schedule and identify any resources or studies that will be necessary for the Science Committee to evaluate the proposal and make any recommendations, if necessary.

7.12.3. Stakeholder Committee Review.

Within 14 days of receipt of a draft proposal for a Nonroutine AMP Decision, the Program Manager will convene a meeting of the Stakeholder Committee. With the consensus agreement of the Stakeholder Committee, obtained through polling of the members, the Program Manager may delay the meeting by up to an additional 14 days. The Program Manager will provide each member of the Stakeholder Committee a copy of the proposal and the written recommendation of the Science Committee, along with any other available supporting information, in advance of the meeting. If the Science Committee has not had sufficient time to complete its evaluation and recommendation of the draft proposal, the Program Manager will convene another meeting of the Stakeholder Committee within 14 days of receipt of the Science Committee's evaluation report. The Stakeholder Committee will take action on the proposal as provided below.

a. Consensus.

At the meeting to consider the draft proposal, the Stakeholder Committee will seek to achieve consensus on a recommendation regarding the proposal.

b. Recommendation.

The Stakeholder Committee will have 60 days from the date of its initial meeting

on the draft proposal to develop, approve, and submit a report with its recommendation on the proposal to the Program Manager. The Stakeholder Committee may, for good cause, request more time to submit its report, and such request will not be unreasonably denied by the Program Manager.

c. Adoption by Three-fourths Majority.

Any recommendation of the Stakeholder Committee for a Nonroutine AMP Decision will require at least a three-fourths majority of the entire Stakeholder Committee membership to be adopted. In the absence of consensus, the report of the Stakeholder Committee report will include a succinct summary of the competing positions.

d. Recommendation Forwarding.

The Stakeholder Committee will deliver its report on the proposal in writing to the Program Manager. The Program Manager will promptly deliver the Stakeholder Committee report to the Implementing Committee and the Service.

7.12.4. Implementing Committee Decision.

The Program Manager will call a meeting of the Implementing Committee within 14 days of receipt of the Stakeholder Committee's report on a proposal for a Nonroutine AMP Decision. The Implementing Committee will take action on the proposal as provided below.

a. Approval or Disapproval.

If the report includes a recommendation for a change to a Biological Goal or a Biological Objective, the Implementing Committee may either: (1) approve the recommendation of the Stakeholder Committee and direct the Program Manager

to commence discussion with the Service on the proposal; or (2) disapprove (by any vote other than unanimous approval) the Stakeholder Committee recommendation and direct the Program Manager to provide a written explanation of the disapproval to the Stakeholder Committee and to the Service. Any substantial alteration to a Biological Goal or Biological Objective will be based only upon new science developed during Phase I of the HCP. The Parties acknowledge that such an alteration will require a Permit Amendment.

b. Unanimous Vote Required.

A unanimous vote by the voting members of the Implementing Committee will be required to move forward with any proposed Nonroutine AMP Decision.

c. Discussion With the Service.

After consideration of the Stakeholder Committee report on a proposed modification to a Conservation Measure, the Implementing Committee, through the Program Manager, or, in the case of a modification that would primarily affect an individual Party and does not require a Permit Amendment, the Party that would be primarily affected, after notice to the Program Manager, may commence discussion with the Service on the proposed modification, and implement the modification if approved by the Service so long as the modification is not substantially less likely to achieve the Biological Goals and Biological Objectives than the Conservation Measure described in the HCP, as it may have been modified through the AMP.

d. Additional Approval by Implementing Committee and EAA.

A Nonroutine AMP Decision involving an increase in the Annual Program Budget will require approval by the Implementing Committee and the EAA Board of Directors. A Nonroutine AMP Decision that requires an amendment, transfer,

or adjustment to the Annual Program Budget will be subject to applicable EAA budgeting, procurement, and disbursement policies and procedures.

e. Additional Approval by All Parties.

If a Nonroutine AMP Decision involves an Additional Conservation Measure, the written approval of all of the Parties will be required, in addition to approval by the Implementing Committee, to implement the Additional Conservation Measure.

f. Discontinuance of a Phase I Conservation Measure.

Notwithstanding the unanimous vote requirement in Subsections 7.7.5 and 7.12.4.b, a Phase I Conservation Measure may be discontinued during the Permit Term by an affirmative vote of at least three voting members of the Implementing Committee if the measure is not needed to achieve any Biological Goal or Biological Objective.

g. Right of Protest.

The right of any member of the Stakeholder Committee to protest any Permit Amendment under consideration by the Service is recognized.

Section 7.13. Scientific Record.

7.13.1. Supplementation of the Scientific Record.

During Phase I, the Implementing Committee will ensure that the Program Manager continues to supplement the Scientific Record in accordance with Chapter 6 of the HCP to include the best scientific and commercial data available as necessary to evaluate, for each Covered Species, whether:

a. the Biological Objectives are necessary and adequate to meet the Biological Goals; and

b. the Conservation Measures are necessary and adequate to meet the Biological Objectives.

7.13.2. Identification of Research and Modeling.

The research and modeling to be performed in connection with the AMP include the following:

a. Ecological Modeling.

The EAA will develop an ecological model to better understand biological and ecological relationships, processes, interactions, and responses over time of the systems being studied, and to predict ecological responses to changes in environmental conditions. The ecological model will address as many of the objectives and criteria listed in Subsection 6.3.3 of the HCP as possible. The EAA, through the Program Manager, will seek input from the Science Committee on the design and use of the model, and will seek input from the Implementing Committee on significant issues which arise in development of the model. The EAA, through the Program Manager, will also inform the SRP of planning and development related to the ecological model. The EAA will, as it determines to be appropriate, seek comment and evaluation from the SRP in order to help ensure that the SRP is able to rely on the model results in making its determinations pursuant to Subsection 7.13.7.

b. Applied Research Facility and Other Studies.

The EAA will support and coordinate the construction of an applied research

facility as described in Subsection 6.3.4 of the HCP. The primary purpose of the applied research facility will be to provide data and information important for informing AMP decisions during Phase I and Phase II of the Program. Key studies to be performed are more completely described in Subsection 6.3.4 of the HCP. As authorized in the Annual Party Work Plans and Cost Estimates and the Annual Program Budgets, other studies will be performed on Texas Wild Rice enhancement as described in Subsection 6.3.5 of the HCP and on non-native snails and gill parasites as described in Subsection 6.3.6 of the HCP, and studies and data collection efforts recommended by the EARIP Expert Science Subcommittee (2008 and 2009) and Dr. Thomas Hardy (2011) may be undertaken. The Party responsible for a study will, through the Program Manager, seek input from the Science Committee on the design of the study, and will seek input from the Implementing Committee on significant issues which arise in the course of the study. The EAA, through the Program Manager, will also inform the SRP of activities related to the applied research facility and associated studies. The EAA will, as it determines to be appropriate, seek comment and evaluation from the SRP in order to help ensure that the SRP is able to rely on the study results in making its determinations pursuant to Subsection 7.13.7.

c. Edwards Aquifer Groundwater Modeling Improvements.

The EAA will make improvements to its MODFLOW model, and will create a new groundwater model, as described in Section 6.3.2 of the HCP. The goals of the model improvements include but are not limited to:

(1) improving the simulated transient water level residuals output;

(2) incorporating additional Edwards Aquifer characterization data and information as may be appropriate and available;

(3) incorporating reconceptualizations of boundary conditions,

geologic structures and stratigraphy, hydraulic architecture, recharge, and water budget; and

(4) improving calibration with respect to Comal Springs elevation, discharge, and observed instrumental record well level measurements throughout the Edwards Aquifer region.

The EAA, through the Program Manager, will keep the Implementing Committee informed on the progress of the model improvements and creation of the new model. The Implementing Committee may, through the Program Manager, provide comments to the EAA on the model improvements and the creation of the new model. The EAA, through the Program Manager, will also keep the SRP apprised of activities related to the creation of the new model and to groundwater modeling improvements and seek such SRP input as the EAA, in consultation with the Implementing Committee, determines to be appropriate in order to help ensure that the SRP is able to rely on the modeling results in making its determinations pursuant to Subsection 7.13.7.

7.13.3. Other Studies.

The Implementing Committee will also ensure the performance of other studies, research and experimentation determined to be necessary during the AMP.

7.13.4. Deadlines for Research and Modeling.

The Program Manager will compile all relevant completed research, modeling and other data not later than December 31, 2017.

7.13.5. Science Committee Review.

Not later than January 15, 2018, the results of the research and modeling, along with the data compiled by the Program Manager, will be submitted to the Science Committee for review and comment. All information submitted to the Science Committee will at the same time also be made available to the SRP, the Implementing Committee and the Stakeholder Committee. All Science Committee review and comment will be completed and incorporated into a report to the Program Manager not later than May 15, 2018. The Program Manager will submit the report from the Science Committee summarizing its review pursuant to this Section to the SRP, the Implementing Committee, and the Stakeholder Committee as soon as possible after its completion.

7.13.6. Science Review Panel Research Review.

Not later than June 1, 2018, the Program Manager will deliver the results of the research and modeling, along with the data compiled by the Program Manager, and the report of the Science Committee, to the SRP and request the determinations required by Subsection 7.13.7 in the form of a written report to be provided not later than September 30, 2018. On or before October 15, 2018, the Program Manager will distribute the report of the SRP to the Implementing Committee, the Stakeholder Committee, and the Science Committee.

7.13.7. Action on Science Review Panel Determinations.

The Implementing Committee will take such actions on the determinations of the SRP as provided in this Subsection.

a. If Some Objectives Not Necessary.

If the SRP determines for any Covered Species that the Scientific Record establishes that the full complement of Biological Objectives is not necessary to

meet the Biological Goals, then the Implementing Committee will propose changes to the Biological Objectives applicable to that Covered Species based solely on, and in accordance with, the Scientific Record utilizing the procedures for a Nonroutine AMP Decision set forth in Section 7.12.

b. If Objectives Are Not Adequate.

If the SRP determines for any Covered Species that the Scientific Record establishes that the Biological Objectives are not adequate to achieve the Biological Goals, then the Implementing Committee will propose changes to the Biological Objectives applicable to that Covered Species based solely on, and in accordance with, the Scientific Record utilizing the procedures for a Nonroutine AMP Decision set forth in Section 7.12.

c. If Conservation Measures Not Needed.

If the SRP determines that the Scientific Record establishes that any Phase I Conservation Measure is not needed to achieve the Biological Objectives, then the Implementing Committee will propose discontinuation of that Phase I Conservation Measure utilizing, the procedures for a Nonroutine AMP Decision set forth in Section 7.12.

d. If Phase I Measures Are Achieving Objectives.

If the SRP determines that the Scientific Record establishes the Phase I Conservation Measures are achieving the Biological Objectives, then neither the Presumptive Phase II Conservation Measure nor any other Phase II Conservation Measure will be pursued.

e. If Phase I Measures Are Not Achieving Objectives.

(1) If the SRP determines that the Scientific Record establishes the Phase I Conservation Measures are not sufficient to achieve the Biological Objectives, then the Implementing Committee will consider modifications to the Phase I Conservation Measures based solely on, and in accordance with, the Scientific Record, utilizing the procedures for a Nonroutine AMP Decision set forth in Section 7.12.

(2) If, however, the Implementing Committee does not recommend modifications to the Phase I Conservation Measures sufficient to achieve the Biological Objectives, based on direction from the SRP about the degree to which those objectives are not being achieved, the Implementing Committee will direct the Program Manager to initiate, not later than January 31, 2019, the procedures for Strategic AMP Decisions set forth in Section 7.14.

f. If Review Fails or is Inconclusive.

If, contrary to its duties as set out in Subsection 7.10.3, the SRP fails to make a determination or determines that the Scientific Record is inconclusive about whether the Phase I Conservation Measures are achieving the Biological Objectives, the Implementing Committee will coordinate with the Service as part of the AMP, and attempt to reach a conclusion that the Presumptive Phase II Conservation Measure or another Phase II Conservation Measure either is or is not necessary to achieve the Biological Objectives. The Implementing Committee will proceed as provided below:

(1) If the Implementing Committee concludes that the Presumptive Phase II Conservation Measure or other Phase II Conservation Measures are necessary, the Implementing Committee will direct the Program

Manager to initiate the procedures for Strategic AMP Decisions set forth in Section 7.14.

(2) If the Implementing Committee concludes that neither the Presumptive Phase II Conservation Measure nor any other Phase II Conservation Measure is necessary, the Implementing Committee will inform the Service and seek the Service's concurrence, as part of the AMP, that the Scientific Record supports the conclusion to not pursue these measures. If the Service does not concur, the Implementing Committee will direct the Program Manager to initiate, not later than January 31, 2019, the procedure for Strategic AMP Decisions set forth in Section 7.14.

(3) If the Implementing Committee, after coordination with the Service, is unable to reach a conclusion that alternative Phase II Conservation Measures or the Presumptive Phase II Conservation Measure either are or are not necessary, the Implementing Committee will direct the Program Manager to initiate, not later than January 31, 2019, the procedure for Strategic AMP Decisions set forth in Section 7.14.

Section 7.14. Procedures for Strategic AMP Decisions.

Strategic AMP Decisions regarding Phase II of the Program will be made on the basis of the best scientific and commercial data available in accordance with this Section.

7.14.1. Submission of Proposals.

If directed by the Implementing Committee pursuant to Section 7.13 to initiate the procedures for Strategic AMP Decisions, a draft proposal for a Strategic AMP Decision may be brought forward by the Program Manager, the Implementing Committee or any three members of the Stakeholder Committee. Any such draft proposal will be forwarded

in writing to the Program Manager. The Program Manager will promptly forward the draft proposal to the Implementing Committee and the Stakeholder Committee, as appropriate, and to the Science Committee.

7.14.2. Science Committee Review.

Upon receipt or development of a draft proposal for a Strategic AMP Decision, the Program Manager will convene a meeting of the Science Committee as soon as practicable to discuss the draft proposal and to develop a schedule and identify resources or studies, if any, that will be necessary for the Science Committee to evaluate the proposal and make any recommendations.

7.14.3. Stakeholder Committee Review.

a. Draft Proposal.

If a draft Strategic AMP Decision proposal is received prior to January 31, 2019, the Program Manager will present the draft for initial consideration by the Stakeholder Committee on a convenient time schedule designed to ensure completion of review in a timely and efficient manner with reasonable access to scientific review and input.

b. Meeting Convened.

(1) If one or more draft Strategic AMP Decision proposals are received later than January 31, 2019, the Program Manager will convene, within 14 days of receipt of the draft proposal, a meeting of the Stakeholder Committee. With the consensus agreement of the Stakeholder Committee obtained through polling of the members, the Program Manager may delay the meeting by up to an additional 14 days. The Program Manager will provide each member of the Stakeholder

Committee a copy of each draft Strategic AMP Decision proposal and the written recommendation of the Science Committee, along with any other available supporting information, in advance of the meeting.

(2) If the Science Committee has not had sufficient time to complete its evaluation and recommendation of each draft proposal, the Program Manager will convene another meeting of the Stakeholder Committee within 14 days of receipt of the Science Committee's evaluation report. The Program Manager may include multiple and alternative draft Strategic AMP Decision proposals for consideration by the Stakeholder Committee at a single meeting.

c. Recommendation.

At the meeting to consider the draft Strategic AMP Decision proposal(s), the Stakeholder Committee will seek to achieve consensus on a recommendation regarding each proposal.

d. Develop Report.

The Stakeholder Committee will have 180 days from the date of its initial meeting on the proposal to develop, approve and submit its report to the Program Manager on each draft Strategic AMP Decision proposal. The Stakeholder Committee may, for good cause, request additional time to develop a report. Approval of the request for additional time will be granted at the sole discretion of the Implementing Committee, but will not be unreasonably withheld.

e. Science Committee Prior Consideration.

The Stakeholder Committee will not be required to make a recommendation on a draft Strategic AMP Decision proposal without the opportunity to consider formal

input from the Science Committee on the draft proposal.

f. Three-fourths Majority.

Any recommendation of the Stakeholder Committee on a draft Strategic AMP Decision proposal will require at least a three-fourths majority of the entire Stakeholder Committee membership to be adopted. In the absence of consensus, the report of the Stakeholder Committee report will include a succinct summary of the competing positions.

g. Report Forwarded.

The Stakeholder Committee will deliver a report with its recommendation on each draft Strategic AMP Decision proposal(s) in writing to the Program Manager. The Program Manager will deliver the report of the Stakeholder Committee to the Implementing Committee and to the Service.

7.14.4. Implementing Committee Decisions.

The Program Manager will call a meeting of the Implementing Committee within 14 days of receipt of the report from the Stakeholder Committee to consider the report. The Implementing Committee will not consider approval of any draft proposal for a Strategic AMP Decision without first reviewing the Stakeholder Committee report on the proposal in accordance with this Section.

a. Unanimous Vote Required.

After review and discussion of a draft proposal, the Implementing Committee will vote on the proposal. Any decision by the Implementing Committee to proceed with a draft proposal will be made by unanimous vote.

b. Accepted Proposal.

The Implementing Committee will proceed on a draft proposal that is accepted as provided below.

(1) If the Implementing Committee accepts the recommendation of the Stakeholder Committee on a draft proposal, the Program Manager will inform the Stakeholder Committee and the Service of the decision.

(2) If the recommendation that was accepted calls for implementing one or more Phase II Conservation Measures other than the Presumptive Phase II Conservation Measure as described in Subsection 5.5.2 of the HCP, the Implementing Committee will direct the Program Manager to initiate discussions with the Service about amending the Permit to implement the recommended modification.

(3) If the recommendation that was accepted calls for implementing the Presumptive Phase II Conservation Measure, then the Implementing Committee will commence action to implement the Presumptive Phase II Conservation Measure and ensure that it is fully implemented by December 31, 2020.

c. Rejected Proposal.

The Implementing Committee will take action on a draft proposal that is rejected as provided below.

(1) If the Implementing Committee rejects a recommendation of the Stakeholder Committee, the Implementing Committee will direct the Program Manager to provide a written explanation of the rejection to the Stakeholder Committee and to the Service.

(2) If the recommendation that was rejected calls for implementing Phase II Conservation Measures other than the Presumptive Phase II Conservation Measure as described in Subsection 5.5.2 of the HCP, the Implementing Committee will either commence steps to implement the Presumptive Phase II Conservation Measure, or present alternate proposed Phase II Conservation Measures for expedited consideration by the Stakeholder Committee.

(3) If the Implementing Committee subsequently elects to pursue an alternate Phase II Conservation Measure that was previously presented for formal consideration by the Stakeholder Committee and not favorably recommended, the Implementing Committee may direct the Program Manager to provide a written explanation for the decision to the Service and to initiate discussions with the Service to implement the alternative Phase II Conservation Measure.

(4) If the recommendation that was rejected calls for proceeding with the Presumptive Phase II Conservation Measure as described in Subsection 5.5.2 of the HCP, the Implementing Committee may initiate steps to pursue an alternative Phase II Conservation Measure only if the alternative Phase II Conservation Measure was previously presented to the Stakeholder Committee for formal consideration.

d. No Resolution.

If the Program Manager initiates the Strategic AMP Decision process under Section 7.14 and the Implementing Committee fails to reach a resolution on the Strategic AMP Decision and take action to commence discussion with the Service on or before December 31, 2019 on the Strategic AMP Decision, the Parties will undertake the Presumptive Phase II Conservation Measure as described in

Subsection 5.5.2 of the HCP and ensure that it is fully implemented by December 31, 2020.

e. No Compelled Measure Not in HCP or AMP.

No Party may be compelled to take any Conservation Measure, including any Strategic AMP action not included in Chapter 5 of the HCP or approved through the AMP.

f. The Parties may not pursue a Phase II Conservation Measure other than the Presumptive Phase II Conservation Measure as described in Subsection 5.5.2 of the HCP without first presenting the proposed measure to the Stakeholder Committee for formal consideration pursuant to this Section.

Article Eight – General Provisions

Section 8.1. Term.

This Agreement will be effective on January 1, 2012, and will continue in effect until the end of the Permit Term. In the event the Service denies the Application of the Parties for the Permit, this Agreement becomes null and void for all purposes on the date of final action taken by the Service.

Section 8.2. Remedies.

The Parties recognize that failure in the performance of any Party's obligations hereunder cannot be measured in money damages. Each Party therefore agrees in the event of any default on its part that each Party will have available to it only the equitable remedy of mandamus and/or specific performance, but not termination as long as the Permit is outstanding. It is the intent of the Parties to this Agreement that any default will be subject to the remedy of mandamus and/or specific performance to the extent that mandamus and/or specific performance is possible under

the existing circumstances. It is the further intent of the Parties that money damages will not be available to any Party under any circumstances. If any Party fails to appropriate funds necessary to discharge that Party's obligations under this Agreement and a court of competent jurisdiction fails to enforce that obligation, then this Agreement will terminate with regard to that Party, and the other Parties will have the right to petition the Service to terminate the Permit with regard to the defaulting Party.

Section 8.3. Default – Notice and Opportunity to Cure.

If any Party fails to perform any obligation or make any payment in the required amount when due under this Agreement, any other Party may, without prejudice to any other right or remedy it may have under this Agreement, provide written notice of default to the nonperforming Party. If written notice of default is provided to a nonperforming Party, a copy of said notice will also be provided to every other Party. The nonperforming Party has 60 days from receipt of the notice within which to remedy the default.

Section 8.4. Payments from Current Revenue.

The Parties acknowledge that pursuant to the requirements of Texas Government Code Section 791.011(d)(3), a Party to this Agreement that pays for the performance of services must make those payments from current revenues available to that Party. A Party to this Agreement will never have the right to demand payment by another Party of any obligations assumed by or imposed upon that Party under or by virtue of this Agreement from any funds raised or to be raised by taxation (other than revenues from a regional sales tax as an alternative funding source under Subsection 6.4.1), and a Party's obligation under this Agreement will never be construed to be a debt of the Party of such kind as to require it under the Constitution and laws of the State to levy and collect an ad valorem tax to discharge such obligation. The Parties agree that the cost of all Conservation Measures and other Program-related activities will be paid solely from Program Funding defined in this Agreement, and that the Parties will not be obligated to provide funding beyond the sources and limitations identified in Article Five.

Section 8.5. Rights Regarding Books and Records.

Each Party will permit any other Party upon reasonable notice to examine and copy all the books and records kept by the Party regarding this Agreement. In addition, upon reasonable prior written notice to the Party, any other Party may conduct a complete audit of the books and records kept by the Party regarding this Agreement as well as upon the information and documentation used to prepare the books and records. Any such audit will be at the requesting Party's sole expense and will be prepared by a certified public accounting firm. If the audit report discloses actual errors in the books and records such that the charges assessed to another Party are in error then such error will be corrected for the period up to four years after the erroneous charge was paid and all payments reconciled over the subsequent twelve month period beginning with the audited Party's fiscal year. If the error identified in the audit is greater than the cost of the audit, the audited Party will reimburse the requesting Party the cost of the audit.

Section 8.6. Mediation.

In the event any controversy arising under this Agreement is not resolved by informal negotiations between the Parties within 30 days after any Party requests negotiations, then, upon the request of any Party, the controversy will be referred to the voluntary settlement procedure known as mediation, which process will be governed by the Texas Civil Practice and Remedies Code, Chapter 154, or its successor statute. The Parties will attempt to select a mutually acceptable mediator. Failing identification of a mutually acceptable mediator, the mediation will be conducted by the University of Texas School of Law Center for Public Policy Dispute Resolution. The mediation process will continue until the controversy is resolved, the mediator makes a finding that there is no possibility of settlement through mediation, or either Party chooses not to continue further. All costs and expenses of the mediation (including the mediator's fees) will be shared equally by the Parties involved in the mediation, provided however, that costs incurred by each Party will be costs solely of such Party.

Section 8.7. Interpretation.

The caption headings of this Agreement are for reference purposes only and will not affect its interpretation in any respect. Unless the context otherwise requires, words of the masculine gender will be construed to include correlative words of the feminine and neuter genders and vice versa. This Agreement and all the terms and provisions will be liberally construed to effectuate the purposes set forth herein and to sustain the validity of this Agreement.

Section 8.8. Participation by the Parties.

Each Party to this Agreement represents to the others that it is empowered by law to execute this Agreement and other agreements and documents and to give such approvals, in writing or otherwise, as are or may hereafter be required to accomplish the same, and that its execution of this Agreement has been duly authorized by action of its governing body.

Section 8.9. Force Majeure.

If by reason of Force Majeure any Party hereto will be rendered unable wholly or in part to carry out its obligations under this Agreement, then if such Party will give notice and full particulars of such Force Majeure in writing to the other Parties within a reasonable time after the occurrence of the event or cause relied on, the obligation of the Party giving such notice, so far as its performance is prevented by such Force Majeure, will be suspended during the continuance of the inability then claimed, but for no longer period, and any such Party will endeavor to remove or overcome such inability with reasonable dispatch. The term "Force Majeure" as employed herein will mean acts of God, strikes, lockouts or other industrial disturbances, acts of public enemy, orders of any kind of the Government of the United States or the State of Texas, regulatory restrictions by a groundwater district (other than those of the EAA as described in the Program Documents), any civil or military authority, insurrection, riots, epidemics, landslides, lightning, earthquake, fires, hurricanes, tornados, blue northers, storms, floods, washouts, any drought defined as an Unforeseen Circumstance in Section 8.2 of the HCP, restraint of government and people, civil disturbances, explosions, extraordinary breakage or accidents to

machinery, pipelines or canals, partial or entire failure of water supply, or on account of any other causes to the extent not reasonably within the control of the party claiming such inability. The Parties acknowledge that nothing in this provision affects the authority of the Service to suspend or revoke the Permit, either partially or in its entirety, as to the Party experiencing the inability or as to all Parties.

Section 8.10. Indemnification.

To the fullest extent allowed by law, each Party agrees on behalf of itself and its successors and assigns to defend, save and hold harmless the other Parties and their officers, directors, and employees from and against any and all claims, losses, expenses, costs, demands, judgments, causes of action, suits, and liability for personal injury or property damage (including but not limited to all costs of defense, such as fees and charges of attorneys, expert witnesses, and other professionals and all court or other dispute resolution costs) resulting from the negligence or other wrongful acts or omissions of the Party or an officer, director or employee of the Party.

Section 8.11. Modification.

This Agreement may be amended only by written agreement of all of the Parties. No change, amendment, or modification of this Agreement will be made or be effective that will: (a) cause this Agreement to diverge from or create an inconsistency with any Program Document; or (b) affect adversely the prompt payment when due of all money required to be paid by a Party under the terms of this Agreement.

Section 8.12. Addresses and Notice.

Unless otherwise provided herein, any notice, communication, request, reply, or advice (herein severally and collectively, for convenience, called "Notice") provided or permitted in this Agreement to be given, made, or accepted by any Party to the other Parties will be in writing and may be given or be served by depositing the same in the United States mail postpaid and registered or certified and addressed to the Party to be notified, with return receipt requested, or

by delivering the same to an officer of such Party, or by prepaid telegram when appropriate, addressed to the Party to be notified. Notice deposited in the mail in the manner hereinabove described will be conclusively deemed to be effective, unless otherwise stated herein, from and after the expiration of three days after it is so deposited. Notice given by electronic communication or in any other manner will be effective only if and when receipt is acknowledged by the Party to be notified. For the purposes of notice, the addresses of the Parties will, until changed as provided in the last sentence of this Section, be as follows:

If to the EAA:

General Manager
Edwards Aquifer Authority
1615 N. St. Mary's Street
San Antonio, Texas 78215

If to New Braunfels:

City Manager (with copy to Watershed Manager)
City of New Braunfels
424 South Castell Avenue
New Braunfels, Texas 78130

If to San Marcos:

City Manager
City of San Marcos
630 East Hopkins
San Marcos, Texas 78666

If to the University:

President
Texas State University – San Marcos
601 University Drive
San Marcos, Texas 78666

If to San Antonio:

President/Chief Executive Officer
San Antonio Water System
2800 U.S. Highway 281 North
San Antonio, Texas 78212

Any Party which changes its address or contact person for notice under this Agreement will provide at least five days' written notice to the other Parties.

Section 8.13. State or Federal Laws, Rules, Orders, or Regulations.

This Agreement is subject to all applicable federal and state laws and any applicable permits, ordinances, rules, orders, and regulations of any local, state, or federal governmental authority having or asserting jurisdiction but nothing contained herein will be construed as a waiver of any right to question or contest any such law, ordinance, order, rule, or regulation in any forum having jurisdiction. Each Party represents that, to the best of its knowledge, no provisions of any applicable federal or state law, nor any permit, ordinance, rule, order, or regulation of any Party will limit or restrict the ability of such Party to carry out its respective obligations under or contemplated by this Agreement.

Section 8.14. Severability.

The Parties hereto specifically agree that in case any one or more of the sections, subsections, provisions, clauses, or words of this Agreement or the application of such sections, subsections, provisions, clauses, or words to any situation or circumstance should be, or should be held to be, for any reason, invalid or unconstitutional, under the laws or constitutions of the State or the United States of America, or in contravention of any such laws or constitutions, such invalidity, unconstitutionality, or contravention will not affect any other sections, subsections, provisions, clauses, or words of this Agreement or the application of such actions, subsections, provisions, clauses, or words to any other situation or circumstance, and it is intended that this Agreement

will be severable and will be construed and applied as if any such invalid or unconstitutional section, subsection, provision, clause, or word had not been included herein, and the rights and obligations of the Parties hereto will be construed and remain in force accordingly.

Section 8.15. Waiver.

Notwithstanding anything to the contrary contained in this Agreement, any right or remedy or any default under this Agreement, except the right of a Party to receive the payments from another Party, which will never be determined to be waived, will be deemed to be conclusively waived unless asserted by a proper proceeding at law or in equity within four (4) years after the occurrence of such default. No waiver or waivers of any breach or default (or any breaches or defaults) by any Party hereto or of the performance by any other Party of any duty or obligation hereunder will be deemed a waiver thereof in the future, nor will any such waiver or waivers be deemed or construed to be a waiver of subsequent breaches or defaults of any kind, character or description, under any circumstances.

Section 8.16. Venue.

It is specifically agreed among the Parties to this Agreement that in the event that any legal proceeding is brought to enforce this Agreement or any provision hereof, the same will be brought in the County in which the principal administrative offices of the Defendant or any one Defendant are located.

Section 8.17. Succession and Assignment.

This Agreement is binding on and inures to the benefit of the Parties hereto and their respective successors, representatives, and assigns. This Agreement may not be assigned by any Party hereto without prior written notice to and approval by the other Parties, which consent may be withheld without cause.

Section 8.18. Entire Agreement.

This Agreement, along with the other Program Documents, constitutes the entire agreement among the Parties with respect to the matters described herein.

Section 8.19. Applicable Law.

This Agreement will be governed by and construed in accordance with the laws of the State, and the obligations, rights, and remedies of the Parties hereunder will be determined in accordance with such laws without reference to the laws of any other state or jurisdiction, except for applicable federal laws, rules, and regulations.

Section 8.20. Counterparts.

This Agreement may be executed in counterparts, each of which will be an original and all of which together will constitute but one and the same instrument.

Section 8.21. Officers and Agents.

No officer or agent of the Parties is authorized to waive or modify any provision of this Agreement. No modifications to or rescission of this Agreement may be made except by a written document signed by the Parties' authorized representatives.

Section 8.22. Recitals.

The Parties agree that the recitals in this Agreement are true and correct and are incorporated into the terms of this Agreement.

Section 8.23. Approval by Parties.

Each Party affirms that it has taken all necessary official action to approve this Agreement.

Section 8.24. Goods and Services.

The Parties agree that the mutual commitments stated in this Agreement to provide operational, regulatory and implementation services in execution of the HCP and mutual discharge of the Implementing Agreement constitute an agreement by each Party for providing goods and services to the other Parties, that payments due from the EAA and the mutual provision of goods and services are amounts due and owing under this Agreement, and that this Agreement is subject to Chapter 271, Subchapter I, of the Texas Local Government Code.

Section 8.25. No Third Party Beneficiary; No Partnership.

This Agreement is not intended to confer any rights, privileges or causes of action upon any third Party other than the Parties to this Agreement. The relationship of the Parties under this Agreement is not and will not be construed or interpreted to be a partnership, joint venture or agency. The relationship of the Parties will be an independent contractor relationship. No Party will have the authority to make any statements, representations or commitments of any kind, or to take any action, which will be binding on another Party.

IN WITNESS WHEREOF, the Parties hereto acting under authority of their respective governing bodies have caused this Agreement to be duly executed as of the Effective Date.

Signatures continue on next page

EDWARDS AQUIFER AUTHORITY

By:_____ Date: 01/03/2012
Karl J. Breher, General Manager

ATTEST:

By:_____ Date: 01/03/2012
Jennifer Wong-Espafza, Assistant to Board Secretary

APPROVED AS TO FORM:

By:_____ Date: 01/03/2012
Darrell Alan Frownfelter, General Counsel

CITY OF NEW BRAUNFELS

By:_____ Date:_____
Michael Morrison, City Manager

ATTEST:

By:_____ Date:_____
Patrick Aten, City Secretary

APPROVED AS TO FORM:

By:_____ Date:_____
Paul Isham, City Attorney

Signatures continue on next page

EDWARDS AQUIFER AUTHORITY

By:_____ Date:_____
Karl J. Dreher, General Manager

ATTEST:

By:_____ Date:_____
Jennifer Wong-Esparza, Assistant to Board Secretary

APPROVED AS TO FORM:

By:_____ Date:_____
Darcy Alan Frownfelter, General Counsel

CITY OF NEW BRAUNFELS

By:_____ Date: 12/28/11
Michael Morrison, City Manager

ATTEST:

By: Danny S. Batts II, Dep. City Secretary Date: 12/28/11
for Patrick Aten, City Secretary

APPROVED AS TO FORM:

By: Valeria M. Acevedo Date: 12/28/11
City Attorney

Signatures continue on next page

CITY OF SAN MARCOS

By:_____ Date: 12/30/11
James R. Nuse, P.E., City Manager

ATTEST:

By:_____ Date: 12/30/11
Jamie Lee Pettijohn, City Clerk

APPROVED AS TO FORM:

By:_____ Date: 12/30/11
Michael Cosentino, City Attorney

CITY OF SAN ANTONIO
ACTING BY AND THROUGH ITS SAN ANTONIO WATER SYSTEM

By:_____ Date:_____
Robert R. Puente, President/CEO

ATTEST:

By:_____ Date:_____
Becky Gonzalez, Executive Administrative Assistant

APPROVED AS TO FORM:

By:_____ Date:_____
Phil Steven Kosub, Senior Water Resources Counsel

Signatures continue on next page

CITY OF SAN MARCOS

By:_____ Date:_____
James R. Nuse, P.E., City Manager

ATTEST:

By:_____ Date:_____
Jamie Lee Pettijohn, City Clerk

APPROVED AS TO FORM:

By:_____ Date:_____
Michael Cosentino, City Attorney

CITY OF SAN ANTONIO
ACTING BY AND THROUGH ITS SAN ANTONIO WATER SYSTEM

By:_____ Date: 12/29/11
Robert R. Puente, President/CEO

ATTEST:

By: Becky Gonzalez Date: 12/29/11
Becky Gonzalez, Executive Administrative Assistant

APPROVED AS TO FORM:

By:_____ Date: 12/29/11
Phil Steven Kosub, Senior Water Resources Counsel

Signatures continue on next page

TEXAS STATE UNIVERSITY – SAN MARCOS

wm By: Denise M. Trauth Date: 1/4/2012
Denise M. Trauth, President

ATTEST:

By: William A Nance Date: 1/3/12
William Nance, Vice President for Finance and Support Services, Texas State University-San Marcos

APPROVED AS TO FORM:

By: Diane Corley Date: 1/4/2012
Diane Corley, Associate General Counsel, Texas State University System

APPENDIX S:

SAWS ASR WORK GROUP, “SAWS ASR CONCEPT,” FEBRUARY 2011

Edwards Aquifer Recovery Implementation Program (EARIP)
SAWS Aquifer Storage & Recovery (ASR) Activity

The SAWS Twin Oaks ASR (SAWS ASR) is an underground storage reservoir in the Carrizo sand aquifer in southern Bexar County. As a SAWS Water Management Project, it is designed to store permitted Edwards Aquifer water in years when demand is less than available supply. The stored water is then pumped back to the SAWS distribution system during drought periods and/or times of high demand. The SAWS 2009 Water Management Plan Update states that the water in the ASR will be utilized in Stage 3 and 4 of Critical Period Management to help meet SAWS ratepayer needs.

The estimated, but untested capacity of the SAWS ASR is 200,000 acre-feet. By agreement with the Evergreen Underground Water Conservation District SAWS may pump 100% of the Edwards water stored in the SAWS ASR. To accomplish that return even if the stored water does mix with Carrizo water to some degree, the SAWS ASR site has a 30 millions of gallons per day (MGD) water treatment plant. So far, however, during SAWS ASR use in tests and in the droughts of 2006 and 2008-2009 the returned water has retained its Edwards Aquifer characteristics.

Currently (early 2011), the use of the SAWS ASR is limited by its single pipeline. The pipeline on the east side of Bexar County connects Twin Oaks to the pump stations at Seale, Artesia (south of IH 35 near Ft. Sam Houston) and Randolph (south of IH 35 near the north east juncture of IH 35 and Loop 410 interchange).

The SAWS ASR facility has a capacity to inject or return 60 MGD (184 acre-feet per day) in a drought. The ASR as of February 1, 2011 has 90,000 acre-feet in storage.

Referring to the SAWS 2009 Water Management Plan Update and assuming the short and mid-term projects are successful, SAWS water supply is sufficient to meet projected demand. Even if there is a repeat of the drought of record the plan indicates surplus supplies until 2040 when 16,000 acre-feet would be needed. The analysis of SAWS' water supplies reflected in the 2009 Water Management Plan Update reveals that SAWS has considerable flexibility in the supply situation. That flexibility can be utilized to offset Edwards pumping demands during a focused drought period resulting in positive spring flow at Comal and San Marcos Springs (San Marcos is limited by the regional bypass or structural geology and both spring communities by localized activities) to meet the needs of the Endangered Species during a drought of record.

Why is it Desirable to Fill the ASR through the Relaxed Rate Described in this Paper

- Until SAWS completes the Western Integration Line, the limitation of the ASR is the one pipe outlet. The limitation is one of quantity and flow direction. Water can either be

injected in the ASR, or ASR and local Carrizo water must be flowing to San Antonio. The pipe must be in action.

- SAWS ratepayers paid for the ASR with expectation that it would return water during Stage 3 and 4. This water is excess stored Edwards water that was available during low demand periods.
- The ratepayer's expectations must be fulfilled before the ASR can be used to address regional needs to protect spring flow, unless they agree to a change of purpose.
- The "Good News" is that the SAWS ratepayer expectations to have access to local Carrizo and ASR water in Stage 3 and 4 can be addressed in addition to the Regional need to protect spring flow "if" the "relaxed fill" schedule continues.
- The "10-year Recharge Average" identified the drought of record and described a topping off schedule to provide adequate water in the ASR to meet drought of record requirements to have approximately 126,000 acre-feet to return during recovery operations.
- The conditions described in this paper also allow SAWS to utilize local Carrizo and ASR water during high demand times and to store SAWS excess Edward's supplies during low demand periods.
- In the typical year with normal rainfall, utilizing the relaxed refilling schedule, SAWS can pump its local Carrizo water to ratepayers in the summer while storing excess supplies in the normal low demand winter months.
- The relaxed fill schedule also is more conducive to dividing costs into yearly segments. It reduces the need for high initial costs and allows that cash reserves be built for the demands for topping off and returning the water to San Antonio.
- SAWS relies on the pumping of its local (Bexar County) Carrizo water to counteract the natural inclination of the injected water to flow down towards the Coast. The wells are positioned for that purpose.

SAWS' ASR as a Bottom Up Activity in the EARIP Habitat Conservation Plan (HCP)

It is believed that the SAWS ASR can fulfill its role in the 2009 Water Management Plan Update and also provide considerable spring flow. This can be achieved when ASR is used with the other management strategies of the "Bottom Up" package; Voluntary Irrigation Suspension Program Option (VISPO), the Regional Conservation Program and the Stage 5 Emergency Pumping Reduction as the final activity triggered in the sequence (ASR would implement after VISPO and Conservation and before Stage 5).

The current proposal calls for the SAWS ASR to begin supplementing up to 60 MGD of SAWS Edwards pumping when monitoring well J-17 indicates that the aquifer level is 630 feet msl and Comal Spring flow reaches 75 cubic feet per second (cfs). The described reduction in SAWS pumping would add approximately 15 cfs during the worst month of a drought similar to the drought of record (an average of 46 cfs during that worst year) to spring flow at Comal Springs and approximately 29 cfs during the worst month of drought similar to the drought of record (an average of 14 cfs during that worst year) to spring flow at San Marcos Springs according to the

MODFLOW model simulations. These results are also predicated on the layered approach and the regional efforts of VISPO (Dry Year Option) and conservation strategies being implemented.

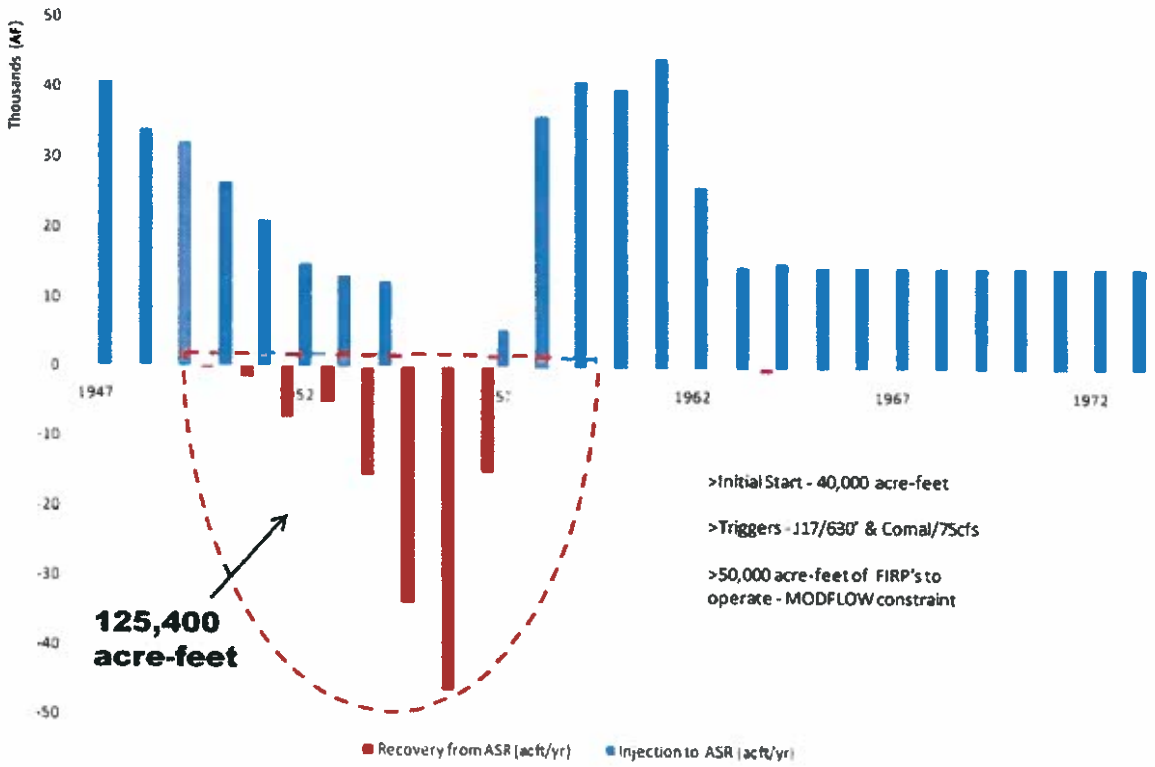
Arranged in the order described, the modeling indicates that the VISPO and Regional Conservation Programs will provide approximately 14 cfs spring flow at Comal Springs during the driest period of the drought of record. These strategies provide more benefit than 14 cfs during the Intermittent Period of the drought of record because they are triggered earlier.

The key to the SAWS ASR contribution to the protection of the Endangered Species is to reduce SAWS' pumping as per the volumes reflected in Graph #1.

GRAPH 1

LATEST EARIP MODELED HYPOTHETICAL OPERATION

(HDR Simulation 1-13-2011)



Preparation for the Drought of Record

SAWS will continue its weather related, cost effective relaxed filling of the ASR with a goal to have at least 120,000 acre-feet in storage prior to the arrival of a decade reminiscent of the drought of record. Eighty-thousand acre-feet of that water will be dedicated to the Regional HCP to protect spring flow. A key and important factor will be identifying the presence of such a drought with enough time to "top-off" the ASR strategy. SAWS suggests monitoring the

instrumental records 10-year rolling average of recharge information included in the Edwards Aquifer Authority's (EAA) annual hydrologic report. This can be like the proverbial canary in the coal mine helping to identify which droughts might require aggressive action.

SAWS Responsibilities in Fulfilling the Regional Commitment

The key to the SAWS ASR contribution to the protection of the Endangered Species at the Springs is to reduce Edwards Aquifer pumping as per the volumes modeled and reflected in Graph #1.

The modeling represented in Graph #1 utilizes the capabilities of the SAWS ASR at the current time.

As SAWS 2009 Water Management Plan Update is implemented, the pumping reduction at 630 ft msl at J-17 and spring flow of 75 cfs at Comal Springs may be accomplished through the use of the SAWS ASR, or some combination of other water supplies implemented as part of SAWS 2009 Water Management Plan. SAWS integration infrastructure is a carefully timed activity to balance many factors. A portion of the planned offset may be attributed to molecules of water coming from Local Carrizo or brackish desalination activities. It is important to remember that these supplies are for future growth and integration infrastructure for ASR opportunities will be expanded in coordination with diversification.

Costs in the EARIP Regional HCP are calculated for use of the SAWS ASR, the least expensive source of water of the planned new projects.

Identifying the Drought of Record and Managing the SAWS ASR in that Period

The advent of the early drought of record will be identified when the 10-year average of recharge falls below 500,000 acre-feet. At that point SAWS will **increase storage** (relative to the fact that SAWS has been targeting 120,000 acre-feet 2/3 for the Region and 1/3 available for use per the SAWS 2009 Water Management Plan Update) to an average of approximately 16.25 MGD. It is expected that this pattern will continue for three years at which time the 10-year recharge level will have fallen to 450,000 acre-feet and be on a trajectory towards 320,000 acre-feet.

HDR and Todd Engineers initially utilized the MODFLOW model with the SAWS ASR as being completely empty (0 acre-feet in storage). The model period began in 1947. At this time, the 10-year rolling average of recharge, according to estimates maintained by the EAA, was 489,000 acre-feet. Since the SAWS ASR has over 90,000 acre-feet stored, using the 500,000 acre-feet 10-year rolling average provides an additional level or degree of conservatism.

At the time when the 10-year rolling recharge rate has fallen to a range of <450,000 to >320,000 acre-feet per year, SAWS will revise its injection and recovery pattern to one of storage in quarters one and four of approximately 13.5 MGD to recovery of approximately 14.25 MGD in

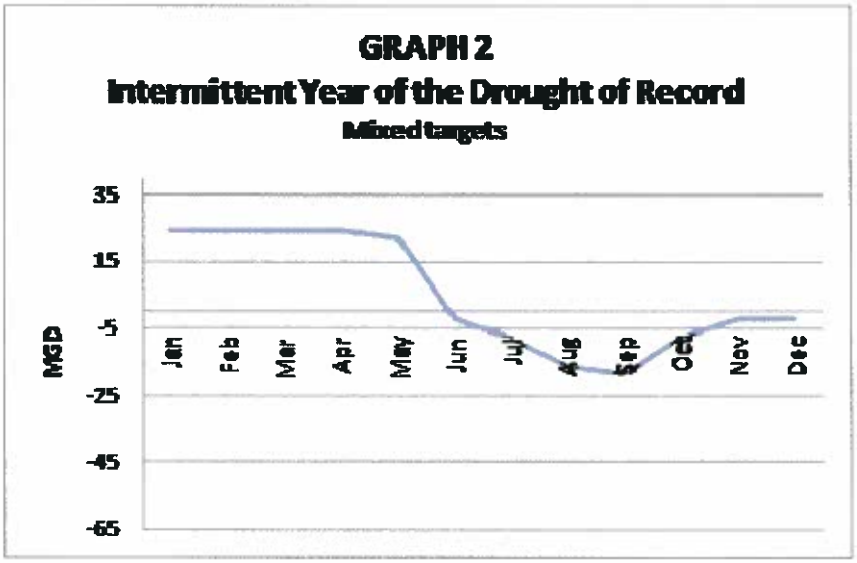
quarters two and three when J-17 levels and spring flow triggers dictate similar to the simulations. This period is known as the intermittent operations.

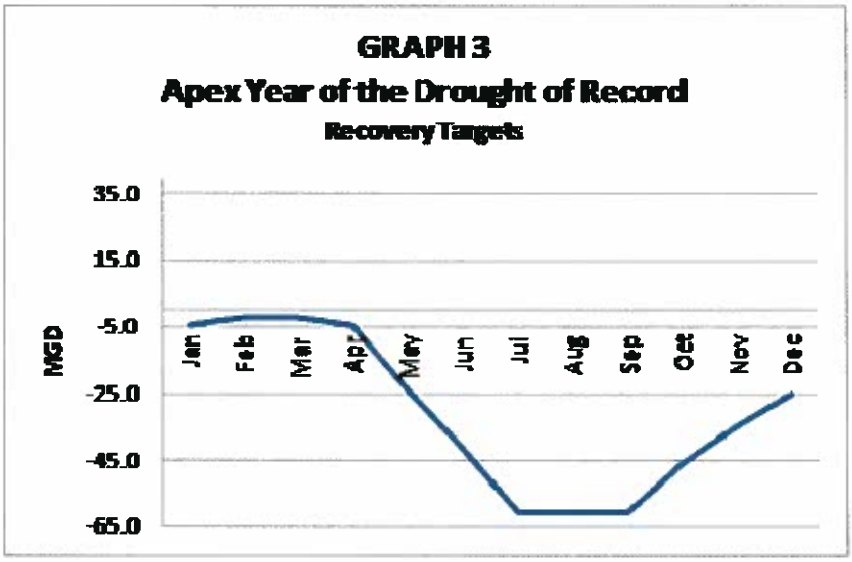
During years of the drought of record when the 10-year average recharge rate has fallen from the intermittent range to ≤320,000 acre-feet will be the most difficult to manage. Groundwater modeling results call for an average recovery rate of 33 MGD and show brief 3rd quarter periods when the recovery will be at the full capacity of 60 MGD when the aquifer level is at or below 630 feet msl and spring flow at Comal Springs is at or below 75 cfs. The modeling calls for considerable discretion in determining the recovery rate.

The recovery rate may be less than 60 MGD when SAWS management determines that spring flow is not likely to continue to fall because rainy weather is forecast or the spring flow levels and/or aquifer levels are on an upward trend. This period in the management of SAWS ASR is to insure that spring flow does not fall below 30 cfs, paralleling the management that occurred in 2009, that resulted in a stabilization of aquifer levels just above 640 feet; preventing a drop into Stage 3.

During the apex of a decadal drought, SAWS ASR will be in full recovery mode with an average of approximately 40 MGD. During this period the SAWS ASR is expected to be operating at full capacity, 60 MGD during the 3rd quarter of the worst two years of the drought of record.

Graphs #2 reflects the concepts described as the intermittent year of the drought of record. Graph #3 reflects the concepts described for the apex year of the drought of record. The graphs collectively represent planning averages for intra-year variation based on modeling simulations.





The following tables represent illustrative monthly targets in MGD, which are episodic when considering traditional water utility operations. The tables reflect having a minimum of 80,000 acre-feet (2/3 of the target) ready for regional use during the implementation of the ASR strategy. All of the leasing options are in place by this point and the ASR strategy would be implemented in a way to be as representative as possible of the modeling performed for the EARIP by its technical experts. The regional advisory group would make recommendations to best optimize the SAWS ASR strategy during the intermittent and apex periods.

EARLY PERIOD – Illustrations:

This period is indicative of a topping off resulting in ~54,000 acre-feet of water stored in addition to the targeted start-up

ADVENT PERIOD-INJECTION TARGETS

Month	Year1	Year2	Year3
January	20	20	15
February	20	20	15
March	20	20	15
April	20	15	15
May	20	15	15
June	20	15	15
July	15	15	15
August	15	15	15
September	15	15	15
October	15	15	15
November	15	15	15
December	15	15	15

INTERMITTENT PERIOD – Illustrations:

This period represents continued timely storage of an amount of water (1st and 4th quarters primarily) ~41,500 acre-feet of water and a beginning of more intense recovery modes to account for a return to SAWS customers of ~18,500 acre-feet, which provides the relief on the Edwards required for spring flow benefits.

INTERMITTENT PERIOD-INJECTION TARGETS

Month	Year4	Year5	Year6	Year7
January	15	15	10	15
February	15	15	10	15
March	15	15	10	15
April	15	15	10	10
May	15	15	10	10
June	15	15	nuetral	nuetral
July	15			
August		RECOVERY		
September				
October	15	15		
November	15	15	nuetral	
December	15	15	10	nuetral

INTERMITTENT PERIOD-RECOVERY TARGETS

Month	Year4	Year5	Year6	Year7
January				
February				
March				
April		INJECTION		
May				
June				
July		10	10	10
August	10	10	30	20
September	10	10	30	20
October			10	10
November	INJECTION			10
December				

APEX PERIOD – Illustrations:

This period is primarily protection of deep drought of record conditions returning ~109,000 acre-feet to assist in reducing focused drought stress sufficient enough to maintain the plans prescribed spring flow.

APEX PERIOD-INJECTION TARGETS

Month	Year8	Year9	Year10	Reset
January	10	nuetral		
February	10	nuetral		
March	10	nuetral		
April	10			
May	10			
June				
July		RECOVERY		
August				nuetral
September				nuetral
October				nuetral
November				15
December				15

APEX PERIOD-RECOVERY TARGETS

Month	Year8	Year9	Year10	Reset
January			20	40
February	INJECTION		20	30
March			10	30
April		10	20	20
May		20	40	20
June	10	40	60	10
July	30	60	60	10
August	40	60	60	
September	40	60	60	
October	30	40	60	
November	10	30	50	
December	10	20	40	

*neutral in all practical terms falls in as a "recovery" activity and could be the Local Carrizo returned with a smaller amount of stored Edwards as a blend (10 MGD) to ensure that the overall recovery falls in line with the commitment – 126,000 acre-feet.

Regional Discussion Group

The decisions that accomplished the 2009 stabilization of aquifer levels were made by SAWS management with advice from the Aquifer Management Team, a group of SAWS administrators and technical staff representing various SAWS departments.

A similar 10 member discussion group will be formed to advise SAWS management on SAWS ASR use during the intermittent and apex periods. In addition to five SAWS representatives, the Regional Aquifer Discussion Group will include two representatives of the Edwards Aquifer Authority, and single representatives of the EARIP representing downstream interests, agricultural pumpers, and environmental group. The SAWS administration will call meetings of the Regional Discussion Group to consider the advice related to regional aquifer management, but retain ultimate SAWS ASR management decision power.

Other Droughts

The Bottom Up slate of activities was organized to maintain minimum spring flow at or near 30 cfs during the drought of record.

The question has been raised asking, "what about other droughts?" If the Regional portion of SAWS ASR is reserved for the drought of record as identified by the "10-year Cumulative Recharge Average" what about the droughts in 1984 and 1996 when Comal spring flow fell below 75 cfs but the "10-year Cumulative Recharge Average" was still relatively high. The SAWS ASR would in fact address those droughts without reducing its capability to address the drought of record.

Examining the Senate Bill 3 modeling results for the period 1960 – 2000, there are five droughts that would reach ASR Regional trigger levels.

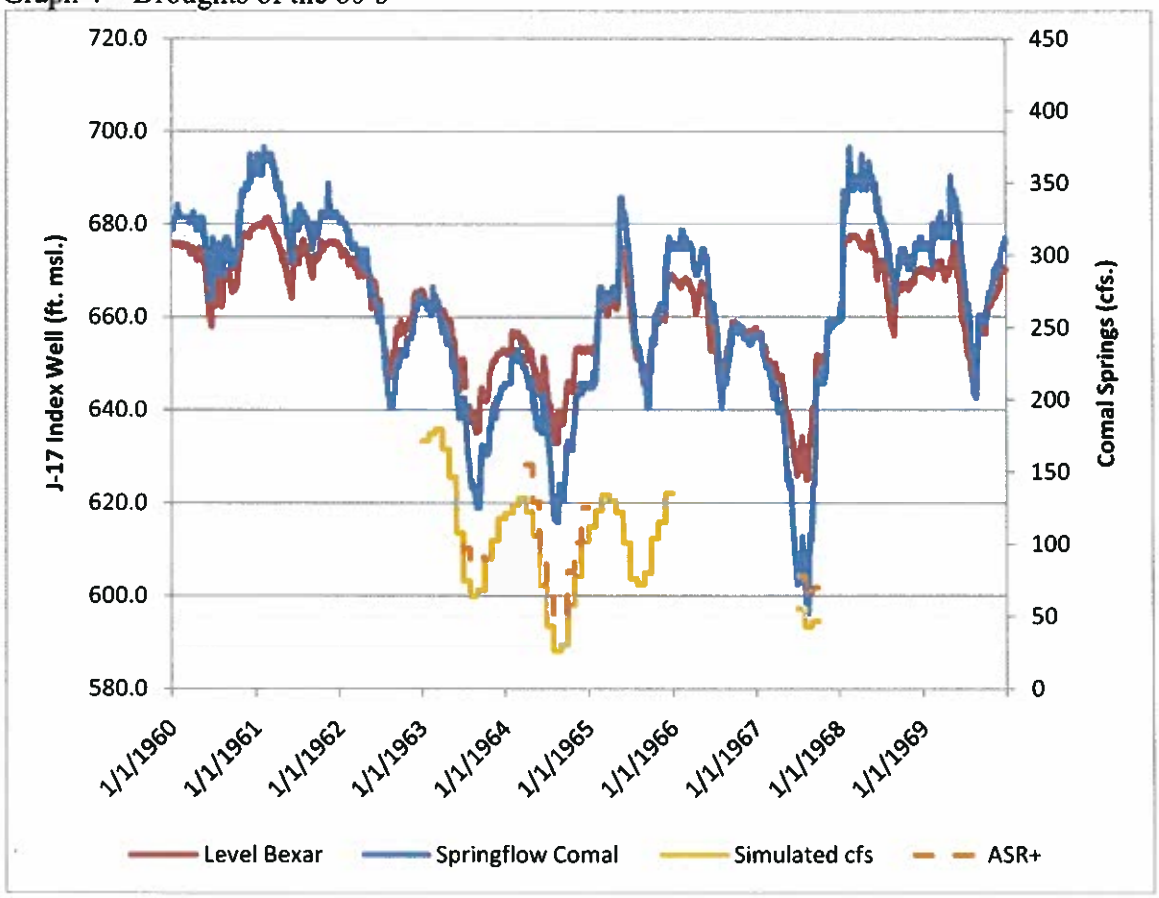
In the 60's there are three such droughts (see graph 4) with one drought each occurring in the 1980's and one drought in the 1990's. See graphs 5 and 6 respectively.

As the notes under the graph indicate, the triggered droughts in 1963, 1964 and 1967 would require 7,950 acre-feet, 23,850 acre-feet and 7,950 acre-feet of water from the ASR to maintain the minimum spring flow. The total for the decade of the 60's would be approximately 40,000 acre-feet of water. The 40,000 acre-feet of water from the ASR would provide over 20,000 acre-feet of extra spring flow.

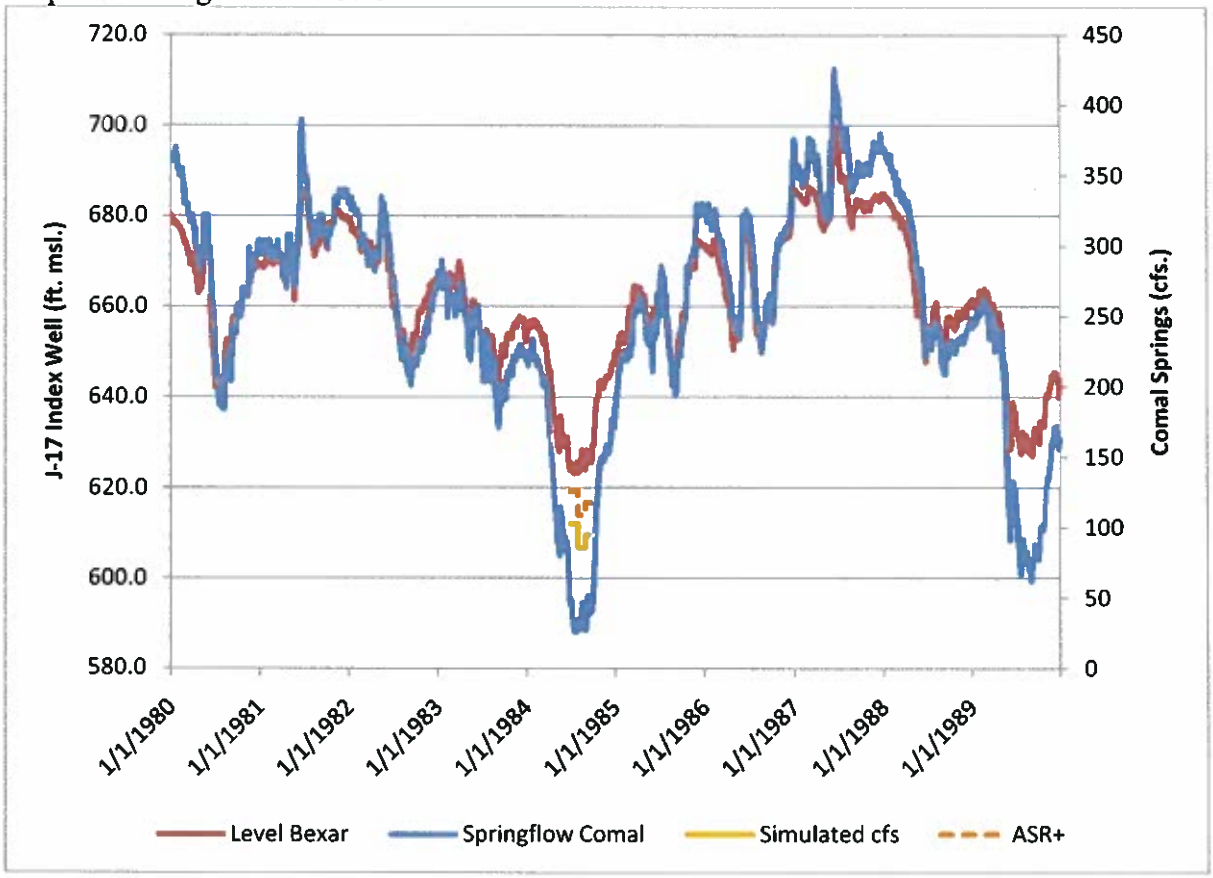
The model simulated droughts in 1984 and 1996 would require approximately 7,950 acre-feet of water from the ASR. The contribution from the ASR would add approximately 4,000 acre-feet of spring flow during each of the two droughts.

There is considerable question whether the modeled trigger levels at Comal Springs in the 60, 80 and 90's would actually be reached because of the impact of the VISPO, Regional Conservation, and SAWS 2009 Water Management Plan Update actions during Stage 3 and Stage 4 of the drought, but if they did, it is clear from this analysis that the water would be available from SAWS ASR to maintain minimum spring flow. The 80,000 acre-feet pre-drought of record reserve could handle the most demanding of the droughts identified in the modeling short of the drought of record.

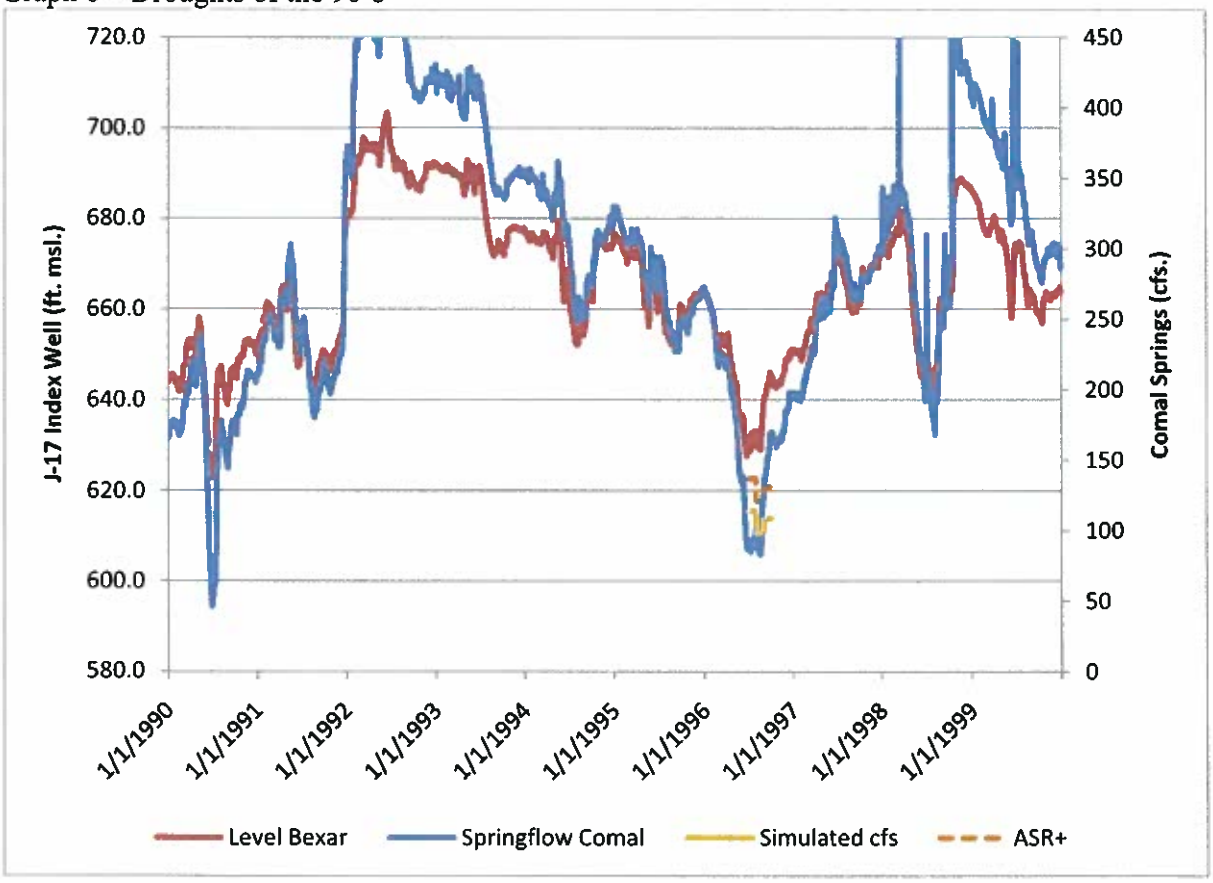
Graph 4 – Droughts of the 60's



Graph 5 – Droughts of the 80's



Graph 6 – Droughts of the 90's



SAWS 2009 Water Management Plan Update ASR Activities

The modeling in response to the SAWS original ASR inquiry, 20,000 acre-feet in Stage 3 and 20,000 acre-feet in Stage 4 did not impact modeled spring flow levels. The model assumed that the reduction in SAWS pumping in Stage 3 and Stage 4 would be pumped by other Edwards Aquifer pumpers. That pumping was labeled "enhanced pumping."

There was considerable debate whether the "enhanced pumping" was a real phenomenon. The experience in 2009 was cited where it appears that ASR replacement water kept Aquifer levels from dropping into the Stage 3 zone. There was no rain and water use continued at Stage 2 levels but with no evidence of "enhanced pumping" as the Aquifer levels at J-17 and spring flow stayed steady for two months in a deep summer drought.

It is a question that will be answered in thorough examination of the MODFLOW mechanisms during the Adaptive Management process but in the meantime it appears that SAWS ASR use in Stage 3 and 4 may, in fact, have more impact on spring flow than credited by the model. This activity at least provides insurance that the Bottom Up activities will be capable of maintaining minimum spring flow.

The use of 40,000 acre-feet of SAWS ASR to fulfill the SAWS 2009 Water Management Plan Update does not reduce the ASR's ability to fulfill the requirements of the Bottom Up activities, it complements them. It will address or nearly address the challenges of maintaining spring flow at the Springs during modeled droughts that are severe enough to bring Comal spring flows below the 75 cfs trigger level but do not qualify as the drought of record.

Water for the EARIP SAWS ASR Project

The project identifies the need for 200,000 acre-feet of water to be injected prior to and during the drought of record to provide 126,000 acre-feet of replacement water for SAWS use in lieu of pumping Edwards' water.

The water could potentially come from the 50,000 acre-feet of new leases modeled for the project; water already stored in the SAWS ASR; SAWS excess water; Section 1.14(h) water; or some combination of the sources.

Factors to consider when determining the best source of water to use for the EARIP SAWS ASR Project include:

- SAWS needs to fulfill its 2009 Water Management Plan Update expectations for the ASR;
- Capabilities of the infrastructure;
- Costs of various options of water sources;
- Modeling impact on the mix of water selected;
- Impact to the agriculture industry in the region; and
- Impact on the water market.

The most desirable water supply option for the project would be the one that does not limit SAWS flexibility to meet the 2009 Water Management Plan Update or stretch capability of the SAWS ASR infrastructure. It is also desirable that the water source selected be relatively inexpensive and contributes to the full modeling impact expected from the project. It would also be best if the option selected caused minimal disruption to the viability of the regional agricultural industry and to the stability of the Edwards water market.

The best way to proceed seems to use 80,000 acre-feet (2/3 of the 120,000 acre-foot target) of water that will already be stored in the SAWS ASR at the time of HCP implementation in combination with new water from two sources. One-third of the planned 50,000 acre-feet of new water (16,667 acre-feet) would be leased immediately with the remaining injection water being obtained from leases obtained as the Drought of Record nears. The 50,000 acre-feet target for modeling would still be utilized and its need further investigated through Adaptive Management and model feedbacks.

The combination of new water and SAWS water will meet the requirement for injection water if the drought of record arrives, and causes less disruption to the water market and the agricultural industry during the period of Adaptive Management.

Fifty Thousand Acre-Feet of Leased Water to Fill the ASR

The 50,000 acre-feet of leased water that is included as part of the SAWS ASR activity is not required to fill the ASR. SAWS has sufficient water rights during the period of the HCP (15 years) that the topping-off could be accomplished with SAWS rights. The significance of the 50,000 acre-feet is more for its impact for contributing to spring flow as a reduction in pumping during the drought of record.

HDR reports that approximately half of the impact on spring flow for the project is credited to the fact that this water is not being pumped except to refill the ASR.

This proposal attempts to duplicate the spring flow impact of the original SAWS ASR activity modeled by HDR in a manner that reduces costs and disruption to both by managing the leasing in a different manner than was originally visualized.

One-third of the 50,000 acre-feet of water will be leased with the implementation of the HCP. The second-third will be leased when the "10-year Rolling Recharge Average" reaches 572,000 acre-feet and the third portion will be leased when and if the average reaches 450,000 acre-feet. To insure that the water is available, options at $40 per year will be purchased with $150 per year paid when the options are called in.

The leases will be for five years with an option to extend for an additional five years. This system will allow the water to be used for ASR topping-off if necessary and will allow the water to be unpumped when SAWS ASR is returning water to SAWS during the drought of record.

It is believed that the majority of the spring flow impact from retirement of the 50,000 acre-feet occurs during the drought of record. Because of the "Enhanced Pumping" phenomenon, impact is minimal when the Edwards Aquifer is at Stages 1, 2, 3 and 4 levels or greater.

Costs

The SAWS ASR cost in excess of $250 million to construct. The SAWS ASR activity of the EARIP calls for use of approximately 2/3 of its capacity. Depreciating the asset over 52 years provides for $4.8 million depreciation per year. Two-thirds of that amount is $3.216 million.

Yearly maintenance costs, if the SAWS ASR is in a relaxed injection mode, are $2 million. During the drought of record "topping off" and pumping period costs will increase significantly, largely due to electric costs. The costs to inject an extra 160,000 acre-feet and pump back 126,000 acre-feet during the seven years drought of record period would be approximately $28 million. This would be costs in excess of the $2 million per year.

If only one drought of record occurred in the next 52 years (probability less than 0.03% over 15 years) the share of the maintenance cost due to the EARIP commitment would be $1.33 million due to 2/3 of regular costs and an extra $.54 million per year to pay for the reserve necessary to address a drought of record. Adding a second drought of record would increase the reserve to $1.08 million per year.

The SAWS ASR Project also calls for the leasing of 50,000 acre-feet of water to fill the SAWS ASR prior to the drought of record and to refill it after the drought of record. The cost of that water would be $6,250,000 at a lease price of $125 per acre foot per year.

The $6,250,000 per year has been identified to lease water in order to fill the ASR prior to its need for the drought of record. In the scenario where 16,667 acre-feet is immediately leased and the remaining 33,333 acre-feet is optional at $40 per year to be leased for 10 years when the drought of record is identified at $150 per acre-foot, remainder is leased as the arrival of the drought of record is identified by the 10-year recharge average, $3,351,625 per year would be accumulated until it reaches $50,250,000 (15 years), the estimated cost to lease the additional 33,333 acre-feet of Edwards water identified for filling the ASR in the modeling.

At that point, if the drought of record is not imminent, the collection of the $3,351,625 can be discontinued until the drought of record arrives. This arrangement can be altered as part of the Adaptive Management decision making process.

Note: At a lease price of $125 per acre-foot per year, the initial 16,667 acre-feet would cost $2,083,375 per year. The water obtained at the 572,000 acre-feet 10-year recharge target would cost $150 per year per acre-foot and the 16,667 acre-feet leased at 450,000 acre-feet 10-year recharge target would cost $150 per acre-foot. The water would be leased for 10 years during a drought of record. Total additional costs of that water would be $50,250,000 per Drought of Record.

If two occurrences of the drought of record are planned for in 52 years as per the costing analysis described, the cost would be $100,500,000 for the extra leased water to reach the 50,000 acre-feet identified in the HDR analysis.

With depreciation at $3.22 million, O&M at $3.08 million and water costs at $6.25 million per year, the SAWS ASR Project would cost $12.55 million per year.

Adaptive Management

The SAWS ASR activity as described lends itself to the Adaptive Management approach in several areas including management, water supplies and cost in addition to the primary issue of providing a certain amount of water for enhanced spring flow at Comal and San Marcos Springs.

APPENDIX T:

EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM CONSERVATION WORK GROUP, "WHITE PAPER – WATER CONSERVATION PROGRAM," AUGUST 31, 2010

ATTACHMENT 2

WHITE PAPER –WATER CONSERVATION PROGRAM

Developed by the Conservation Work Group
August 31, 2010

The Edwards Aquifer Recovery Implementation Program (EARIP) stakeholders have expressed interest in including a Water Conservation Program (WCP) as part of the proposed Habitat Conservation Plan (HCP).

The communities and industries in the Edwards Aquifer region have had considerable success in reducing water use. Several local conservation efforts have received state and national recognition. Despite the overall and specific success, the stakeholders recognize opportunities for more savings in most phases of water use. The EARIP appointed a Conservation Work Group to explore water conservation potential for small water communities and water systems and the agricultural sector.[1] The goal was to identify the potential for conserved water to serve as "trade-off" water for the EARIP for use in the proposed Habitat Conservation Plan or long-term adaptive management actions. Opportunities for water savings were especially noted in: residential uses of exempt wells; "lost water" through municipal infrastructure deficiencies; agricultural irrigation; industrial and commercial processes; rural and small community residential plumbing technologies; excessive landscape watering and failure to effectively utilize gray water; and condensate and rain water harvesting for landscape uses. The work group also proposed a voluntary, temporary, term-based program for conserving existing surplus or excess water of water suppliers as part of the WCP.

As proposed by the work group, the EARIP Water Conservation Program could be organized into four components to address the identified conservation opportunities:

I. A Best Management Practices Program for water systems. Small municipal or private water purveyors would contract with a large water purveyor such as the San Antonio Water System (SAWS) to utilize all or portions of an existing best management practice implementation structure.
II. A Technical Assistance Program for water systems. Technical assistance coordinated by the Edwards Aquifer Authority (EAA or Authority) with the cooperation of the staff of the large water purveyors – San Antonio Water System, Bexar Met, San Marcos, and New Braunfels would be provided to help water systems to perform audits, determine and address water loss, and implement programs aimed to reduce waste and encourage conservation.
III. An Agricultural Irrigation Improvement Program. Water savings would be achieved by enhanced irrigation conservation practices funded by cost-sharing through participation in the Natural Resources Conservation Service (NRCS) Agricultural Water Enhancement Program (AWEP).
IV. A Voluntary Dedicated Water Supply Program. Water purveyors with unused Edwards Aquifer inventory derived from conservation or from secured future water supplies may voluntarily dedicate an amount of water as unavailable for pumping for a temporary

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[1] The EARIP Conservation Work Group members are Carl Adkins, Colette Barron Bradsby, Jim Bower, Tyson Broad, Calvin Finch, Javier Hernandez, Rick Ilgner, Annalisa Peace, Humberto Ramos, and Adam Yablonski

period. The dedicated water remains in the aquifer and is intended to benefit the endangered species.

SECTION I – BEST MANAGEMENT PRACTICES PROGRAM FOR WATER SYSTEMS

This portion of the WCP uses existing conservation tools, namely, identified Best Management Practices (BMPs), developed by large water purveyors and replicates them for smaller municipal or private water systems. As an example, the San Antonio Water System offers various parts of its conservation program to subscribers on a menu basis. The water purveyors take advantage of the purchasing power of SAWS for high efficiency toilets, showerheads and other items. The contract also may include education services, leak detection and conservation auditing. Costs are assigned based on SAWS' costs for the materials and administration of the program. Funding may be provided to participating entities to implement BMPs or other conservation services. To provide an example of conservation tools and costs, below is a sample menu of available services and BMPs offered by SAWS:

Water Conservation Partnership
Proposal for Universal City
DRAFT

Service/BMP #	Scope of Service	Cost
School Education BMP # 6	SAWS curriculum and classroom services are offered to schools in the partner's area. A monthly report is prepared to record services delivered. Partner may designate two special education events (1 day each) per year.	Subscription Fee ($1,200/month)
Public Information BMP #5	SAWS public information efforts that cover the partner's area are recorded in a monthly report. The partner's name will be mentioned in the media when appropriate. SAWS personalities will be available for area events.	Covered by Subscription Fee
Conservation Coordinator BMP #8	Part of the time of a senior SAWS Planner (III or IV) will be designated to supervise the production of the Conservation plan and reporting to EAA. Time available to meet with partner staff, Board, or EAA once/month.	Covered by Subscription Fee
Residential Water Use Survey BMP #11	SAWS staff will conduct interior and/or landscape surveys for partner in same way they are conducted for SAWS customers. The surveys will be scheduled by the partner on a designated day/month or period/year for efficiency.	$24/survey
Small Landscape Incentives BMP #15	Bexar County Master Gardeners or another S AWS contractor will review the application and inspect the work. The partner may use the SAWS application and literature handouts.	$60/rebate
Cooling Tower Audit BMP #NA	A SAWS contractor will conduct scheduled audits for the partner	$2,400/audit
SIP (ET) BMP #NA	The partner has SIP kits available at the City or utility offices and for special events. The kits must be purchased in groups of 50.	$3.60/kit
Low-Flow	The partner may take advantage of SAWS' low-flow	$60/toilet

Toilets BMP #12	toilet contracts. SAWS will arrange the delivery of the toilets to designated site in units of 10 or more.	
Showerhead & Flow Restrictors BMP #12	The partner may take advantage of SAWS' showerhead and aerator contract. Kits will be delivered in units of 50 or more.	$3.60/kit
Leak Detection BMP #1	The partner may schedule days of water line survey or to detect the exact location of suspected leaks.	$1,000/day

SECTION I I– TECHNICAL ASSISTANCE PROGRAM FOR WATER SYSTEMS

In many cases, small water purveyors within the Edwards Aquifer region lack the funding, staff and experience to implement a successful water conservation program and/or properly account for water use throughout their distribution system. To assist these small water purveyors, the Edwards Aquifer Authority, along with experts from organizations such as the Texas Water Development Board, Alliance for Water Efficiency, and large water purveyors, will be available to offer technical support when needed. In addition, this group will convene periodically to discuss key conservation issues and organize workshops focused on the implementation of conservation programs. Group discussion attendees can review successes, failures and technical issues related to the implementation of conservation programs in an open forum. The Edwards Aquifer Authority will promote the program to small water purveyor permit holders. The Authority will coordinate meetings and workshops to discuss topics such as:

1. How to properly perform a system water audit.
2. How to identify causes of lost water.
3. The importance of a water meter replacement program.
4. How to implement and enforce water waste prohibition measures.
5. How to implement a plumbing retrofit program or a conservation kit distribution program.
6. How to implement a school and public education program.
7. How to implement a landscape irrigation survey program.
8. How to implement a conservation pricing structure.

In addition to coordinating meetings and workshops, the Authority will identify experts who are willing to share their expertise and first-hand knowledge on such topics as water audits, leak detection and other conservation best management practices. The Authority could put small water purveyors in contact with identified experts upon request.

Through this technical assistance group, there may be an opportunity to combine efforts to negotiate lower prices per unit for ultra low-flow toilets and conservation kits. These efforts could allow small water purveyors to maximize their funds.

The Authority would be responsible for the organization of the Technical Assistance program. However, there would be a heavy reliance on industry experts and organizations with first-hand knowledge. It is believed that staff from large water purveyors would be willing to participate in this program if this activity was identified as an EARIP activity to be included in the HCP or Implementation Plan. A funding source will need to be identified for potential expenses such as meeting room rental and expert services.

SECTION III – AGRICULTURAL IRRIGATION IMPROVEMENT PROGRAM

Through the Agricultural Water Enhancement Program (AWEP), the Natural Resources Conservation Service (NRCS) partners with a local political subdivision or entity to provide financial and technical assistance to farmers and ranchers to assist them in applying agricultural water enhancement activities that conserve ground and surface water and improve water quality on agricultural lands. AWEP provides a 70% cost share basis for conservation practices that will contribute to an improvement in an identified resource concern. Conservation tillage, irrigation scheduling, and brush control may also be eligible for AWEP funding. The Conservation Work Group found that replacement of existing pivot systems may actually provide a higher conservation savings per dollar than replacement of furrow irrigation with pivot or drip irrigation systems. The installation of efficient irrigation systems, which have the potential to conserve water for the duration of the HCP and beyond, are of mutual interest to the NRCS and the EARIP.

As part of the proposed Water Conservation Program, the EARIP would apply to NRCS to administer and monitor an AWEP for the Edwards Aquifer region. In the grant application, the EARIP and NRCS would highlight the nexus between conserved agricultural water and water made available to contribute to endangered species protection. The targeted activities for the AWEP part of the WCP include replacement of older, inefficient pivots with higher efficiency, low pressure pivots; and conversion of furrow/flood irrigation to more efficient center pivot, lateral pivot, or drip irrigation systems. AWEP would provide 70% of installation cost for each project, and the EARIP would provide the remaining 30% of the cost. In return, the irrigator would be required to leave half of the water conserved in the aquifer, neither marketed nor pumped, for ten years.

The estimated cost to the EARIP would be $3,900,000. Approximately 8,250 acre feet of water would be conserved, of which 4,125 acre feet would be required to remain in the aquifer. To assess the potential for regional agricultural conservation, the Conservation Work Group reviewed the following information from the Medina and Uvalde county NRCS offices:

	New Irrigation Systems Installed (last 5 years)	Acres Irrigated by New Irrigation Systems (last 5 years)	Acres remaining in flood irrigation or inefficient pivots (NRCS Estimate)
Medina County	50	8,192	20,000
Uvalde County	94	8,507	13,000
Total	144	16,699	33,000
Yearly Avg. for both counties	29	3,339.8	

- New Irrigation Systems Installed includes all permanent irrigation systems (center pivots, lateral pivots, and drip/micro irrigation) installed either on furrow irrigated land or as replacements for older, inefficient systems under the Environmental Quality Incentives Program (EQIP). They do not include systems installed without NRCS assistance.
- The average increase in irrigation efficiency is estimated to be 30% - 35%.
- The average increase in efficiency and the Acres Irrigated by New Irrigation Systems do not include the dry-land corners that are created by putting a circular pivot in a square field. Typically, this situation results in 75% of the field under the pivot, and 25% in non- irrigated corners.
- The acres remaining in flood/furrow irrigation and inefficient pivots are estimated because not all farmers choose to participate in NRCS/FSA programs and provide their information. EAA records may be used to refine these numbers, but estimates by NRCS staff are reasonably accurate and provide a good starting point.

If the trends demonstrated over the last five years continue, it is expected that approximately 3,300 acres per year will be converted to more efficient irrigation systems. Over five years this will add up to 16,500 acres, which is also half of the NRCS estimate for the land remaining in inefficient irrigation. Since the NRCS will continue to offer EQIP, which provides 70% cost assistance, it is likely that some irrigators may choose to participate in EQIP and not an AWEP that may place additional requirements on participants. It is equally likely that, since EARIP will be offering 100% cost assistance, the EARIP effort will attract some new irrigators who have not been able or willing to pay their 30% of the cost. The Conservation Work Group believes it is reasonable to assume that at least half of the remaining 33,000 acres in Medina and Uvalde counties will be converted to more efficient irrigation systems in five years through the AWEP.

Currently EQIP provides 65%-70% estimated cost share of a pivot at about $37.20 per foot. This means that the full cost of the pivot is estimated to be about $55 per foot. This figure does not include the cost of underground pipe at an estimated cost of $10 per foot. Not all systems will require a new pipeline, but other systems will require a very long pipeline, depending on their distance from the well. This works out to about $700 per acre for a 120 acre circular pivot.

Assuming one foot of base irrigation water remains for irrigation, and assuming irrigation efficiency increases from 60% to 90%, 1/3 acre foot of water will be conserved for every acre converted to more efficient irrigation. In addition, dry-land corners will conserve water at a full acre foot per acre. For a 120 acre circular pivot, this works out to 40 acre feet conserved under the pivot and 40 acre feet conserved on the corners, for a total of 80 acre feet conserved.

If 16,500 acres were converted from furrow irrigation to circular pivots, the total cost would be $11,550,000, and 11,000 acre feet of water would be conserved. This is, of course, assuming absolutely ideal conditions. Installation costs per foot for circular pivots are likely to increase. Not all pivots will be able to make perfect circles, which makes the cost per acre rise. Drip systems have a higher cost per acre than pivots. Linear pivots and drip irrigation typically don't have any dry-land corners associated with their installation, which would cut down on the amount of conserved water. More realistic numbers might be $13,000,000 and 8,250 (75% of 11,000) acre feet conserved.

AWEP would provide 70% of the funding. Under the proposed plan, the EARIP would provide an additional 30% of the funding, or $3,900,000. In return, irrigators would be required to leave half of the conserved water, 4,125 acre feet, not to be pumped for a period of ten years. This works out to a cost of $945.45 per acre foot to the EARIP.

SECTION IV – VOLUNTARY DEDICATED WATER SUPPLY PROGRAM

Component 1 – Purveyor Surplus Water Supplies

Water purveyors that have extra water supplies for a specified period of time due to water conservation or secured future water supplies may voluntarily dedicate an amount of water to the EARIP that would be unavailable for pumping for a set time period.

This part of the WCP would have water purveyors inventory their supplies in relation to demand and identify the surplus that exists for some number of five year blocks. A purveyor may then commit to not pump the identified water for the period specified. The dedicated water stays in the Edwards Aquifer to provide springflow. This commitment of surplus water is included in the HCP and allows modeling to occur at a reduced pumping level for the specified committed period. The purveyor retains ownership and has the water available for growth needs beyond the committed water.

It is anticipated that large and small purveyors will be attracted to participate because the conserved water will support the EARIP goals and objectives and will reduce the need for certain expensive engineered solutions. Benefits of the conserved water supply program are that it can be implemented immediately, and it would allow for an adaptive management period to test the capability of critical period rules, the dry year option, SAWS Aquifer Storage and Recovery systems, land stewardship and other activities intended to maintain springflow for the endangered species before expensive engineered solutions must be implemented.

Based on preliminary discussions with water purveyors, it is believed that at least 10,000 – 15,000 acre-feet of surplus water is available for the WCP for a period of 10 – 15 years.

Component 2 – Organizing a SAWS type Water Conservation Program for the Region

This component envisions building on the success of the SAWS Conservation Program to implement conservation activities throughout the region. To accomplish this component a number of questions would have to be answered.

1. How much water is available to be conserved?
2. Which activities would be used to conserve the water and how much would they cost?
3. How would water savings accomplished through the activities be translated to springflow to benefit the endangered species?
4. How would the program be organized?
5. How would a Water Conservation Program built on the SAWS model be administered and funded?

1. How much water is available to be conserved?

The expectation is that water entities that have implemented water conservation efforts with results equal to or greater than SAWS has achieved would not participate in the conserved water portion of the EARIP Water Conservation Program. These entities include Bexar Met, San Marcos, and New Braunfels water utilities. However, if one or more of these entities could utilize available funding to achieve additional conservation, they may seek to participate in this program. The EARIP decision to fund participation would have to take into consideration total available budget, estimated costs and expected results. It is possible, for example, that one or more of the large utilities may have a "lost water" condition that could be addressed. To be conservative in projections of participation, the work group initially subtracted these four large water purveyors from the universe of potential conserved water savings. Additionally, the group did not include agricultural irrigation as a source of savings.

The work group estimated that Edwards Aquifer area communities and industries utilize approximately 500,000 acre-feet of water and production agriculture uses approximately 40% of that total, leaving 300,000 acre-feet for all other users. Subtracting the supplies of the four largest water purveyors (SAWS – 200,000 acre-feet, Bexar Met – 32,000 acre-feet, San Marcos – 1,400 acre-feet and New Braunfels – 3,000 acre-feet)produces leaves an amount of approximately 65,000 acre-feet per year for targeted water conservation. Based upon Region L Water Planning Group statistics for water use, the work group found it reasonable to assume that per capita water use for the target population is approximately 140 gallons per person per day, which is about 10% greater than SAWS' high water demand goal of 126 gallons per capita per day. This rough calculation identifies the available water to be saved at about 6,500 acre-feet.

Exempt Wells and Small Residential Well Systems- Reduction in Edwards Aquifer pumping

The EAA reports that exempt wells pump approximately 14,500 acre-feet of Edwards' water. The 14,500 acre-feet was included in the estimated 65,000 acre-feet total identified for conservation savings. With no city or large utility to serve as a mechanism to secure funding assistance or guide conservation practices, individual well owners and small residential well systems have likely been lagging in water conservation. Individual wells are also not subject to mandatory conservation or drought management programs. Program sponsors are needed to access the individual and small system pumpers and to properly monitor and credit associated water savings. The work group discussed working through the EAA, counties, or non-profit organizations to provide conservation education to well owners and serve as a funding pass through organization to provide financial assistance for things such as water and energy efficient plumbing fixtures and appliances and rainwater collection systems. Financial support through the EARIP would require that 50% of the conserved water remain in the aquifer for a set period of time.

2. Which activities would be used to conserve the water and how much would they cost?

The work group believes that the use of Best Management Practices to produce structural changes that result in permanent savings would be the easiest to monitor and document. Conservation audits are effective in reducing water use up to 20% in the average house audited but the results are harder to measure and are more likely to be more temporary.

Other education methods targeting behavior change are also hard to document savings but are important to complement the structural changes.

Examples of such structural BMPs include:

High efficiency toilets
Industrial processes
Commercial processes
Infrastructure improvements ("lost water")
Condensate, rain water harvesting and gray water for landscape watering

Based upon SAWS' experience with specific structural programs – namely, the use of high efficiency toilets, showerheads and faucet aerators, and an industrial/commercial rebate program, reasonable costs and water savings can be projected. SAWS' overall cost per acre-foot of water saved is approximately $500. Also based on SAWS' experience, it is assumed that leak detection and other activities to eliminate "lost water" will deliver results at $500 per acre-foot.

Details of the costs and savings experienced by SAWS are as follows:

High Efficiency Toilets - Each old toilet that is replaced in a home saves 12,500 gallons per year on average. More water is saved for old toilets replaced in schools and commercial establishments such as restaurants. Each toilet conversion saves .04 acre-feet per year. Once an old toilet is replaced, the savings are permanent because all new toilets are now more water efficient than pre-1992 toilets. The Caroma two speed high efficiency toilet distributed by SAWS costs the utility approximately $100 per unit.

High Efficiency Showerheads and Faucet Aerators - Replace showerheads and faucet aerators in a typical household and 10,500 gallons per year is saved. The fixture generally last for 10 years and providing one set of showerheads and faucet aerators to a household costs $6.

Industrial and Commercial Process Rebates – In this program, SAWS pays 50% of the cost of technological changes that save water up to $400 per acre-foot saved over 10 years. SAWS spends approximately $500,000 per year on this program, although the budget is limiting in some years. The funds are spent on small items such as using air cooled ice machines and efficient dish rinsing apparatus and large items such as the implementation of water recycling systems for microchip manufacturing.

Gray Water, Rain Water Harvesting and Condensate Collections - The idea of reducing potable water use for landscape watering by utilizing gray water, rain water harvesting and condensate collection has been an attractive option for some water uses. It is believed that homeowners and businesses would retrofit their structures to collect the water for use on landscapes. Unfortunately, the water savings accomplished by such systems are not as cost effective as other conservation activities; an investment of $500 would not usually result in a savings of an acre-foot of water. The work group proposes that program participants must agree to temporarily (perhaps 15 years) retire one acre-foot of water for every $1,000 rebate

offered by the program even if a $1,000 investment on their part would not result in two acres of water saved.

Based upon SAWS data, the economic return for inclusion of technology to capture and use rain water, gray water and condensate in new construction is greater than the return from retrofitting a structure. Benefits of new technology could be expanded if local communities would require, by ordinance, that new development or construction include such technology.

Leak Detection (Lost Water) - One of the most desirable ways to conserve water is to reduce the "lost water" that occurs in the transmission and distribution of water by water purveyors. Water losses hurt the bottom line of water providers and result in wasting a scarce resource. SAWS has reduced its lost water amount from approximately 25% in the 1980's to about 8% at the present time. It is believed that many water purveyors in the Edwards Region have lost water ratios of 15% or greater. If the small water purveyors targeted by this activity pump approximately 65,000 acre-feet and average a 15% lost water ratio, the lost water would approximate 9,750 acre-feet. If the program goal was to reduce lost water to 10%, the water conserved would total 3,250 acre-feet. SAWS' experience with leak detection indicates that it is reasonable to expect that lost water can be reduced at the cost of $500 per acre-foot.

3. How would water savings accomplished through a SAWS type program be translated into springflow to benefit the endangered species?

The most reasonable way to translate the conserved water into springflow appears to be to subsidize the conservation activities and receive in return a commitment from the benefactor of the subsidy to reduce the subject Edwards' pumping by a portion of the water saved. If the commitment amounts to 50% of the water saved for a period of 15 years, the cost per acre-foot of the program would be approximately $1,000 per acre-foot. It seems likely that the participant would agree to the idea of receiving half of the saved water immediately and half after 15 years.

4. How would the program be organized?

The program would target the water pumped by small non-agricultural pumpers in the Edwards' Region, an amount assumed to be approximately 65,000 acre-feet per year.

The program would subsidize conservation activities in the five categories described below and based upon the SAWS program. In return, the entity sponsoring the conservation activity (water purveyor, local government, Edwards' permit holder, etc.) would commit to reduce Edwards' pumping by 50% of the savings achieved (more for the gray water, rain water harvesting, and condensate collection activity) for 15 years through a contract with the Regional entity. Fifty percent of the water saved would be available to the purveyor for growth immediately and the other 50% would be available after 15 years.

a) Target 24,000 high flow toilets in the Region
   Cost over 10 years at $150 per toilet will be ≈ $3.6 million
   Savings – 12,500 gallons per year = 918 acre-feet per year
   Reduced pumping equals 50% of savings = 459 acre-feet per year

b) Target 24,000 homes in the Region to receive efficient showerheads and faucet aerators at $6 per home. The total cost would be $144,000 and 798 acre-feet of water would be saved (10,500 gallons per home). If 50% was committed to reduced pumping, it would be 394 acre-feet.

c) Target a reduction of "lost water" from 15% to 10% for a savings of 3,200 acre-feet at $500 per acre-foot.

Fifty percent of the savings would equal 3,250 acre-feet per year which would be 1,625 acre-feet of less pumping for 15 years.

d) Target 1,000 acre-feet per year savings through a large scale retrofit program.

At $500 per acre-foot that would cost $500,000. The savings would translate into 500 acre-feet less pumping for 15 years.

e) Target a savings of 1,000 acre-feet of landscape watering savings through use of gray water, rain water harvesting, and condensate at $500 per acre-foot for a cost of $500,000.

Savings could be achieved by providing rebate for conversions; rebate for new construction and ordinances that require use of gray water, condensate and/or rain water harvesting.

Fifty percent of the savings would be 500 acre-feet per year for a reduction in pumping of 500 acre-feet per year for 15 years.

Total approximate budget:	Total Water Savings	Temporary Pumping Reductions
Toilets - $3.6 million	918	459
"Lost Water" - $3.25 million	3,250	1,625
Large Scale Retrofit - $500,000	1,000	500
Rain water – $500,000	1,000	500
Shower Heads & Faucets - $144,000	798	394
$7.99 million	6,966	3,478

5. How would a Conservation Program built on the SAWS model be administered and funded?

A regional conservation program could be administered by a subcontractor through a contract with the EAA that would directly contract with Edwards' permit holders or the customers of Edwards' permit holders.

Funding would best be accomplished by a region wide sales tax. A secondary option may be an Edwards' Conservation fund fee of $5 per acre-foot of Edwards' permitted supplemented by a matching amount of legislated funds to represent a downstream contribution.

Scaling up or down:

50% of water saved becomes permanent pumping reduction

- More pumping savings but entities are less likely to participate

50% of water saved is not pumped for 25 years instead of 15 years

- More pumping savings but entities are less likely to participate

Increasing rebates

- Entities are more likely to participate but funding becomes a more difficult issue

Component 3 – Combining Component 1 and 2

Component 1, "Dedicated Purveyor Surface Water Supplies" could be operated as an HCP activity by itself.

It is believed that somewhere around 15,000 acre-feet would be available for a period of 10 – 15 years. Such a commitment would reduce the period of time that Senate Bill 3 modeling would show springflows at Comal County at 30 cubic feet per second or less.

Another option would be to link Component 1 with a Regional Water Conservation Program (Component 2) on the SAWS model to achieve a 25-year reduced pumping commitment. Limiting the program to the smaller water purveyors and exempt wells would limit the water savings possible to about 3,483 acre-feet. If the program was opened to Bexar Met, New Braunfels, San Marcos and SAWS, it is believed the program could reduce pumping by 10,000 acre-feet. The Combined Conserved Water Option to follow presents such a program.

Combined Conserved Water Option - 10,000 acre-feet for 25 years

A more ideal situation would be if 10,000 acre-feet of dedicated water supply could be matched to conservation savings of 10,000 acre-feet for a commitment of reduced pumping over a 25-year period. The 10,000 acre-feet of excess water for the first 15 years appears available but, without including Bexar Met, SAWS, San Marcos and New Braunfels, it appears that a total of conserved water any greater than 3,483 acre-feet will be difficult to achieve. To derive the greatest benefit to the EARIP by achieving up to an additional 6,627 acre-feet of committed water savings, the program would need the participation of the four large water providers.

The option that follows reflects a 25-year, 10,000 acre-feet Conserved Water Program that could include the voluntary participation of SAWS, Bexar Met, San Marcos and New Braunfels:

a) Target 80,000 high flow toilets in the Region
   Cost over 10 years at ≈ $150 per toilet ≈ $12,000,000
   Water savings – 12,500 gallons per year per toilet = 3,062 acre-feet
   Reduced pumping at 50% of savings = 1,531 acre-feet

b) Target 80,000 homes in the Region for replacement of inefficient showerheads and faucet aerators at $6 per home cost would be $480,000
   Savings at 10,500 gallons per home would be 2,572 acre-feet

Reduced pumping at 50% of savings = 1,286 acre-feet

c) Target a reduction of "lost water" from 15% to 10% for a savings of 7,500 acre-feet at $500 per acre-feet saved

d) Target 5,000 acre-feet of savings through a large scale retrofit program
At $500 per acre-foot the program would cost $2.5 million
Savings would translate to 2,500 acre-feet less pumping for 15 years

e) Target a savings of 2,000 acre-feet of landscape watering savings through use of gray water, rain water harvesting and condensate at $500 per acre for a cost of $1 million.

Savings could be achieved by providing a rebate for conversions and/or new construction. The new construction can be through voluntary action or as a result of an ordinance requirement.

Fifty percent of the savings would be 1,000 acre-feet per year of pumping reductions.

Total Cost:	Total Water Savings	Pumping Reductions
Toilets - $12 million	3,062	1,531
Lost Water - $480,000	2,572	1,286
Large Scale Retrofit - $7.5 million	7,500	3,750
Rain water – $2.5 million	5,000	2,500
Shower Heads & Faucets - $1.0 million	2,000	1,000
$23.48 million	20,134 acre-feet	10,667 acre-feet

APPENDIX U:

EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM ECOSYSTEM RESTORATION SUBCOMMITTEE, "HIGH PRIORITY RESTORATION AND MITIGATION ACTIONS FOR THE COMAL AND SAN MARCOS SPRINGS ECOSYSTEMS," SEPTEMBER 2010

High Priority Restoration and Mitigation Actions for the Comal and San Marcos Springs Ecosystems

Edwards Aquifer Recovery Implementation Program
September 2010

Prepared by:
Ecosystem Restoration Subcommittee

Submitted to:
Steering Committee of the Edwards Aquifer Recovery Implementation Program

Program Director Gulley and EARIP Steering Committee Members,

The Ecosystem Restoration Subcommittee was asked to revisit previous restoration and minimization reports relating to the Comal and San Marcos Ecosystems, and provide details relating to those restoration actions.

Actions were evaluated based on the following criteria:

- Feasibility of implementation of restoration/mitigation action
- Cost/benefit analysis of restoration/mitigation action
- Direct benefit resulting from the restoration/mitigation action to the endangered species

Consultation and review of the following selections and establishment as high priorioty action items was approved by consensus of the EARIP Ecosystem Restoration Subcommittee, with input and review by the United States Fish and Wildlife Service, the United State Army Corp of Engineers, Texas Parks and Wildlife Department, and other environmental organizations and interests.

The submitted report includes additional details related to the implementation and cost of the previously identified restoration and mitigation actions. Where possible, specific locations and methods for implementing the actions are identified. However, the specific details of implementing most, if not all, of the actions will require further consultation with federal and state entities. Similarly, the cost estimates established by the subcommittee are intended only to establish the scale and magnitude of cost and actual cost may vary greatly at the time of implementation. Additionally, many of the restoration actions require annual costs, which may be largely dependent on the initial success of the proposed action and are thus difficult to estimate. A very broad estimate of all the restoration packages follows in table form but does not include IMa's, snail removal, or LID incentives (estimates for these recommended actions could not be established).

	One-Time Implementation $$	Annual On-Going $$/yr
San Marcos	$5,181,000.00	$541,000.00
Comal	$2,035,000.00	$490,000.00
Total	$7,216,000.00	$1,031,000.00

Consideration should also be given to the timing and sequencing of the restoration actions as certain actions may be complimentary or may be combined to save money and reduce negative impacts to the habitats. For example, the removal of non-native vegetation in the San Marcos River may be achieved more efficiently and with less disturbance to the habitat if all identified non-native species were removed simultaneously rather than individually.

It is important to note that while the below restoration and mitigation actions were identified as the top priorities with the greatest direct benefit to the listed species, this listing and prioritization is not meant to detract from the importance of all the restoration and mitigation actions identified

in the previous reports as low or medium priority. The importance of a particular action, regardless of its assigned prioritization, may change in response to future conditions or changes to the ecosystem. Thus, all of the restoration and mitigation actions identified in the totality of all reports should be considered in the HCP or as components of adaptive management to more completely reach the goal of restoring the habitats and recovering the listed species.

Respectfully,
Nathan Pence
EARIP Ecosystem Restoration Subcommittee Chair

High Priority Restoration and Mitigation Actions for the Comal and San Marcos Springs Ecosystems

	Restoration Action	Issue or Problem Addressed	Approved by Steering Committee at 03/12/2010 EARIP Meeting	Adaptive Management or Restoration/ Minimization	Method of Implementation and Frequency	Estimated Cost Must give exact $ figure and method used to determine	Direct Benefit to Listed Species	Potential Negative Impact	Additional Comments
San Marcos River	Protection of Texas wild-rice (Zizania texana) Access and Exclusion Zones, Floating Vegetation Removal, and Sedimentation Removal	Currently, recreational access is not controlled and Texas wild-rice stands are trampled and uprooted during access in shallow areas of the river	X	Restoration and Minimization	Permanent access should be located at dog beach, Lion's Club Tube Rental, Bicentennial Park, Wildlife Annex, and potentially other areas. Areas between access points should be planted with vegetation that discourages streamside access (i.e. prickly pear, blackberry brambles). Additionally, instream exclusion zones should be established, perhaps through the State Scientific Area designation. Kiosks showing access points, exclusion zones, and associated educational components should be installed at key locations	**One-Time Implementation Cost: $375,000** 5 sites x $75,000/site = $375,000. Includes limited walkways and stairs, bank stabilization, and signage. Additional costs would be an extra $50,000 for educational signage and exclusion zones for Texas wild-rice **Long-Term Annual Cost: $20,000/yr**	Reduces stress and mortality to Texas wild-rice	Increased impervious cover and reduced recreational access	State Scientific Area Designation is dependent upon approval from TPWD Commission. Stakeholder involvement is critical. U.S. Army Corps of Engineers is currently working with the City of San Marcos to determine the feasibility of this project. For success, enforcement is essential
		Floating vegetation causes direct mortality of Texas wild-rice by contributing to low light levels, smothering plant stands, and inhibiting flowering	X		Floating vegetation mats could be either pushed downstream out of listed species critical habitat or physically removed from the system. Mats should be pushed or removed two times a week during the recreation season and monthly during offseason	**One-Time Implementation Cost: $80,000** Pushing plants downstream currently costs the City of San Marcos $20,000 per year for 1/4 mile of cleared river. Pushing mats from Spring Lake Dam downstream to IH 35, approximately 1 mile, makes our estimated project cost $80,000 per year. Removing mats would likely increase costs by at least four times this amount **Long-Term Annual Cost: $80,000/yr**	Reduces mortality to Texas wild-rice and increases sexual reproductive success	Pushing vegetation downstream sends mats to downstream locations. Removal causes loss of aquatic life. Potential trampling of aquatic plants and associated turbidity	Removal of floating debris over Texas wild-rice stands must have an approved protocol and be accomplished with permission of USFWS and TPWD
		Deposition of sediments on or around Texas wild-rice stands causes direct mortality by smothering or burying stands. Targeted areas should include Upper (upstream of University Drive) and Lower Sewell Park, at and downstream of the confluence with Purgatory Creek, the Hopkins Bridge area, and upstream of IH 35	X	Restoration and Minimization	Sediment may be removed by physical or mechanical methods. An underwater vacuum is one possible mechanical method. Any non-native vegetation that has established in these sediments should also be removed and Texas wild-rice established	**One-Time Implementation Cost: $500,000** Based on cost of Crypto removal and native reestablishment in the San Marcos River in 2008, the projected cost is $500,000 per mile of river restored. Thus, the estimated cost for our target areas is estimated to cost $500,000 **Long-Term Annual Cost:** Annual costs will be dependent upon sedimentation patterns. Estimated recurrence interval is 5-10 years, but is heavily dependent on timing of flood events	Reestablish Texas wild-rice habitat and stands	Disturbance to habitat and possible take of Endangered Species. Temporary water quality impairments	Removal of sediment must be accomplished with a USACE 404 and TPWD sand and gravel permit. U.S. Army Corps of Engineers is currently working with the City of San Marcos to determine the feasibility of this project. Sediment removal may be combined with non-native vegetation removal to save money and reduce impact to habitat
San Marcos River	Prohibition of hazardous materials routes that cross the River, springs, or associated direct tributaries	Roads that cross the San Marcos River are not identified hazardous materials routes, but hazardous materials are allowed to cross. A spill could be catastrophic depending on location	X	Restoration and Minimization	Work with TXDot to establish prohibited routes. Would require signage and legislation	**One-Time Implementation Cost: $10,000** Cost would include signage and possible costs incurred in the legal process **Long-Term Annual Cost: $0.** Minimal, if any	Prevent extinction of species and/or possible damage to habitat caused by a catastrophic spill	Could cause inconvenience through less direct routes	Work with TXDoT, Hays County, City of San Marcos, and state agencies to establish restricted zones, cost is to install signage and designate alternative routes
San Marcos River	Stop or limit introductions of non-native species by aquarium "dumps"	Citizens often dump their entire aquarium into the river when they no longer can keep the aquarium, thus introducing non-native species to the ecosystem		Restoration and Minimization	This action will be minimized through education (signage and brochures) and offering alternatives to citizens and students wanting to get rid of unwanted aquatic pets. The EARIP should consider partnering with the River Systems Institute, Texas State University and local citizen groups to help distribute educational materials. Partnerships with the school districts should also be considered. Signage should also be provided to local pet shops and bait shops	**One-Time Implementation Cost: $20,000** Costs in the first year for design of the campaign and printing of materials. With yearly costs for additional printing **Long-Term Annual Cost: $5,000/yr** For additional signage and continued education efforts	Reduce competition of non-natives on the listed species and reduce the introduction of "new" non-native species	None	Enforcement and education are key elements. One potential campaign and marketing resource could be Habitattitude (existing campaign by USFWS and NOAA)
San Marcos River	Stop or limit introductions of non-native species by the use of non-native bait species	The use of non-native species as bait can result in the introduction of "new" non-natives and potential new aquatic diseases		Restoration and Minimization	Establish local ordinance prohibiting the use of non-native bait species in the San Marcos Springs ecosystem. This action will be minimized through education (signage and brochures) and through the identification of native bait choices for citizens. The EARIP should consider partnering with the River Systems Institute, Texas State University and local citizen groups to help distribute educational materials. Partnerships with the school districts should also be considered. Signage should also be provided to local pet shops and bait shops	**One-Time Implementation Cost: $20,000** Costs in the first year for design of the campaign and printing of materials. With yearly costs for additional printing **Long-Term Annual Cost: $5,000/yr** For additional signage and continued education efforts	Reduce competition of non-natives on the listed species and reduce the introduction of "new" non-native species	Loss of revenue to bait shops and loss of bait choices for anglers	Enforcement and education are key elements. One potential campaign and marketing resource could be Habitattitude (existing campaign by USFWS and NOAA)
San Marcos River	Include private landowners (riverside and tributary) in riparian restoration	On private property, citizens often groom a yard right to the waters edge, reducing the natural ability of a riparian zone to filter runoff		Restoration and Minimization	As plans take shape for the reestablishment of the riparian zone, public stakeholder meetings should be held and land owners should be asked to participate in the plan. Reimbursement for the price of native plants should be provided to private landowners by the EARIP. A program should be developed including criteria to qualify and preferred natives to replant	**One-Time Implementation Cost: $10,000** Costs in the first year to reimburse landowners for native plants and to market the program to land owners. Funding for following years is dependant on participation and success of the program **Long-Term Annual Cost: $5,000/yr** Costs will decrease after the first few years as vegetation is established	Improved water quality through the natural ability of a properly functioning riparian zone	Temporarily increased turbidity during transplant process	There are several private residents and one commercial business on the San Marcos River that are between IH35 and Spring Lake. Should also focus on tributaries: Sessoms, Sink, Purgatory, and Willow creeks
San Marcos River	Restoration of riparian zone with native vegetation (public lands)	On public property (e.g. parks and golf courses), entities often groom property right to the waters edge, reducing the natural ability of a riparian zone to filter runoff. Other concerns include trampled banks that increase erosion and the establishment of non-native vegetation		Restoration and Minimization	As plans take shape for the reestablishment of the riparian zone, public entities should be asked to participate in the plan. Reimbursement for the price of native plants should be provided to public entities by the EARIP. A program should be developed including criteria to qualify and preferred natives to replant	**One-Time Implementation Cost: $100,000** Costs in the first year to reimburse for native plants and to market the program. Funding for following years is dependent on participation and success of the program **Long-Term Annual Cost: $20,000/yr** Costs will decrease after the first few years as vegetation is established	Improved water quality through the natural ability of a properly functioning riparian zone	Temporarily increased turbidity during transplant process	Establishment and width determination of buffer zone along rivers edge should be based upon best available science and should consider desired recreational access (see previous restoration action item involving Texas wild-rice and recreational access). U.S. Army Corps of Engineers is currently working with the City of San Marcos to determine the feasibility of this project around Spring Lake area

High Priority Restoration and Mitigation Actions for the Comal and San Marcos Springs Ecosystems

Restoration Action		Issue or Problem Addressed	Approved by Steering Committee at 03/13/2010 EARIP Meeting	Adaptive Management or Restoration/ Minimization	Method of Implementation and Frequency	Estimated Cost Must give exact $$ figure and method used to determine	Direct Benefit to Listed Species	Potential Negative Impact	Additional Comments
San Marcos River	Control of harmful non-natives: domestic waterfowl, tilapia (*Oreochromis aureus*), nutria (*Myocastor coypus*), armored catfish (family Loricariidae, *Hypostomus spp.* and *Pterygoplichthys spp.*), ramshorn (*Marisa cornuarietis*), *Melanoides tuberculatus*, hydrilla (*Hydrilla verticillata*), hygrophila (*Hygrophila polysperma*), elephant ears (*Colocasia esculenta*) and water hyacinth (*Eichhornia crassipes*)	Domestic Waterfowl are known to feed directly on Texas wildrice and the seedheads, which effect population size, reproductive success, and genetic variability	X	Restoration and Minimization	Selective netting and give aways to land owners, once a year after Easter. Control of non-natives will require annual efforts and non-natives should be disposed of out of the flood plain	**One-Time Implementation Cost: $20,000** The cost is largely labor associated with trapping the waterfowl and an educational campaign. Estimates per year are thought to be around $10,000 - $20,000 per year **Long-Term Annual Cost: $10,000/yr**	Reduces the loss of Texas wild-rice stands and seedbank	Public acceptance	City code should prohibit the feeding of wildlife, i.e. The River Pub and Grill sells duck food
		Tilapia are detrimental to the habitat of all associated endangered species		Adaptive Management	Tilapia are a tropical species that will congregate in winter near spring openings and other warm water sources. When the species congregate this creates the opportunity to use seines, gill nets, cast nets, or other methods to remove large quantities with minimal impact to the habitat. Artificial heating could be one method used to congregate fish in areas away from springs and endangered species to minimize the impacts from collection efforts. Initial efforts in year one should be intense and take place during the winters first freeze, with continued control every winter. Numerous removals during each winter would be most productive. Control of non-natives will require annual efforts and non-natives should be disposed of out of the flood plain	**One-Time Implementation Cost: $10,000** State and Federal agencies or Universities should be involved and would reduce the labor cost. Equipment costs are estimated near $10,000 for nets and other misc. gear. Artificial heating is very expensive. If heaters are used the price would greatly increase dependant on the size of heaters and water volume manipulated **Long-Term Annual Cost: $10,000/yr**	Removal primarily benefits the fountain darter. Non-native species compete with native species for resources and alter habitat among other issues. Specifically, tilapia destroy vegetation by making bare ground nests. During times of low flow and drought this could further reduce already limited habitat for the fountain darter	Collection efforts may impact fountain darters or their habitat. If electroshocking is used it is detrimental to the Fountain Darter and other species	
		Nutria feed directly on Texas wild-rice and the seedheads, which effect population size, reproductive success, and genetic variability	X	Restoration and Minimization	Texas Wildlife Services has an assistance program to assist with control of nuisance nutria. This is done once a year during the winter months. Control of non-natives will require annual efforts and non-natives should be disposed of out of the flood plain	**One-Time Implementation Cost: $1,000** Minimal Cost for bait and poison **Long-Term Annual Cost: $1,000/yr**	Reduces the loss of Texas wild-rice stands and seedbank	Public acceptance and secondary poison	The City of New Braunfels has had a successful program implemented since 2007
		Armored catfish control - Numbers of these non-natives are growing and are detrimental to the habitat of all associated endangered species. Armored catfish are herbivores and burrow into the sediment of banks and lake bottom	X	Restoration and Minimization	Armored catfish are a tropical species that will congregate in winter near spring openings and other warm water sources. When the species congregate this creates the opportunity to use seines, gill nets, cast nets, or other methods to remove large quantities with minimal impact to the habitat. Initial efforts in year one should be intense and take place during the winters first freeze, with continued control every winter. Numerous removals during each winter would be most productive. Control of non-natives will require annual efforts and non-natives should be disposed of out of the flood plain	**One-Time Implementation Cost: $10,000** State and federal agencies or universities should be involved and would reduce the labor cost. Equipment costs are estimated near $10,000 for nets and other misc. gear **Long-Term Annual Cost: $10,000/yr**	Fountain darter is main beneficiary. Non-native species compete with native species for resources and alter habitat among other issues. Specifically, armored catfishes create large burrows causing the loss of vegetation, destabilizing banks, and other impacts. During times of low flow and drought this could further reduce already limited habitat for the fountain darter	Collection efforts may impact fountain darters or habitat	Armored Catfish are also known to eat detritus and periphyton
		The ramshorn snail during low flow is a threat to vegetation communities and the Melanoides snail is the intermediate host for the gill parasite		Adaptive Management	Physical removal by dredge or hand. Control of non-natives will require annual efforts and non-natives should be disposed of out of the flood plain	**One-Time Implementation Cost:** Cost will be based upon method of removal. EARIP pilot study may help refine estimated cost **Long-Term Annual Cost:** Annual cost will be based upon method of removal. EARIP pilot study may help refine estimated cost	Reduced potential infection of fountain darters by Asian trematode (*Centrocestus formosanus*) and more stable vegetative communities during drought	Habitat destruction if dredging occurs. Temporarily increased turbidity during removal process. Potential take of other listed species during removal process	Pilot study is currently being funded by the EARIP
		Hydrilla is highly invasive and covers a large percentage of river bottom, thus crowding out preferred darter habitat and occupying potential Texas wild-rice habitat	X	Restoration and Minimization	Hydrilla may be removed by physical or mechanical means. An underwater vacuum is one possible mechanical method. Removed plants should be replaced with native aquatic vegetation that may include Texas wild-rice where conditions are suitable. Control of non-natives will require annual efforts and non-natives should be disposed of out of the flood plain	**One-Time Implementation Cost: $1,000,000** Based on cost of Crypto removal and native reestablishment in the San Marcos River in 2008, the projected cost is $500,000 per mile of river restored. Based on this estimate, the removal of Hydrilla from proposed area, including Spring Lake and 2 miles of river, is estimated to cost $1,000,000. This includes sections of Spring Lake, the slough arm of Spring lake, and the San Marcos River from Spring Lake to just below IH 35 **Long-Term Annual Cost: $50,000/yr**	Hydrilla removal and native replacement would increase preferred darter habitat and increase potential Texas wild-rice habitat	Disturbance to habitat. Possible take of Endangered Species. Temporary water quality impairments	To ensure success of revegetation, water flow and quality conditions should be considered, as well as uses of that stretch of river. Removal of Hydrilla in its totality ensures success by limiting recolonization. U.S. Army Corps of Engineers is currently working with the City of San Marcos to determine the feasibility of this project. Hydrilla removal may be combined with non-native vegetation removal to save money and reduce impact to habitat
		Hygrophila is a non-native species that covers a large percentage of river bottom, thus crowding out preferred darter habitat and occupying potential Texas wild-rice habitat		Restoration and Minimization	Hygrophila may be removed by physical or mechanical means. An underwater vacuum is one possible mechanical method. Removed plants should be replaced with native aquatic vegetation that may include Texas wild-rice where conditions are suitable. Control of non-natives will require annual efforts and non-natives should be disposed of out of the flood plain	**One-Time Implementation Cost: $1,000,000** Based on cost of Crypto removal and native reestablishment in the San Marcos River in 2008, the projected cost is $500,000 per mile of river restored. Thus our project of Spring Lake and 1 mile of river restored is estimated to cost $1,000,000. This mile of restored river would include sections of Spring Lake, the slough arm of Spring lake, and the San Marcos River from Spring Lake to just below IH 35 **Long-Term Annual Cost: $50,000/yr**	Hygrophila removal and native replacement may increase fountain darter and Texas wild-rice habitat	Disturbance to habitat. Possible take of Endangered Species. Temporary water quality impairments	It may be best to obtain grants to fund a contractor to remove the initial mass of non-natives and then have a volunteer program to stay on top of the non-natives. U.S. Army Corps of Engineers is currently working with the City of San Marcos to determine the feasibility of this project. U.S. Army Corps of Engineers is currently working with the City of San Marcos to determine the feasibility of this project. Hygrophila removal may be combined with non-native vegetation removal to save money and reduce impact to habitat
		Spread of non-native Elephant ears is causing a reduction in diversity and loss of natives. Elephant ears are highly invasive and can reach densities that alter the ecosystem. Elephant ears also contribute to increased evapotranspiration		Restoration and Minimization	Elephant ears may be removed by physical or chemical means. Removal will likely entail physical removal of the plant itself, along with herbicide treatment of remaining tubers. Removed plants should be replaced immediately with native vegetation that may include Texas wild-rice where conditions are suitable. Control of non-natives will require annual efforts and non-natives should be disposed of out of the flood plain	**One-Time Implementation Cost: $1,000,000.** Cost will be based upon method of removal. Because of difficulty of removal, cost may reach $1,000,000 **Long-Term Annual Cost: $50,000/yr**	Open up available habitat to flowering and sexually reproducing populations of wild rice by allowing plants to occupy shallower and slower flowing water	Temporarily increased turbidity during removal	Long term O/M efforts will be necessary. U.S. Army Corps of Engineers is currently working with the City of San Marcos to determine the feasibility of this project
		Water hyacinth is a floating non-native species that causes direct mortality of Texas wild-rice by contributing to low light levels, smothering plant stands, and inhibiting flowering rice habitat. Without removal efforts hyacinth has the ability to completely cover Spring Lake, altering the water chemistry (e.g., DO) and available light		Restoration and Minimization	Water hyacinth may be removed by physical or mechanical means (harvester). Control of non-natives will require annual efforts and non-natives should be disposed of out of the flood plain	**One-Time Implementation Cost: $5,000** This program is currently being conducted by the San Marcos River Foundation with volunteer labor. Estimated cost is for equipment to be used by SMRF for removal **Long-Term Annual Cost: $5,000/yr** Annual cost reflects control of successive non-natives, such as water lettuce	Control of water hyacinth has the potential to improve WQ and increase available light		If water hyacinth in Spring Lake is not removed, during water events they have the potential to smother and dislodge Texas wild-rice plants in Sewell Park. U.S. Army Corps of Engineers is currently working with the City of San Marcos to determine the feasibility of this project

High Priority Restoration and Mitigation Actions for the Comal and San Marcos Springs Ecosystems

	Restoration Action	Issue or Problem Addressed	Approved by Steering Committee at 03/23/2010 EARDP Meeting	Adaptive Management or Conservation/ Mitigation	Method of Implementation and Frequency	Estimated Cost Range (Cost to ES Share and Method used to determine)	Direct Benefit to Listed Species	Potential Negative Impact	Additional Comments
San Marcos River	Create emergency plan in case of dam failure	Should a dam breach, it could result in the sudden loss of habitat for Texas Texas wild rice and other native aquatic vegetation or could present the opportunity to increase habitat for the listed species A plan should be in place to address each dam in the event of a breach		Adaptive Management	TCEQ, USACE, USFWS, and TPWD should be added to provide directive Once directive is provided stakeholder opinion should be sought out Edits to the plan should be made based on comments The plan should be distributed and implemented if a dam fails	**One-Time Implementation Cost: $0** No associated costs with developing the response plan, but actual repairs or replacement, if desired, will have costs associated with them **Long-Term Annual Cost: $0/yr**	Could present the opportunity to increase habitat for the listed species		If the dam is privately owned, cooperation of the land owner will be required TCEQ must approve any dam alteration through the permitting process USFWS is currently modeling potential habitat creation or loss due to dam alteration
San Marcos River	Establishment of aggressive and frequent water quality monitoring (surface, stormwater, and ground) that considers location, time of day, day of week, time of year, and all water quality parameters deemed significant	Efforts to monitor water quality around Spring Lake and the San Marcos River should be increased Trends, adaptive management measures, and concerns should be identified as soon as possible		Adaptive Management	Sampling criteria should be established through a stakeholder process, including where and when samples will be taken Parameters evaluated should be established based on need	**One-Time Implementation Cost: $20,000** Monitoring may be accomplished, to some extent, through the work of volunteer groups such as Texas Master Naturalists and the Texas Stream Team to collect water samples, but analyses will require funding $20,000 should be given by the EARDP to an organizing agency to administer and design a WQ sampling program **Long-Term Annual Cost: $20,000/yr**	Early detection of water quality impairments that may negatively impact the listed species Gathered data will also contribute to body of knowledge on the Edwards Aquifer system	Potential misinterpretation of data by the public	Rivers System Initiative (San Marcos observation and monitoring program) has a grant to conduct water quality sampling, but specific details are not known
San Marcos River	Implementation of Best Management Practices (BMPs) to address stormwater quality runoff in and around Spring System, could include stormwater retention ponds, water quality basins, rain gardens, wetlands, and storm sewer filters	During rain events, surface runoff enters directly into spring systems and adjacent tributaries without water quality filtration or settling Water Quality concerns from direct runoff can adversely impact threatened and endangered species and their habitat		Restoration and Maintenance	Determine areas of direct runoff into spring systems that could adversely impact endangered species Areas of particular focus should be on suspected point and non-point source pollution inflow locations Areas of concern include, but are not limited to impervious cover, golf course and industrial runoff areas Based on the determined areas of concern, implement the BMP that best addresses that concern Monitoring could also be conducted during qualifying rain events (> 0.5") to obtain background parameters and to identify pollutants flowing into the MS4	**One-Time Implementation Cost: $1,000,000** Cost will be dependent on which and the number of BMP's are implemented Construction of retention/settling ponds or mechanical filtration would be anticipated, establishing the high cost associated with this action Monitoring and maintenance of the BMP's is an important aspect to optimize their efficiency An annual budget will need to be allocated for this effort **Long-Term Annual Cost: $200,000/yr**	Improved Water Quality Difficult to quantify positive effects unless a good background data base is developed, water quality monitoring is an important aspect to this activity	Cost and public / developer perception could be a factor	Efforts should focus on anticipated 2012 TPDES/MS4 permit compliance related activities and stormwater treatment for to benefit ES and habitat Consider illicit discharge program (illegal dumping to sanitary sewer systems/MS4), Hazmat incidents (spill response & prevention), overall overall/infiltration of sewer mains, construction site runoff, public education, pesticide & fertilizer application, PAH impacts and storm event data collection

High Priority Restoration and Mitigation Actions for the Comal and San Marcos Springs Ecosystems

	Restoration Action	Issue or Problem Addressed	Approved by Steering Committee at 03/13/2010 EARIP Meeting	Adaptive Management or Restoration/Minimization	Method of Implementation and Frequency	Estimated Cost Must give exact $$ figure and method used to determine	Direct Benefit to Listed Species	Potential Negative Impact	Additional Comments
Comal River	Control of harmful non-natives tilapia (*Oreochromis aureus*), armored catfish (family Loricariidae, *Hypostomus spp.* and *Pterygoplichthys spp.*), ramshorn (*Marisa cornuarietus*) and *Melanoides tuberculatus*	Control of Tilapia - Numbers of these non-natives are growing and are detrimental to the habitat of all associated endangered species	X	Restoration and Minimization	Tilapia are a tropical species that will congregate in winter near spring openings and other warm water sources. When the species congregate this creates the opportunity to use seines, gill nets, cast nets, or other methods to remove large quantities with minimal impact to the habitat. Artificial heating could be one method used to congregate fish in areas away from springs and endangered species to minimize the impacts from collection efforts. Initial efforts in year one should be intense and take place during the winters first freeze, with continued control every winter. Numerous removals during each winter would be most productive. Control of non-natives will require annual efforts and non-natives should be disposed of out of the flood plain	**One-Time Implementation Cost: $10,000** State and Federal agencies or Universities should be involved and would reduce the labor cost. Equipment costs are estimated near $10,000 for nets and other misc. gear. Artificial heating is very expensive. If heaters are used the price would greatly increase dependant on the size of heaters and water volume manipulated **Long-Term Annual Cost: $10,000/yr**	Fountain darter mainly. Non-native species compete with native species for resources and alter habitat among other issues. Specifically, tilapia destroy vegetation by making bare ground nests. During times of low flow and drought this could further reduce already limited habitat for the fountain darter	Collection efforts may impact fountain darters or habitat. If electroshocking is used it is detrimental to the fountain darter and other species	Possible locations for artificial heating could include backwaters near the golf course, Bleeders creek slough, and other back water areas. This method has not been tested or proven effective
		Armored catfish control - Numbers of these non-natives are growing and are detrimental to the habitat of all associated endangered species. Armored catfish are herbivores and burrow into the sediment of banks and lake bottom	X	Restoration and Minimization	Armored catfish are a tropical species that will congregate in winter near spring openings and other warm water sources. When the species congregate this creates the opportunity to use seines, gill nets, cast nets, or other methods to remove large quantities with minimal impact to the habitat. Artificial heating could be one method used to congregate fish in areas away from springs and endangered species to minimize the impacts from collection efforts. Initial efforts in year one should be intense and take place during the winters first freeze, with continued control every winter. Numerous removals during each winter would be most productive. Control of non-natives will require annual efforts and non-natives should be disposed of out of the flood plain	**One-Time Implementation Cost: $10,000** State and Federal agencies or Universities should be involved and would reduce the labor cost. Equipment costs are estimated near $10,000 for nets and other misc. gear. Artificial heating is very expensive. If heaters are used the price would greatly increase dependant on the size of heaters and water volume manipulated **Long-Term Annual Cost: $10,000/yr**	Fountain darter is main beneficiary. Non-native species compete with native species for resources and alter habitat among other issues. Specifically, armored catfishes create large burrows causing the loss of vegetation, destabilizing banks, and other impacts. During times of low flow and drought this could further reduce already limited habitat for the fountain darter	Collection efforts may impact fountain darters or habitat	Possible locations for artificial heating could include backwaters near the golf course, Bleeders creek slough, and other back water areas. This method has not been tested or proven effective. Armored catfish are also known to eat detritus and periphyton
		The ramshorn snail during low flow is a threat to vegetation communities and the Melanoides snail is the intermediate host for the gill parasite		Adaptive Management	Physical removal by dredge or hand. Control of non-natives will require annual efforts and non-natives should be disposed of out of the floodplain	**One-Time Implementation Cost:** Cost will be based upon method of removal. EARIP pilot study may help refine estimated cost **Long-Term Annual Cost:** Annual cost will be based upon method of removal. EARIP pilot study may help refine estimated cost	Reduced potential infection of fountain darters by Asian trematode (*Centrocestus formosanus*) and more stable vegetative communities during drought	Habitat destruction if dredging occurs. Temporarily increased turbidity during removal process. Potential take of other listed species during removal process	Pilot study is currently being funded by the EARIP
Comal River	Optimization of Fountain Darter (*Etheostoma fonticola*) Habitat in the Old/New Channel of the Comal River	Discharge from Landa Lake to the old and new channels of the Comal River are currently set at a constant flow and never changed. An established flow regime creating the maximum amount of usable habitat for the fountain darter would be beneficial, especially during low flows. Change in flow volume does not relate on a 1:1 basis with usable habitat (reference Hardy models)	X	Adaptive Management	Implement a flow regime developed by a third party using the gated culverts at tee box # 2 and the LCRA weir would be necessary. Coordination with Spring-fed pool operation should be considered	**One-Time Implementation Cost: $25,000** Cost would be associated with development of the flow regime. City of New Braunfels staff could be utilized at no cost to make adjustment to valve configuration and clean intake screens. It is estimated that a third party could establish the needed flow regime and criteria for $25,000 **Long-Term Annual Cost: $5,000/yr** Annual cost is for labor to maintain valve and gates	Fountain darters benefit from ensured flow, required water quality parameters, and creation of the maximum usable habitat	Some habitat may not be maintained to protect higher quality habitat	Draft MOU available, possible flow regime in the 2003 draft Mgmt Plan by Hardy et al. 1999
Comal River	Establishment of riparian zones and removal of sediment in select areas to promote beetle (*Heterelmis comalensis* and *Stygoparnus comalensis*) habitat	Riparian habitat along the western shore of Landa Lake from the headwaters of Spring Run 3 downstream to the Gazebo, contains little native riparian vegetation	X	Restoration and Minimization	Method of riparian zone establishment includes the removal of all non-natives and replanting of native vegetation representing a functioning riparian zone. Trees and plants with extensive root systems should be given preference to create the maximum beetle habitat. Fine sediment coverings exposed roots and springs should be removed also. The riparian zone should be checked several times a year for continued success and removal of reestablished non-natives. It is also possible the area will need to be protected for the first year until the riparian zone becomes established	**One-Time Implementation Cost: $140,000** Project size is estimated at 10 acres. Plants for establishment of riparian zone are estimated at $4,000/acre, labor for planting at $3,000/acre (includes planning), and sediment removal at $5,000/acre, plus an extra $20,000 because of hard to reach areas. Total project cost of $140,000 **Long-Term Annual Cost: $15,000/yr** Costs should diminish after the first few years as vegetation is established	Comal Springs riffle beetles are thought to feed on detritus (fungus and bacteria growing on woody debris, and leaf litter) within spring-influenced riparian zones. They are also known to prefer areas free of fine sediments. Establishing a native riparian zone benefits the riffle beetle by increasing the amount of usable habitat and food sources. Having a larger population when drought occurs likely increases the ability of the species to withstand the drought. In addition, riparian restoration also benefits the system through bank stabilization and nutrient and sediment processes	Reduced recreational access and temporary turbidity	This location was chosen because the western shoreline of Spring run 3 is known to have numerous spring orifices that contain beetles and the riparian habitat is significantly degraded. One species to specifically target would be elephant ears (*Xanthosoma sagittifolium* and *Colocasia esculenta*)
		Riparian habitat along the western shore of Landa Lake from the end of Spring Run 3 upstream to the Water Oriented Recreation District #1 property line, contains little native riparian vegetation	X	Restoration and Minimization					This location was chosen because the western shoreline of Landa Lake is known to have numerous spring orifices that contain beetles and the riparian habitat is significantly degraded. This area was also chosen because it is one of the deeper parts of the lake (i.e. will hold water longest during drought) and also because the population of riffle beetles found along this shoreline is thought to be the most genetically diverse found in Landa Lake. One species to specifically target would be Elephant Ears (*Xanthosoma sagittifolium* and *Colocasia esculenta*)
Comal River	Prohibition of hazardous materials routes that cross the Comal River, springs, or associated direct tributaries	Roads that cross the Comal River are not identified hazardous materials routes, but hazardous materials are allowed to cross. A spill could be catastrophic depending on location	X	Restoration and Minimization	Work w/ TXDot to establish prohibited routes. Would require signage and legislation	**One-Time Implementation Cost: $10,000** Cost would include signage and possible costs incurred in the legal process **Long-Term Annual Cost: $0/yr**	Prevent extinction of species caused by one spill	Could cause inconvenience through less direct routes	Work with TXDoT, Comal County, City of New Braunfels, and state agencies to establish restricted zones, cost is to install signage and designate alternative routes. City of New Braunfels has existing hazardous materials response plan

High Priority Restoration and Mitigation Actions for the Comal and San Marcos Springs Ecosystems

	Restoration Action	Issue or Problem Addressed	Approved by Steering Committee at 03/13/2010 EARIP Meeting	Adaptive Management or Restoration/Minimization	Method of Implementation and Frequency	Estimated Cost (Must give exact $$ figure and method used to determine)	Direct Benefit to Listed Species	Potential Negative Impact	Additional Comments
Comal River	Include private landowners (riverside and tributary) in riparian restoration	On private property, citizens often groom a yard right to the waters edge, reducing the natural ability of a riparian zone to filter runoff		Restoration and Minimization	As plans take shape for the reestablishment of the riparian zone, public stakeholder meetings should be held and land owners should be asked to participate in the plan. Reimbursement for the price of native plants should be provided to private landowners by the EARIP. A program should be developed including criteria to qualify and preferred natives to replant	**One-Time Implementation Cost: $100,000** Cost in the first year to reimburse landowners for native plants and to market the program to land owners. Funding for following years is dependant on participation and success of the program. **Long-Term Annual Cost: $10,000/yr** Costs should diminish after the first few years as vegetation becomes established	Improved water quality through the natural ability of a properly functioning riparian zone	Temporarily increased turbidity during transplant process	Should focus on the private homes around Landa Lake, and property on the associated tributaries Bleiders and Dry Comal creeks. One species to specifically target would be elephant ears (*Xanthosoma sagittifolium* and *Colocasia esculenta*.)
Comal River	Restoration of riparian zone with native vegetation (public lands)	On public property (e.g. parks and golf courses), entities often groom property right to the waters edge, reducing the natural ability of a riparian zone to filter runoff. Other concerns include trampled banks that increase erosion and the establishment of non-native vegetation		Restoration and Minimization	As plans take shape for the reestablishment of the riparian zone, public entities should be asked to participate in the plan. Reimbursement for the price of native plants should be provided to public entities by the EARIP. A program should be developed including criteria to qualify and preferred natives to replant	**One-Time Implementation Cost: $500,000** Cost in the first year to reimburse for native plants and to market the program. Funding for following years is dependant on participation and success of the program. **Long-Term Annual Cost: $50,000/yr** Costs should diminish after the first few years as vegetation becomes established	Improved water quality through the natural ability of a properly functioning riparian zone	Temporarily increased turbidity during transplant process	Establishment and width determination of buffer zone along rivers edge should be based upon best available science and should consider desired recreational access (see previous restoration action item involving Texas wildrice and recreational access). One species to specifically target would be elephant ears (*Xanthosoma sagittifolium and Colocasia esculenta*.) An agreement for no mow zones along San Felipe Springs was established between City of Del Rio and TPWD to protect the Devils River minnow and may serve as an example
Comal River	Stop or limit introductions of non-native species by aquarium "dumps"	Citizens often dump their entire aquarium into the river when they no longer can keep the aquarium, thus introducing non-native species to the ecosystem		Restoration and Minimization	This action will be minimized through education (signage and brochures) and offering alternatives to citizens and students wanting to get rid of unwanted aquatic pets. The EARIP should consider partnering with the River Systems Institute, Texas State University and local citizen groups to help distribute educational materials. Partnerships with the school districts should also be considered. Signage should also be provided to local pet shops and bait shops	**One-Time Implementation Cost: $20,000** Costs in the first year for design of the campaign and printing of materials. With yearly costs for additional printing. **Long-Term Annual Cost: $5,000/yr** For additional signage and continued education efforts	Reduce competition of non-natives on the listed species and reduce the introduction of "new" non-native species	None	Enforcement and education are key elements. One potential campaign and marketing resource could be Habitattitude (existing campaign by USFWS and NOAA)
Comal River	Stop or limit introductions of non-native species by the use of non-native bait species	The use of non-native species as bait can result in the introduction of "new" non-natives and potential new aquatic diseases		Restoration and Minimization	Establish local ordinance prohibiting the use of non-native bait species in the Comal Springs ecosystem. This action will be maintained through education (signage and brochures) and through the identification of native bait choices for citizens. The EARIP should consider partnering with the River Systems Institute, Texas State University and local citizen groups to help distribute educational materials. Partnerships with the school districts should also be considered. Signage should also be provided to local pet shops and bait shops	**One-Time Implementation Cost: $20,000** Costs in the first year for design of the campaign and printing of materials. With yearly costs for additional printing. **Long-Term Annual Cost: $5,000/yr** For additional signage and continued education efforts	Reduce competition of non-natives on the listed species and reduce the introduction of "new" non-native species	Loss of revenue to bait shops and loss of bait choices for anglers	Enforcement and education are key elements. One potential campaign and marketing resource could be Habitattitude (existing campaign by USFWS and NOAA)
Comal River	Implementation of Best Management Practices (BMPs) to address stormwater quality runoff in and around Landa Lake, could include stormwater retention ponds, water quality basins, rain gardens, wetlands, and storm sewer filters	During rain events, surface runoff enters directly in to Landa Lake, spring runs and adjacent tributaries without water quality filtration or settling. Water Quality concerns from direct runoff can adversely impact threatened and endangered species and their habitat		Restoration and Minimization	Determine areas of direct runoff into Landa Lake and Springruns that could adversely impact spring endangered species. Areas of particular focus should be on suspected point and non-point source pollution inflow locations. Areas of concern include, but are not limited to impervious cover, golf course and industrial runoff areas. Based on the determined areas of concern, implement the BMP that best addresses that concern. Monitoring could also be conducted during qualifying rain events (> 0.5") to obtain background parameters and to identify pollutants flowing into the MS4	**One-Time Implementation Cost: $1,000,000** Cost will be dependent on which and the number of BMP's are implemented. Construction of retention/settling ponds or mechanical filtration would be anticipated, establishing the high cost associated with this action. Monitoring and maintenance of the BMPs is an important aspect to optimize their efficiency. An annual budget will need to be allocated for this effort. **Long-Term Annual Cost: $200,000/yr**	Improved water quality	Hard to quantify positive effects unless a good background data base is developed, water quality monitoring is an important aspect to this activity. Cost and public / developer perception could be a factor	Efforts should focus on anticipated 2012 TPDES/MS4 permit compliance related activities and stormwater treatment for to benefit ES and habitat. Consider illicit discharge program (illegal dumping to sanitary sewer systems/MS4), Hazmat incidents (spill response & prevention), overflows/infiltration of sewer mains, construction site runoff, public education, pesticide & fertilizer application, PAH impacts and storm event data collection
Comal River	Development of permanent and one-day Household Hazardous Wastes (HHW) collection programs (including (scon & drugs) along with increasing awareness about discarding HHW	Often hazardous materials are discarded by flushing down toilets or pouring on the ground, down an abandoned well, or in a storm sewer		Restoration and Minimization	Development of a HHW Program can be initiated through the TCEQ and/or the waste disposal division of the City. State and local agencies could establish a 4 times a year program and could be a contributing activity that can be recognized in the City's anticipated MS4 compliance and Stormwater permit. A consideration could be to hire an environmental firm that specializes in waste disposal services such as Clean Harbors Environmental Inc. or Curbside Inc.	**One-Time Implementation Cost: $150,000** The cost of the program would be associated with staffing, advertising, disposal, and law enforcement (if drugs are accepted). Collection dates and reasoning/benefits to dispose of hazardous materials properly should be advertised heavily. The cost would be annual as this program would need to be conducted annually. **Long-Term Annual Cost: $150,000/yr**	Improved stormwater quality, sub-surface flows to springs and effluent discharge	Quantifying the water quality improvements could be challenging, but overall, not a controversial issue. Water quality monitoring is an important aspect to this activity	The City of New Braunfels does currently have a limited HHW program and could be considered as a compliance activity as part of their upcoming MS4 permit issuance which is believe to occur in 2012
Comal River	Implement an aerobic and anaerobic septic system registration, evaluation, and permitting program to prevent subsurface pollutant loadings from potentially being introduced to the spring ecosystem	Malfunctioning, non-permitted/registered or poorly maintained septic systems can adversely effect water quality. Some underground septic systems potentially leach nutrients (i.e. nitrates) and other constituents of concern into the springs ecosystem via groundwater transport pathways and waterways that drain into spring ecosystems		Restoration and Minimization	Associated municipalities and entities should participate in the existing TCEQ permitting, maintenance, and construction program for on-site sewage facilities (septic systems). The regulatory body should consider a more frequent analysis of the systems treatment capacity greater than TCEQ's program requirements. Another option, in conjunction with TCEQ would be to assist those affected by the new program, the City/County could mail information/registration packages to owners of land parcels that lie within 500 feet of the edge of a specified waterway	**One-Time Implementation Cost: $10,000** Costs would be minimal to the EARIP, as users must pay the registration fee with TCEQ. A cost associated with information mailings could be considered. However, if a conventional system is in need of upgrading, a program rebate or financial assistance should be considered. **Long-Term Annual Cost: $10,000/yr**	Improved water quality	The cost for an upgrade to a more efficient system could be a financial burden upon the homeowner. Some home owners may also be unwilling to voluntarily register and participate in the program	A review of the existing systems and their current permitting status, type of system and their effluent water quality along with system condition should be performed above TCEQ's current conditions
Comal River	Establish incentive program that promotes new low impact development and reduces the percentage of impervious cover	Impervious cover reduces aquifer recharge and contributes to stormwater pollution. Vehicles and roadways combined represent a direct pathway for pollutants to waterways during rain events		Adaptive Management	Refer to the LID EARIP Workgroup for Implementation Strategies and BMP's. The Ecosystem Restoration Subcommittee supports their conclusions and recommendations. Criteria and incentives need to be established	**One-Time Implementation Cost: ???** Cost of the program would be associated with reimbursement or credit for conversion of impervious to pervious cover and incentives for new LID development and is dependent upon the type of incentives offered. **Long-Term Annual Cost: ???**	Reduction of impervious cover improves the quantity and quality of water recharging the aquifer. Also improves the quality of surface water runoff and attenuates floodflows	Cost of development increases	Could target specific areas around Landa Lake or direct tributaries
Comal River	Establishment of aggressive and frequent water quality monitoring (surface, stormwater, and ground) that considers location, time of day, day of week, time of year, and all water quality parameters deemed significant	Efforts to monitor water quality around Landa Lake and the Comal River should be increased. Trends, adaptive management measures, and concerns should be identified as soon as possible		Adaptive Management	Sampling criteria should be established through a stakeholder process, including where and when samples will be taken. Parameters evaluated should be established based on need	**One-Time Implementation Cost: $20,000** Monitoring may be accomplished, to some extent, through the work of volunteer groups such as Texas Master Naturalists and the Texas Stream Team to collect water samples, but analyses will require funding. $20,000 should be given by the EARIP to an organizing agency to administer and design a WQ sampling program. **Long-Term Annual Cost: $20,000/yr**	Early detection of water quality impairments that may negatively impact the listed species. Gathered data will also contribute to body of knowledge on the Edwards Aquifer system	Potential misinterpretation of data by the public	The Clean Rivers Program is currently monitoring water quality in the ecosystem

High Priority Restoration and Mitigation Actions for the Comal and San Marcos Springs Ecosystems

	Restoration Action	Issue or Problem Addressed	Approved by Steering Committee at 03/13/2019 EARIP Meeting	Adaptive Management or Restoration/Mitigation	Method of Implementation and Frequency	Estimated Cost Must give exact $$ figure and method used to determine	Direct Benefit to Listed Species	Potential Negative Impact	Additional Comments
Require Additional Information	Control of the non-native Asian trematode (*Centrocestus formosanus*), from both Spring Systems	The gill parasite can cause stress to the fountain darter and eventually mortality, especially during low flows	X	Adaptive management	Method needs to be established, possible baffle and aeration systems installed on low water dams and water control structures	The cost is unknown. Depends on method of implementation	Reduced stress or mortality to the fountain darter	??	Two possible partial but untested control methods are physical removal of *M. tuberculatus* (by dredging) and water turbulence (dams, riffles, and air bubble) to kill drifting *C. formosanus* cercaria. These methods have not been tested or proven effective
	In-Situ Refugia at Comal	In-Situ Refugia may create temporary habitat for endangered species in their native habitat during times of low flow	X	Adaptive management	Needs more work study, Biowest is currently conducting a feasibility study		Depends on approach and BioWest determination. Presumably the fountain darter and possibly the beetles	??	This is dependant on results of the BioWest In-Situ Refugia feasibility study. Bio-West indicates in-situ refugia is only viable at flows between 130-50 cfs