Protecting and Restoring Environmental Flows and Water Levels in Prairie Rivers and Streams in the Great Plains

Final Report

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## Abstract

The Great Plains Landscape Conservation Cooperative (GPLCC) has participated in watershed-based conservation planning efforts which identify flow protection and restoration strategies as priority conservation actions to conserve native fishes in the Great Plains. Through this initiative, the Great Plains Environmental Flow Information Toolkit (GP EFIT) was developed to inform identification of voluntary environmental flow protection and restoration strategies. The GP EFIT is a web-based geospatial platform that provides data and information on water use, hydrologic alteration, and environmental flow targets to meet conservation objectives. It has three dashboards or user interfaces: hydrology, ecology, and water planning. By increasing efficiencies and effectiveness of environmental flow conservation efforts, the GP EFIT will provide a valuable decision support tool for resource managers, water providers, and conservation organizations facing the challenges of conserving Texas’ water resources and rich natural heritage.

## 1.0 Introduction

The Southern Great Plains in Texas include portions of the Canadian, Red, Brazos, and Colorado river basins (Figure 1). The aquatic and riparian ecosystems of the Great Plains are dependent on a natural flow regime that consist of subsistence flows, base flows, high flow pulses, and overbanking flows (See TIFP 2008). The hydrologic characteristics of each of these flow components play important roles in maintaining ecological, chemical and physical processes that support native biodiversity, water quality, channel maintenance and sediment transport, and connectivity in vertical, longitudinal, and lateral dimensions (Annear et al. 2004).

Surface water diversions, groundwater pumping, and invasive riparian vegetation cause hydrologic alterations by reducing flows, especially during periods of drought and in hot summer months. Dam operations alter natural flow regimes by modifying hydrologic characteristics (e.g., magnitudes, seasonal timing, rate of change, duration, frequency) of base flows, high flow pulses and overbanking flows and by extending dry and no flow periods. Temporal changes in flow regimes and barriers to movement can disrupt completion of fish life cycles through impaired migration, spawning and recruitment. Furthermore, extended duration and frequencies of zero-flow days and modified base flows alter the quantity and quality of instream habitat conditions necessary for aquatic life. All these effects, including fragmentation and reduced longitudinal and lateral connectivity, contribute to losses of aquatic biodiversity within the Great Plains (Perkin et al. 2014; Bunn and Arthington 2002).

In Texas, ownership and regulation of water differs between groundwater and surface water. Surface water flowing in a clearly defined water course (i.e., river or stream) is considered state property; groundwater is water found beneath the land’s surface and is considered the property of the landowner. Groundwater is governed by the rule of capture which allows landowners the right to capture the water beneath their property, regardless of the impacts of that pumping on neighboring wells, as long as the water is not wasted. Surface water, on the other hand, belongs to the State of Texas. With few exceptions, a water right permit is required to impound, divert, or use state water. Water right permits specify the amount of water to be diverted or stored as well as the location, diversion rate, type use, and priority date of the right. Texas operates primarily on the prior appropriation system in which the oldest water rights have the first claim on available water (i.e., first in time, first in right). Prior to 1985, the State generally did not consider impacts on fish and wildlife when granting surface water right permits. With over 90% issued before 1985, most Texas water rights do not contain environmental provisions. Since 1985, the Texas Commission on Environmental Quality (TCEQ) and its predecessor agencies have included some level of environmental flow protections on new water rights; however, the level of protection varies widely from permit to permit. These environmental conditions normally involve a restriction on when, or how much, water can be taken from a river or stream to ensure some water still flows downstream.

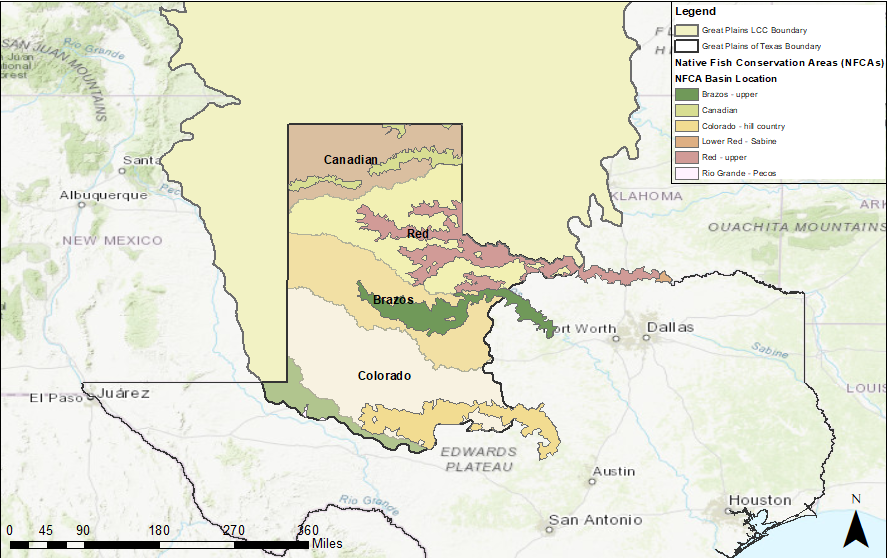
More recently, new surface water right permits and major amendments include special conditions related to the State’s recently adopted environmental flow standards. These 

Figure . Great Plains LCC area and Native Fish Conservation Areas of the Southern Great Plains in Texas.

standards represent the outcome of the legislatively mandated Senate Bill 3 (SB 3) environmental flows process created by the 80th Texas Legislature in 2007. The process set out a comprehensive, statewide approach for identifying surface water necessary to protect environmental flow regimes in Texas rivers and bays by establishing environmental flow standards to be applied to newly issued or amended water rights (Loeffler 2015). By 2014, environmental flow standards had been adopted for most of the state (except for the Canadian, Red, Cypress, and Sulphur river basins). The process for identifying environmental flows to benefit river, bay, and estuary ecosystems while balancing human needs relied upon input from local stakeholder groups (Basin and Bay Area Stakeholder Committee [BBASC]) with membership ranging from municipal and agricultural water users to commercial anglers, along with basin-specific expert science teams (Basin and Bay Expert Science Team [BBEST]). Although TCEQ adopted flow standards, in many cases existing unappropriated flows are not sufficient to meet environmental flow needs. A critical step in the SB 3 process is to identify voluntary strategies to meet environmental flow standards, especially in fully appropriated basins. Texas Water Code §11.0235(d-3) (2) instructs that, in those basins where the environmental flow standards are not met, “a variety of market approaches, both public and private, for filling the gap must be explored and pursued.”

To assist in filling this gap, the Texas Parks and Wildlife Department (TPWD) developed the Great Plains Environmental Flow Information Toolkit (GP EFIT), a web-based geospatial decision support tool for environmental flow management. Key project deliverables include:

* A web-based geospatial tool, the GP EFIT;
* Matrix of high priority conservation areas and recommended flow protection and restoration strategies (Table 8 and Figure 3); and
* List of potential partners for water acquisitions, leases, or other voluntary incentive-based programs (Appendix 3).

To provide these and other deliverables, TPWD hired an FTE and subcontracted with Texas Conservation Science, Inc. (TCS), The Nature Conservancy (TNC), and a programmer (Mingshu Yin) familiar with the dashboard GIS framework. TPWD also worked with a number of volunteers and interns to generate data layers.

Simple instructions on the use and functions of the GP EFIT, as well as 4 case studies, are included in this report. A demonstration on how to use the GP EFIT Hydrologic Dashboard is available at:

<https://www.youtube.com/watch?v=Uj7hohFWu9A&feature=youtu.be>

The GP EFIT can be accessed at:

<https://tpwd.texas.gov/landwater/water/conservation/water_resources/efit/index.phtml>

## 2.0 Great Plains Environmental Flow Information Toolkit

The objective of the GP EFIT is to inform efforts to identify opportunity areas for the protection and restoration of environmental flows and align potential environmental flow management strategies for those areas. It is composed of three web-based dashboards, each representing the functional and informational needs defined by three scenarios (hydrology, flow-ecology, and water planning), and a set of supporting data layers.

The three scenarios (or dashboards) were derived from end-user input on GP EFIT development. A list of approximately 200 individuals and organizations was compiled to identify potential end-users. These included staff from state and federal natural resource agencies, academics, members of regional water planning groups, landowners, representatives of agriculture and conservation communities, and others with an interest in environmental flow and water management issues. Surveys (Appendix 1) were used to gather input from potential end-users and TPWD staff attended meetings and conferences to present information about the GP EFIT. One-on-one and small-group interviews were conducted to gain additional end-user feedback. Telephone calls, e-mails, and webinars were also used to directly communicate with stakeholders and potential end-users. The first EFIT webinar, held on August 30, 2019, demonstrated a draft hydrology dashboard and summarized supporting data layers. Additional webinars are planned once all dashboards are functional.

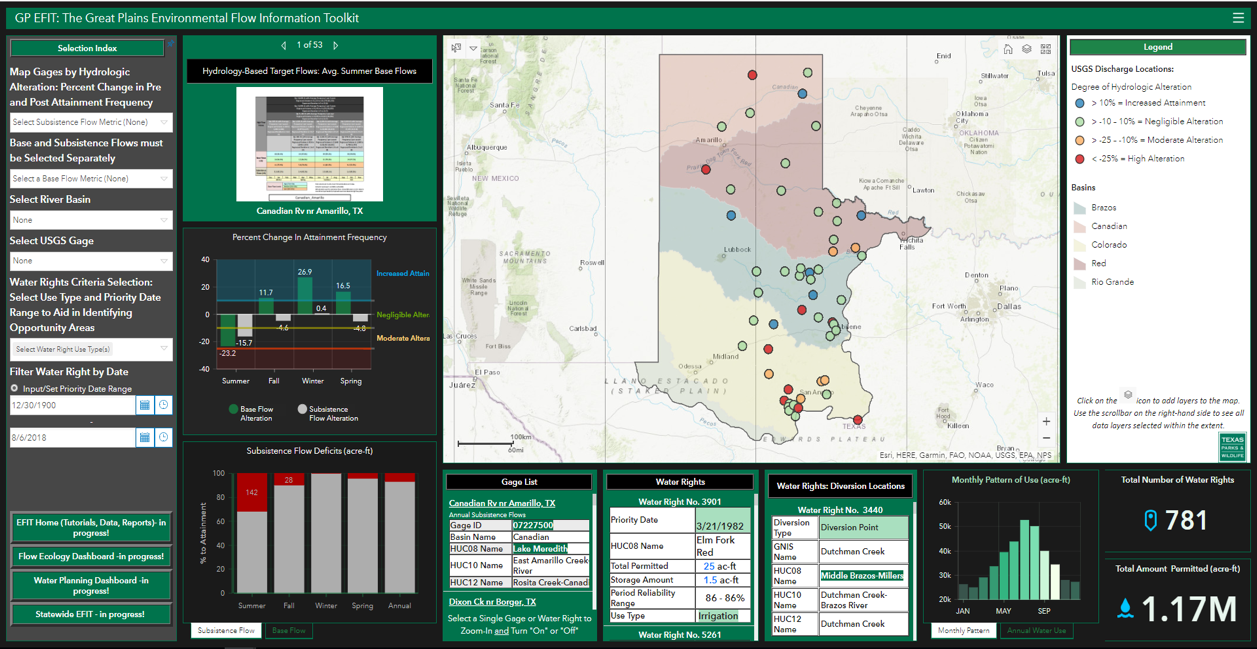
Data layers available in the toolkit are presented in Appendix 2 and provide information on stream hydrology, surface water rights and use, biology (e.g., native ranges of fishes and mussels, invasive species), conservation areas such as NFCAs, groundwater wells, and other geographic information. The following sections discuss properties of each of the dashboards.

### 2.1 GP EFIT Hydrology Dashboard

The Hydrology Dashboard (Figure 2) has several functions centered around a map of USGS gages color-coded by the degree of hydrologic alteration (defined by percent change in attainment frequencies between pre- and post-alteration periods). A selection index (far left in Figure 2) allows users to filter by river basin, by gage, and by seasonal flow components (such

as subsistence and base flows). Once a gage is selected information on hydrology-based flow targets, the degree of hydrologic alteration by season and flow component, and flow deficit (volumetric shortfall) for a given season and flow component is displayed for that gage. Further, as data is geographically filtered the number of surface water rights, amount of use permitted, and the pattern of use is dynamically updated within the selected geography (see TCS 2019 Task 1 for details related to the water rights geospatial tool and the bottom right panel in Figure 2). A selection index (far left in Figure 2) also allows filtering water rights by priority date and use type; several additional selection tools are available to allow fine and coarse-scale filtering (e.g., by 8-digit HUC). By comparing water rights information and flow deficits, end-users can evaluate opportunities and areas for environmental flow management.

Figure . The GP EFIT Hydrology Dashboard user interface.



### 2.1.1. Hydrology-based flow targets, attainment frequencies, and flow deficits

Several tools and tests were used to develop flow targets for the Hydrology Dashboard (see TCS 2019 Task 2 for details). In summary, 135 USGS historical gage flow records representative of the natural or least impacted hydrologic period of record (pre-alteration period) were used in the calculation of flow targets. A post-alteration period was also defined. The pre-alteration period used a simple rule to define impact date as the date at which 20% of the upstream area was regulated by upstream reservoir development - the impact date typically defined the break between pre- and post-alteration periods. Twenty years was set as a minimum length of period of record; however, to add more gages to the toolkit, 10 years was used as the minimum if the 10-year period represented the range of variability observed within the entire 1900-2018 record (see TCS 2019 for details).

Streamflow targets were calculated using the Indicators of Hydrologic Alteration (IHA) software (TNC 2007) and the Hydrology-Based Environmental Flow Regime (HEFR) tool (see Opdyke at al. 2014). IHA was used to classify daily gage data into flow components (e.g., base flow or high flow pulse) using default criteria (TCS 2019); IHA rejected 16 gages. Output from IHA was then brought into HEFR for calculation of flow statistics for wet, average, and dry conditions and generate, for each gage, a HEFR table (see Figure 2, top of left panel) of streamflow targets, attainment frequencies, and hydrological characteristics (e.g., frequency, rate of change, etc.)

To quantify the degree of hydrologic alteration, the percent change in attainment frequency between pre- and post-alteration periods was calculated (see TCS 2019 for details) for each gage by season, hydrologic condition, and flow component (base and subsistence flows). Hydrologic alteration was defined as follows:

* Less than -25% difference = High Alteration;
* between -25% and -10% = Moderate Alteration;
* between -10% and 10% = Negligible Alteration; and
* greater than 10% = Increased Attainment (indicates a greater attainment in post-alteration period)

For each gage, alteration graphs for the average hydrologic condition are in the middle position of the left panel (Figure 2).

Flow deficits or volume shortfalls were also calculated for each gage by season, hydrologic condition, and flow component (see TCS 2019 for details); a graph of deficits is included for the average hydrologic condition at the bottom of the left panel in Figure 2.

### 2.2 GP EFIT Ecology Dashboard

The Ecology Dashboard serves similar information as the Hydrology Dashboard but uses different approaches for calculating flow targets, attainment frequencies, and flow deficits; these approaches are detailed in Smith and Garmany (2019). In addition to an extensive literature review (Smith and Garmany 2019) regional flow-ecology relationships were generated with random forest models using fish occurrence data paired with USGS gage data (see Smith and Garmany 2019 for details) across the river basins. The fish database included 3100 collections: 358 in the Canadian River basin, 1042 in the Red, 598 in the Brazos, and 1102 in the Colorado. Flow-ecology relationships were developed for target fishes (e.g., pelagic broadcast spawning cyprinids; see Table 2 in Smith and Garmany 2019) in each basin using 65 ecologically important hydrologic metrics (e.g., median June flow). However, the Colorado River basin was excluded because of insufficient fish data for target taxa. Flow targets for each species and metric were then derived from the partial dependence plots from the random forest models (see figures 7 and 8 in Smith and Garmany 2019). The Ecology Dashboard, under development at this time, will serve flow targets, attainment frequencies, and flow deficits to facilitate an evaluation of flow management strategies focused on specific species and basins.

### 2.3 GP EFIT Water Planning Dashboard

The SB 3 environmental flow process included environmental flow regime recommendations produced by basin-specific expert science teams (BBEST) as well as environmental flow standards adopted by TCEQ and contained in the State of Texas Administrative Code (TAC) Title 30, §298. The science team flow recommendations were based solely on best available data with the goal of maintaining a sound ecological environment and were used to assist the Basin and Bay Area Stakeholder Committees (BBASC) in developing environmental flow standard recommendations for consideration by the TCEQ. In most cases, the science teams relied upon a desktop evaluation of USGS streamflow records overlain with any known flow-ecology relationships or instream flow study results. The desktop hydrology-based approach utilized IHA and HEFR to produce a matrix of flow components that included subsistence flows, base flows, high flow pulses, and overbanking flows. Science teams used additional information on biology, water quality, geomorphology and/or other pertinent information to refine their environmental flow regime recommendations. Each BBASC used their BBEST’s recommended environmental flow regime, along with policy considerations, to develop a set of recommendations about flow protection standards. Through a public rulemaking process, the TCEQ used the BBASC recommendations and other considerations to formulate environmental flow standards for adoption. The adopted flow standards are applied when any new water use permits, or amendments that increase the amount of water to be diverted, are granted. The flow standards as adopted by TCEQ reflect a balancing of environmental needs with future water development needs and may not reflect environmental flow amounts necessary to maintain or restore aquatic ecosystems. The GP EFIT includes both expert science team recommendations and the adopted flow standards for the Brazos and Colorado river basins (the Red and Canadian river basins were not part of the SB 3 process). The Water Planning Dashboard is under construction.

## 3.0 Environmental Flow Protection and Restoration Strategies

Environmental flow protection and restoration strategies can be used to address impacts to riverine systems of the Great Plains in Texas due to hydrologic alteration (Valente et al. 2019). Potential voluntary strategies include environmental water transactions, reservoir re-operations, land use management, and groundwater management and are discussed in the following sections.

### 3.1 Environmental Water Transactions

Surface water right transactions executed for environmental benefits are considered Environmental Water Transactions (EWT). These transactions can take many forms including voluntary agreements with water right holders for long term or single year leases, crop fallowing agreements, permanent water right acquisitions or dedication of return flows. These transactions can increase the quality and quantity of environmental flows. Flow deficit volumes have been calculated to determine the volume of supplemental water needed to mimic target flow attainment frequencies observed under more natural flow regimes. For each flow target, these flow deficit volumes (see figures 12 and 13 in Smith and Garmany 2019) serve as goals for EWTs. The GP EFIT includes tools to identify areas with flow deficits that could be addressed with EWT strategies and allows users to review water rights by location, volume and type use that could be considered for different types of voluntary EWTs to augment the needed amount of flow.

### 3.2 Reservoir Re-operations

For stream segments downstream of reservoirs, opportunities may exist to restore vital components of the flow regime that have been altered by dam operations. Environmental flow releases or pass-throughs can maintain key aspects or restore the natural flow regime of these systems. This has been successfully undertaken on a voluntary, stakeholder-driven basis in several areas (Richter et al. 2006, Warner et al. 2014) including Texas (Smith et al. 2019).

### 3.3 Land Use Management

#### 3.3.1 Invasive Riparian Vegetation Management

The invasive non-native plant salt cedar (*Tamarix* spp*.*) is common in the river basins in the study area and dense, mature stands may contribute to changes in water quantity, water quality, physical processes, riparian vegetation composition, instream habitat and aquatic fauna. Salt cedar may be more drought-tolerant than native species (Glenn and Nagler 2005) and often becomes the dominant woody species in riparian areas in the western United States (Dudley et al. 2000; Doody et al. 2011). While salt cedar is thought to use more water for evapotranspiration than native xeric species (see Shafroth et al. 2005), studies that document substantial water savings in response to moderate to watershed scale management efforts are lacking. In addition to improving low flows under certain conditions, salt cedar management helps restore riparian and instream habitat in support of fish and wildlife resources by allowing native riparian vegetation to replace salt cedar and fostering natural geomorphic processes that allow channel expansion (see Mayes et al. 2019). Efforts to manage, monitor, and model salt cedar management for multiple objectives are underway in watersheds of the upper Brazos River (see Mayes et al. 2019), Colorado River, and Canadian River basins (Canadian River Municipal Water Authority [CRMWA], <https://www.crmwa.com/salt-cedar-management-program>).

#### 3.3.2 Playa Lake Restoration and Management

Though they only cover 2% of the region’s landscape, playa lakes may be the most significant ecological feature in the Texas Great Plains that support a diversity of plants and wildlife, including resident and migratory birds. Playas are shallow, circular-shaped wetlands that are primarily filled by rainfall but may also receive water from irrigation runoff. Approximately 19,300 playas are found in the Great Plains in Texas. Individual playas average slightly more than 15 acres in size and, though larger playas may exceed 800 acres, around 87% are smaller than 30 acres (Texas Parks and wildlife <https://tpwd.texas.gov/landwater/land/habitats/high_plains/wetlands/playa.phtml>).

Current research indicates that playa lakes are an important recharge source for the Ogallala Aquifer, contributing up to 95% of surface flow into the aquifer and improving the quality of the recharge water. Recharge rates in playa basins are 10 to 100 times greater than for areas outside of playa basins, and groundwater recharge may exceed three inches per year in unaltered playas. Recharge through playas is a continuous process. Without recharge contributions from playas, regional recharge to the southern High Plains aquifer could possibly be 1 to 2 orders of magnitude smaller. Properly functioning playa wetlands, which have shrink-swell soils that produce desiccation cracks and rapid infiltration rates, are thus important for the overall recharge contribution to the southern High Plains aquifer (Gurdak and Roe 2009).

#### 3.4 Sustainable Groundwater Management

Development of groundwater from the Ogallala and other high plains aquifers is known to be one of the major impacts to the region’s rivers and streams (Perkin et al. 2017). While flow protections, voluntary water rights transactions and dam re-operations will have value in the region, voluntary groundwater management appears to have the greatest potential for providing ecological benefits. Refined groundwater tools and maps in important ecological areas could help identify opportunity areas for voluntary groundwater withdrawal adjustments aimed at reducing impacts to surface flows. Sustainable groundwater management in these zones could be fostered through changes in aquifer management goals and triggers and through incentives for water transactions.

## 4.0 Opportunities to Protect and Restore Environmental Flows in the Southern Great Plains Native Fish Conservation Areas of Texas

The GP EFIT provides information needed for identifying areas where species and habitats of concern, altered streamflow, and the pieces needed to craft environmental flow protection and restoration strategies intersect. The Hydrologic Dashboard was used to identify such intersecting areas in the Great Plains based on areas of ecological interest (e.g. Native Fish Conservation Areas [NFCA}; degree of flow alteration and deficits for meeting environmental flow targets at USGS gage and HUC scales; and locations, permitted type use and amounts, patterns of use, and storage quantity of individual and cumulative surface water rights. Supplemented with data related to groundwater use, invasive riparian vegetation, playa lake distribution, and reservoir location and size, the water right information can be used to classify viable types of voluntary flow protection and restoration strategies for a given location.

### 4.1 Upper Canadian River Native Fish Conservation Area (NFCA)

#### 4.1.1 Basic Description of the NFCA

The Canadian River is the longest tributary to the Arkansas River and drains portions of Texas, New Mexico, and Oklahoma. In Texas, the river traverses west to east across approximately 305 km (190 miles) of the rural Texas Panhandle. Land use is predominantly irrigated farming and cattle ranching. The largest nearby urban area is Amarillo which is in the Canadian River basin but outside of the NFCA boundaries. The largest cities within the NFCA are Borger and Canadian. Due to low precipitation and high evaporation rates that predominate in the region, the basin has a low average watershed yield. There are only a few tributaries to the mainstem river (e.g., the intermittent Rita Blanca Creek and Dixon Creek). Several northeasterly-running tributaries (e.g., Coldwater Creek, Palo Duro Creek, Kiowa Creek, and Wolf Creek) contribute flows to the Beaver River/North Canadian River in Oklahoma (Texas Water Development Board <http://www.twdb.texas.gov/surfacewater/rivers/river_basins/canadian/index.asp>).

Instream habitat within the Canadian River is typically shallow, sandy, braided channels and supports several imperiled fishes including Peppered Chub *Macrhybopsis tetranema*, Arkansas River Shiner *Notropis girardi* (federally and state threatened in Texas), and Flathead Chub *Platygobio gracilis* (possibly extirpated [Robertson et al. 2017]). Recent surveys have not documented any of these species downstream of Lake Meredith (e.g., Robertson et al. 2017). In Texas, the Canadian River watershed supports 27 species of native fishes and five nonnative fishes (Birdsong et al. 2019).

The entirety of the mainstem Canadian River in Texas as well as a portion of Palo Duro Creek, which flows into the North Canadian River/Beaver River in Oklahoma, has been identified as the Canadian River NFCA (Birdsong et al. 2019). Primary stressors within the NFCA include groundwater extraction, habitat fragmentation, dewatering, flow regime alteration, water pollution, and introduction of non-native species.

There are two USGS streamflow gages within the NFCA in Texas: Gage # 07227500 Canadian River near Amarillo, TX and Gage # 07228000 Canadian River near Canadian, TX. Using hydrology-based flow targets for subsistence and base flows, estimated deficits are 142 ac-ft/yr for summer subsistence and 809 ac-ft for summer base flows at the Canadian River near Amarillo gage (TCS 2019). Using hydrology-based flow targets for base and subsistence flows, the Canadian River near Canadian gage shows no environmental flow deficits in any season (TCS 2019).

#### 4.1.2 Surface Water Rights and Return Flows

There are nine HUC 8s that contribute streamflow or lie within the Canadian River NFCA. The bulk of the surface water rights are in the Lake Meredith HUC 8 with 12 rights for a total authorized quantity of 151, 589 a-ft/yr. The Palo Duro HUC 8 contains 12 water rights with a total authorized amount of 11,666 a-ft/yr. For the rest of the contributing HUCs, there are a combined 12 water rights for 1823 ac-ft/yr.

Within the Canadian River NFCA there are nine permitted surface water rights with a total annual volume of 152,290 ac-ft. Most of the permitted water in the NFCA is for Lake Meredith (151,200 ac-ft/yr). In general, the other water rights in the NFCA are for agricultural, mining, water quality protection connected to the oil industry, and non-consumptive recreational use with a cumulative volume of 1090 ac-ft/yr.

The largest water right for Lake Meredith, the one major reservoir in the Texas portion of the NFCA, authorizes the impoundment of 1,407,572 ac-ft of water and the annual use of 151,200 ac-ft for municipal and industrial uses. Lake Meredith is owned by the Canadian River Municipal Water Authority and governed by the Canadian River Compact. The States of New Mexico, Texas and Oklahoma are all parties to the compact created by agreement of the three states and the federal government in 1950. According to the compact, New Mexico can hold 200,000 ac-ft in Ute Lake before it must release water to Texas. Texas can only hold 500,000 ac-ft in Lake Meredith before it must release water downstream to Oklahoma.

Ute Reservoir, owned and operated by the State of New Mexico, is located about 20 miles west of the Texas state line, has a water surface of 8200 acres and a maximum capacity of 403,000 a-ft. Water from the reservoir is used for municipal purposes. The two reservoirs have effectively bifurcated the Canadian River into discrete segments with altered hydrology and fish communities. Canadian River segments upstream and downstream of Lake Meredith were identified by TPWD (2016a) as ecologically significant based upon proximity to riparian conservation areas and the presence of imperiled species and unique biological communities. Water right permits for diversions and their volumes are summarized by watershed unit (i.e., HUCs that contribute to the upper Canadian River NFCA) in Table 1.

Table 1. Water right permits in contributing watersheds of the Upper Canadian River NFCA.

|  |  |  |  |
| --- | --- | --- | --- |
| HUC 8 name | Number of water rights | Permitted amount (ac-ft/yr) | Storage capacity (ac-ft) |
| Middle Canadian-Trujillo | 0 | 0 | 0 |
| Punta de Agua | 0 | 0 | 0 |
| Lake Meredith | 12 | 151, 589 | 1,409,351.78 |
| Middle Canadian - Spring | 7 | 1471 | 1664.8 |
| Palo Duro | 12 | 11,666 | 61,338.4 |
| Lower Beaver | 1 | 102 | 0 |
| Upper Wolf | 1 | 0 | 862 |
| Lower Wolf | 1 | 20 | 0 |
| Coldwater | 2 | 230 | 30 |
| TOTAL | 36 | 165,078 | 1,473,246.98 |

#### 4.1.3 Groundwater

The Canadian River NFCA is underlain by two aquifers – the minor Dockum and the major Ogallala. The Dockum Aquifer occurs upstream of Lake Meredith and is generally deeper than the Ogallala.  Saturated thicknesses for the Dockum Aquifer range from 100 ft to 2,000 ft.  Concentrations of Total Dissolved Solids (TDS) in the Dockum Aquifer range from less than 1,000 mg/L in the eastern outcrop of the aquifer to more than 20,000 mg/L in the deeper parts of the formation to the west. Groundwater from the aquifer is used for irrigation, municipal water supply, and oil field waterflooding operations, particularly in the southern High Plains. Water level declines and rises have occurred in different areas of the aquifer (George et al. 2011).

The Ogallala Aquifer, which underlays much of the High Plains region, consists of sand, gravel, clay, and silt and has a maximum thickness of 800 feet. Freshwater saturated thickness averages 95 feet. Water to the north of the Canadian River is generally fresh with water quality worsening to the south due to large areas with total dissolved solids in excess of 1000 milligrams per liter. High levels of naturally occurring arsenic, radionuclides, and fluoride in excess of the primary drinking water standards are also present (George et al. 2011).

The Ogallala Aquifer provides significantly more water for users than any other aquifer in the state and approximately 95% of groundwater pumped is used for irrigated agriculture. Throughout much of the aquifer, groundwater withdrawals exceed the amount of recharge, and water levels have declined through time. Although water level declines in excess of 300 feet have occurred in several areas over the last 50 to 60 years, the rate of decline has slowed, and water levels have risen in a few areas (George et al. 2011). Recharge to the Ogallala occurs principally by infiltration of precipitation on the surface and, to a lesser extent, by upward leakage from underlying formations. Only about one inch of the precipitation reaches the water table annually because rainfall is minimal, the evaporation rate is high, and the infiltration rate is slow. The highest recharge infiltration rates occur in areas overlain by sandy soils and in playa-lake basins. Reduced groundwater pumping in some areas of the High Plains has resulted in a reduction in the rate of water-level decline (Ashworth and Hopkins 1995).

In some portions of the range of the Arkansas River Shiner, groundwater pumping has been blamed for lowering of water tables and resultant decreases in streamflow. However, in the area of interest for this document, the Canadian River channel has become incised to an elevation below the major regional aquifer, the Ogallala, so there is little influence on river flows due to the presence of the aquifer. There is some flow from seeps and springs which has, in the past, contributed a minor portion of the river flow, but these flows historically represented less than one percent of the total flow of the river (USFWS 1998).

There are two groundwater conservation districts within the NFCA. The Panhandle Groundwater Conservation District (PGCD) in the middle of the NFCA has a stated purpose to provide for the conservation, preservation, protection, recharging, and prevention of waste of the groundwater, and of groundwater reservoirs or their subdivisions within the district boundaries. The PGCD regulates the Ogallala and Dockum aquifers within its boundaries with a series of rules and regulations on pumping limits, well spacing, and use of best conservation practices.

The Hemphill County Underground Water Conservation District (HCUWCD) is at the easternmost extent of the Canadian River in Texas in Hemphill County. The mission of the HCUWCD is to conserve and protect the groundwater resources of Hemphill County, by ensuring sustainable development through local management and the best available science. The primary aquifer in the district is the Ogallala Aquifer. The district uses a similar set of rules and regulations as the PGCD to achieve its mission.

Across the Canadian River NFCA groundwater use varies by county. Average annual groundwater use is less than 10,000 ac-ft for all counties except Potter and Hutchinson. Potter County in the western portion of the NFCA uses an annual average of 45,400 ac-ft, with the majority used for municipal and irrigation. Hutchinson County’s average annual groundwater use is 79,400 ac-ft with the majority used for irrigation and manufacturing (TWDB 2016).

County wide trends in groundwater well levels from 2000 to the present follows an east-west trend of decreasing to increasing. The majority of wells in Oldham and Potter counties follow a decreasing trend while in Oldham County the percentage of wells decreasing, increasing, or stable are 50%, 22%, and 28%, respectively. In Potter County the percentage of wells decreasing, increasing, or stable are 90%, 10%, and 0%, respectively. In Roberts and Hemphill counties the level of many wells is stable and increasing, respectively. Hutchinson County data is insufficient to determine water level trends.

#### 4.1.4 Land Use Management

##### 4.1.4a Improvements in Agriculture Irrigation Efficiencies

Current and future efforts by the agricultural community to conserve water and improve irrigation efficiencies can reduce withdrawals from the Ogallala Aquifer and potentially restore local groundwater-surface water connections. A combination of approaches to reduce demands on High Plains aquifers include advances in plant breeding to improve plant water-yield ratios, changes in irrigation scheduling, use of efficient irrigation equipment and, where appropriate, a change in crop type. In addition, regional water planning groups in the area encourage the use of all irrigation conservation strategies and the inclusion of conservation education, such as demonstration events, into irrigation conservation programs to enhance the adoption of the recommended practices. The potential water savings due to use of a suite of agricultural conservation strategies is greater than 500,000 ac-ft by year 2070 (Freese and Nichols, Inc. et al. 2016).

##### 4.1.4b Playa Lake Restoration

Counties north of the Canadian River and along the Caprock escarpment have clustered playa basin distributions. Counties southwest of this region have high playa density and regular spatial distribution. Playa lakes are plentiful in the Canadian NFCA and their protection and restoration could potentially help reduce groundwater drawdown in areas of the NFCA. Playas could also serve as an alternate source of water for irrigation, relieving some of the extraction demands from underlying aquifers.

##### 4.1.4c Invasive Riparian Vegetation Management

Invasive riparian vegetation is prominent in the Canadian River watershed including salt cedar *Tamarix* spp. and Russian olive *Elaeagnus angustifolia*. Salt cedar may be the dominant species within the High Plains- Floodplain Deciduous Forest and the High Plains- Riparian Hardwood Forest ecosystem types in the Canadian River watershed (see Robertson et al. 2017). To date, the CRMWA has treated nearly 27,000 acres of salt cedar in the watershed upstream of Lake Meredith to increase flows in the Canadian River, to improve water quality, and improve habitat for native fishes such as the federally listed Arkansas River Shiner. CRMWA estimates that salt cedar (27,000 acres) was using between 80,676 and 188,293 ac-ft/yr. CRMWA is currently maintaining initial eradication efforts by re-treating areas as needed (Canadian River Municipal Water Authority [CRMWA], <https://www.crmwa.com/salt-cedar-management-program>).

#### 4.1.5 Analysis of Opportunities

In the Canadian River NFCA, the greatest probability of occurrence for the rare and imperiled focal species Peppered Chub, Arkansas River Shiner, and Plains Minnow is in the mainstem Canadian River between Ute Reservoir in New Mexico and Lake Meredith in Texas. These two reservoirs control most of the water in the Canadian River NFCA and, as previously noted, have altered the hydrology of the river. Within the NFCA, there are few surface water right permits impacting the river besides the Lake Meredith water right. While groundwater development has impacted the Canadian River and its tributaries, declining water levels from pumping and slow recharge rates have led to a disconnect between surface water and groundwater, reducing the potential efficacy of groundwater-based flow restoration strategies. Therefore, the most promising strategy for maintaining or enhancing streamflow downstream of Ute Reservoir or restoring streamflow downstream of Lake Meredith for these species could be managed dam operations that coordinate releases of water for downstream human needs with environmental flow needs, potentially addressing vital streamflow requirements for important life history requirements of focal species. This has been successfully undertaken on a voluntary, stakeholder-driven basis in other areas (Richter et al. 2006, Warner et al. 2014), including in Texas (Smith et al. 2019). Management of invasive riparian vegetation should continue to improve water quantity and quality in the Canadian River in support of habitat and hydrological conditions needed to maintain focal fishes. The following activities represent potential environmental flow protection and restoration strategies for the upper Canadian River NFCA:

###### Flow Protection Strategies for the Upper Canadian River NFCA

* Management of dam operations to meet environmental and human water needs
* Inclusion of the necessary infrastructure in dams to supply releases of low and high flows as part of a natural flow regime in new reservoirs
* Reduced pumping/drilling in aquifers that contribute flows to the NFCA

###### Flow Restoration Strategies for the Upper Canadian River NFCA

* Surface water rights transactions
* Reservoir reoperation where available and feasible
* Management of salt cedar and other invasive riparian species
* Restore fragmented reaches by mitigating/removing barriers to fish movement
* Improvements in agriculture irrigation efficiencies

### 4.2 Upper Red River Native Fish Conservation Area

#### 4.2.1 Basic Description of the NFCA

#### The Red River begins in New Mexico, extends across the Texas Panhandle and forms the Oklahoma-Texas border to Arkansas. The Texas portion of this river basin is 680 miles long and its drainage area is 24,463 square miles. Smaller streams within the Texas portion of the basin include the forks of the Red River and the Pease, Wichita, and Little Wichita rivers.  The Red River Compact between Arkansas, Louisiana, Oklahoma, and Texas apportions the waters of the Red River and its tributaries.  High levels of naturally occurring chloride in some surface waters of the basin are a concern, and federally funded chloride control projects have been operating there since 1962.  In the past, the region has depended heavily on groundwater supplies, but these supplies are projected to decline in the future.

#### The upper basin is largely comprised of prairie streams and rivers with sandy bottoms and contains substantial amounts of natural chlorides leading to unique fish assemblages. Low rolling hills and prairies and nearly level valleys characterize the lower basin. Eleven water body segments are listed as impaired for not meeting the state water quality standard for bacteria, low dissolved oxygen concentrations and selenium (chronic) in water. Water used for irrigated agriculture accounts for about 76% of the total water use, with municipal use at 15% and industrial uses at less than 10% (TPWD 2006).

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#### Within the Great Plains of Texas landscape, the Upper Red River NFCA starts near Canyon on the Prairie Dog Town Fork Red River and extends eastward to the Red River near Mineral Wells. Portions of the NFCA occur in the Red, Prairie Dog Town Fork, Pease, and Wichita watersheds. Fishes of concern in the Upper Red River NFCA include American Eel Anguilla rostrata, Goldeye Hiodon alosoides, Plains Minnow Hybognathus placitus, Prairie Chub Macrhybopsis australis, Shoal chub Macrhybopsis hyostoma, Silver Chub Macrhybopsis storeriana, Red River Shiner Notropis bairdi, River Shiner Notropis blennius, Chub Shiner Notropis potteri, Suckermouth Minnow Phenacobius mirabilis, Red River Pupfish Cyprinodon rubrofluviatilis, and River Darter Percina shumardi.

#### Primary threats to these species are groundwater extraction, habitat fragmentation, stream dewatering, flow regime alteration, water pollution, and the proliferation of non-native species including invasive salt cedar. Potential groundwater contamination may supplant water quantity as a consideration in evaluating the amount of water available for use in some areas. Water development in the Red River basin has been significant. Major and minor reservoirs are present on forks and tributaries throughout the basin, altering the flow regime and water quality of riverine systems. It is not likely that any state threatened mussels would be found in the Great Plains portion of the Red River basin (Native Fish Conservation Network, <https://nativefishconservation.org/upper-red-river-nfca-profile/>).

### 4.2.2 Surface Water Rights and Return Flows

There are four major watersheds that contribute streamflow to the Upper Red River NFCA – the Red, Prairie Dog Town, Pease, and Wichita. Each of the watersheds has a number of surface water rights for primarily municipal, irrigation and recreation usages. Several rights include authorization for diversion and/or storage of waters with a high brine content to prevent mixing with fresher downstream waters.

##### Red River watershed

Within the Red River watershed, there are 20 water rights with a total authorized use amount of 17,963.2 ac-ft and a storage quantity of 59,642.75 ac-ft. Most of the authorized use and storage is in the Upper Salt Fork Red HUC 8 which contains Greenbelt Reservoir. The reservoir is primarily used for municipal supplies, but also has authorized use for irrigation, industrial and mining. The Lower Salt Fork Red (HUC 8) has five irrigation water rights for 716 ac-ft/yr and the Elm Fork Red (HUC 8) has 10 irrigation and recreation water rights that total 550 ac-ft/yr. Reflecting the arid nature of the area, the reliability of these water rights is generally low.

USGS gage #7299890 at Lelia Lake Creek below Bell Creek near Hedley, TX is the only USGS streamflow gage in the NFCA portion of the Red River sub-watershed. Target subsistence and base flows are low at 1.0 cfs and < 2.0 cfs, respectively, and attainment frequencies are essentially unchanged between pre- and post-flow alteration periods. Water right permit information for diversions and volumes are summarized by watershed unit (i.e., Red River HUCs that contribute to the upper Red River NFCA) in Table 2.

Table 2. Water right permits in contributing Red River watersheds of the Upper Red River NFCA.

|  |  |  |  |
| --- | --- | --- | --- |
| HUC 8 name | Number of water rights | Permitted amount (ac-ft/yr) | Storage capacity (ac-ft) |
| Upper Salt Fork Red | 5 | 16,697 | 59,101.25 |
| Lower Salt Fork Red | 5 | 716 | 420 |
| Elm Fork Red | 10 | 550.2 | 121.5 |
| TOTAL | 20 | 17,963.2 | 59,642.75 |

##### Prairie Dog Town Fork watershed

The Prairie Dog Town watershed has 54 surface water rights for 9739 ac-ft/yr for primarily municipal, irrigation and recreation purposes. There are numerous storage rights for water supply, wildlife, and brine control uses. In general, period reliability for water rights in the Prairie Dog Town watershed is low, especially for rights without ample storage. There are six HUC 8 sub-watersheds within or contributing to the Prairie Dog Town watershed. The Palo Duro (HUC 8) has five water rights with a total authorized use of 876 ac-ft/yr and a storage capacity of 5330 ac-ft. The water rights are primarily for recharge, irrigation, and recreation.

The Tierra Blanca (HUC 8) contains 11 water rights with a total authorized amount of 1082 ac-ft/yr and a cumulative storage capacity of 19,785 ac-ft. Most of the storage is in Buffalo Lake, a reservoir used for wildlife and recreational purposes. Though once a more reliable source of water, in recent years the lake is dry during droughts, although major storms occasionally flood Tierra Blanca Creek. Several species of waterfowl use the lake as a winter refuge (U. S. Fish and Wildlife Service <https://www.fws.gov/refuge/Buffalo_Lake/about.html>). There is one USGS streamflow gage within the HUC 8, Tierra Blanca Creek above Buffalo Lake near Umbarger, TX (#0729550). Subsistence and base streamflows at the gage are highly altered for all seasons with the largest flow deficits in winter.

The Tule sub-watershed (HUC 8) has 15 water rights within its boundaries for a total authorized amount of 6340 a-ft/yr and a storage capacity of 47,663 ac-ft. Most of the appropriated water is associated with Lake McKenzie which has an authorized use of 5200 ac-ft/yr for municipal and industrial purposes and a 46,450 ac-foot capacity reservoir on Tule Creek with an impoundment authorization of not to exceed 13,935 ac-ft of water.

The Upper Prairie Dog Town Fork Red (HUC 8) contains seven water rights for 492 ac-ft/yr and a storage capacity of 8577 ac-ft. Water in this HUC is used for irrigation, recreation, municipal, and multiple uses. The largest reservoir in the HUC is Lake Tanglewood with a permitted capacity of 4897 ac-ft.

The Lower Prairie Dog Town Fork Red (HUC 8) has eight water rights with a total authorized use of 455.5 ac-ft/yr and a combined storage capacity of 16,272 ac-ft. Baylor Lake and Lake Childress account for 12,545 ac-ft of the storage and are used for municipal purposes. USGS gage #7299300 at Little Red River near Turkey, TX is within the Lower Prairie Dog Town Fork Red (HUC 8). Target subsistence and base flows are both 1.0 cfs and, though seldom met, the flow attainment frequencies are consistent between pre- and post-flow alteration periods.

There are eight water rights with a total permitted use amount of 550 ac-ft/yr and 240 ac-ft of storage in the Groesbeck-Sandy (HUC 8). All but one of the water rights is for irrigation, the other is for recreation, and have high reliabilities. Streamflow at the one streamflow gage in the HUC 8, USGS gage #7299670 at Groesbeck Creek at SH 6 near Quanis, TX, shows little alteration. Subsistence flow targets of 1 to 2 cfs are met a high percentage of the time and attainment frequencies for base flows are consistent between pre- and post-flow alteration periods. Water right permit information for diversions and volumes are summarized by watershed unit (i.e., Prairie Dog Town Fork River HUCs that contribute to the upper Red River NFCA) in Table 3.

Table 3. Water right permits in contributing Prairie Dog Town Fork watersheds of the Upper Red River NFCA.

|  |  |  |  |
| --- | --- | --- | --- |
| HUC 8 name | Number of water rights | Permitted amount (ac-ft/yr) | Storage capacity (ac-ft) |
| Palo Duro | 5 | 876 | 5330 |
| Tierra Blanca | 11 | 1082 | 19,785 |
| Tule | 15 | 6340 | 47,663 |
| Upper Prairie Dog Town Fork | 7 | 492 | 8577 |
| Lower Prairie Dog Town Fork | 8 | 455.5 | 16,272 |
| Groesbeck - Sandy | 8 | 550 | 240 |
| TOTAL | 54 | 9795.5 | 97,867 |

##### Pease River watershed

The Pease River watershed includes 19 surface water rights with a total annual authorized use amount of 893.5 ac-ft and storage of 2967 ac-ft. Primary uses of the water are for irrigation, recreation, and multiple/municipal purposes. There are three HUC 8 sub-watersheds within or contributing to the Pease River watershed: the North Pease, the Middle Pease, and the Pease.

The North Pease (HUC 8) has 13 water rights with a total authorized use of 611.8 ac-ft/yr and a storage capacity of 4235 ac-ft. The water rights are primarily for irrigation and recreation. With a few exceptions, most of the water rights have a high reliability.

There are four water rights in the Middle Pease (HUC 8) with a total permitted amount of 158.7 ac-ft/yr and total storage of 155.3 ac-ft. The water rights are for irrigation and recreation and, aside from one irrigation right for 22.7 ac-ft/yr with a reliability of 88% (Certificate of Adjuducation # 5111), the rights are not dependable.

The Pease (HUC 8) contains two water rights with an authorized amount of 195 ac-ft/yr and storage of 455 ac-ft. The water rights are used for irrigation and multiple purposes. Of the two water rights, storage helps to shore up reliability. There are three USGS streamflow gages within the Pease sub-watershed. USGS gage #7307800 at the Pease River near Childress, TXshows no deficits for target flows with increases in attainment frequencies for several seasons at subsistence and base flow levels. Flows at USGS gage # 7308000 at Pease River near Crowell, TX are not altered with the 1.0 cfs subsistence flow met 63 to 83% of the time and base flows met even less often. Target flow attainment frequencies at USGS gage # 7308200 at Pease River near Vernon, TX are intriguing. Subsistence and base flows show increased attainment for spring, summer and winter. For fall, subsistence flows are met slightly more often (4.8%) while base target has a moderate alteration and a deficit of 99 ac-ft. The subsistence flow is 1.0 cfs for all seasons and is met between approximately 64 and 81% of the time. Water right permit information for diversions and volumes are summarized by watershed unit (i.e., Pease River HUCs that contribute to the upper Red River NFCA) in Table 4.

Table 4. Water right permits in contributing Pease River watersheds of the Upper Red River NFCA.

|  |  |  |  |
| --- | --- | --- | --- |
| HUC 8 name | Number of water rights | Permitted amount (ac-ft/yr) | Storage capacity (ac-ft) |
| North Pease | 13 | 611.8 | 4235 |
| Middle Pease | 4 | 158.7 | 155.3 |
| Pease | 2 | 195 | 455 |
| TOTAL | 19 | 965.5 | 5810.8 |

##### Wichita River watershed

The Wichita River watershed contains 27 surface water right permits for 242,660 ac-ft/yr. Most of this amount is in Lake Kemp which has a use amount of 193,000 ac-ft/yr and a capacity of 363,000 ac-ft. Four HUC 8s are within or contribute to the NFCA portion of the Wichita River watershed: the North Wichita, South Wichita, Wichita, and Little Wichita.

The North Wichita (HUC 8) has three water rights with a total authorized use of 3080 ac-ft/yr and a storage capacity of 110,190 ac-ft. Most of the use and storage amount is associated with Truscott Brine Reservoir which, as a component of the federal chloride control project, serves as a regional evaporation lake for receiving waters with high chloride concentrations from area streams. The other water rights are for transporting water to the Truscott Brine Reservoir and irrigation. USGS streamflow gage # 7311700 at North Wichita River near Truscott, TX is within the North Wichita sub-watershed and shows negligible alteration of flow target attainment frequencies except for fall base flows. The fall base flow deficit is about 68 ac-ft.

There are two water rights in the South Wichita (HUC 8) with a total permitted amount of 8780 ac-ft/yr and no authorized storage. The water rights are for the transport of water from the South Wichita River to the Truscott Brine Reservoir during low flow, high saline conditions. Reliability of these water rights is 2%. Two USGS streamflow gages are in the sub-watershed: # 7311800 at South Wichita River near Benjamin and # 7311900 at Wichita River near Seymour, TX. At the South Wichita River near Benjamin, TX, depending on season, attainment frequencies are negligibly altered (summer base and subsistence), moderately altered (fall, winter and spring subsistence flows), and highly altered (fall, winter and spring base flows). Base flow deficits are highest in winter at 142 ac-ft. For the Wichita River near Seymour, attainment frequencies vary by season and flow component. Subsistence flows are negligibly altered in spring, moderately altered summer and fall, and highly altered in winter. Base flows are moderately altered spring and summer and highly altered fall and winter. The fall base flow deficit is 945 ac-ft.

The Wichita (HUC 8) contains 21 water rights with an authorized amount of 230,598 ac-ft/yr and storage of 309,809.35 ac-ft. Most of the use and storage are associated with Lake Kemp and Diversion Lake near Wichita Falls and, to a lesser extent, North Fork Buffalo Lake. The water rights are used for municipal, industrial, and irrigation purposes. Water right permit information for diversions and volumes are summarized by watershed unit (i.e., Wichita River HUCs that contribute to the upper Red River NFCA) in Table 5.

In 1959 the U.S. Congress authorized the U.S. Army Corps of Engineers to develop plans to control the natural salt concentrations in the Red River basin in Texas and Oklahoma. A regional chloride-control plan was developed for the Red River basin that included three brine storage lakes; several low-flow, brine-collection areas in four sub-basins; and pipeline and pumping-station facilities for transporting the collected brines to the storage lakes (U.S. Army Corps of Engineers 1980). The plan to retain the brines in a specific depository by storage and evaporation was found to be the most feasible of several alternatives that were considered (Garza 1983). The chloride control project is in the Wichita River watershed and operates to reduce the chloride load entering Lake Kemp and Diversion Lake. Parts of the project (e.g. Truscott Brine Lake) have been in operation for decades.

Table 5. Water right permits in contributing Wichita River watersheds of the Upper Red River NFCA.

|  |  |  |  |
| --- | --- | --- | --- |
| HUC 8 name | Number of water rights | Permitted amount (ac-ft/yr) | Storage capacity (ac-ft) |
| North Wichita | 3 | 3080 | 110,190 |
| South Wichita | 2 | 8780 | - |
| Wichita | 21 | 230,598 | 309,809.35 |
| Little Wichita | 1 | 200 | 370 |
| TOTAL | 27 | 242,658 | 420,369.35 |

#### 4.2.3 Groundwater

The Upper Red River NFCA is underlain by the major Ogallala and Seymour aquifers and the minor Dockum and Blaine aquifers. Across the Upper Red River NFCA, groundwater use varies by county. There are five counties with average annual groundwater use less than 10,000 ac-ft,, six counties with annual use greater than 10,000 ac-ft but less than 35,000 ac-ft, and six counties with annual use greater than 35,000 ac-ft. Swisher County uses the most groundwater with an annual average of 172,232 ac-ft, followed by Randall County at 57,200 ac-ft/yr.

County wide trends in groundwater well level decline from 2000 to present vary by county. Of the five counties with use less than 10,000 ac-ft, three show stable trends, one has a decreasing trend, and one has insufficient data to determine a trend. Of the six counties with use greater than 10,000 ac-ft but less than 35,000 ac-ft, two show stable trends, three show decreasing trends, and two show increasing trends. Of the six counties with use greater than 35,000 ac-ft, three show stable trends and three show decreasing trends.

The area is part of state regional water planning Region B, whose 2016 water plan (Biggs & Matthews, Inc. et al. 2015) notes that groundwater is a major source of water for much of the western portion of the region. The Seymour Aquifer, which is generally unconfined, is fairly responsive to local recharge and may benefit from enhanced recharge programs. Further study is needed to determine the applicability of such programs, the quantity of increased groundwater supplies that may result from enhanced recharge, and the potential impacts to existing surface water rights and the environment in Region B.

#### 4.2.4 Land Use Management

Few playa lakes occur within the Upper Red River NFCA as most in the Great Plains are west of the NFCA. A cluster of playa lakes are found in the upstream end of the Prairie Dog Town Red River. In general, groundwater well data in the counties with playas show declining water level trends which may limit consideration of playa lake restoration and recharge strategies for addressing environmental flow deficits.

Riparian management of invasive vegetation has been a component of chloride control efforts in the Red River basin. Salt cedar (*Tamarix chinensis*) has become established and dominates the riparian vegetation in many areas of the Wichita River Basin. Encroachment by salt cedar is detrimental because this plant tends to form monocultures having little value for fish or wildlife. While it is generally acknowledged that reducing the salt cedar infestation will result in less water lost through transpiration, the quantity of water remaining instream is difficult to ascertain.

The Region B 2016 water plan (Biggs & Matthews, Inc. et al. 2015) identifies improved agricultural water conservation as a strategy for addressing human water demand deficits and needs in the 50-year water planning horizon. For irrigated agriculture, the primary demand reduction strategies include changes in irrigation equipment, crop type changes and crop variety changes, conversion from irrigated to dry land farming, and water loss reduction in irrigation canals. Calculated at 10% of demand, voluntary on-farm conservation was estimated to reduce demand by over 22,000 ac-ft/yr. Water conserved through water loss reduction on irrigation canals is estimated at over 12,000 ac-ft/yr for the Region B water planning area (Biggs & Matthews, Inc. et al. 2015). In addition, brush control studies indicate there is potential for water loss reduction from brush management, but these losses have been difficult to quantify during periods of drought.

#### 4.2.5 Analysis of Opportunities

Results of attainment frequency analysis of Red River NFCA basin flow targets indicate that degree of alteration of key ecological features of flow varies considerably across the NFCA. While attainment frequencies of metrics at some locations have increased relative to pre-1980 numbers, they have decreased moderately to highly at other sites. This is most notable at the Pease River near Vernon, the South Wichita River near Benjamin and the Wichita River near Seymour. While EWTs might help decrease subsistence and base flow deficits, the highly saline water in parts of the NFCA and low surface water reliabilities throughout the NFCA present problems for developing effective environmental flow strategies. Where available and feasible, reservoir reoperations are an option worthy of investigation as storage improves water right reliability and might offer an opportunity to meet downstream human needs while simultaneously providing environmental flows during critical periods. Additional analysis using projections of the effects of proposed future water management strategies on flows could be used to evaluate potential increases in attainment frequency of ecology-based flow targets. The following activities represent potential environmental flow protection and restoration strategies for the Upper Red River NFCA:

##### Flow Protection Strategies for the Upper Red River NFCA

* Enforcement of water rights, diversion restrictions and volumes
* Avoid fragmentation in critical habitat
* Minimize pumping/drilling from Seymour and other aquifers that contribute flows to the NFCA
* Inclusion of the necessary infrastructure to supply releases from multiple levels to protect water quality conditions and to accommodate releases of low and high flows as part of a natural flow regime in new reservoirs

##### Flow Restoration Strategies for the Upper Red River NFCA

* Surface water right transactions for restoration and future flow needs.
* Reservoir reoperation where available and feasible
* Agricultural demand reductions/conservation
* Restore fragmented reaches by mitigating/removing barriers to fish movement

### 4.3 Upper Brazos River Native Fish Conservation Area

#### 4.3.1 Basic Description of the NFCA

The Upper Brazos River NFCA (Birdsong et al. 2019) comprises the Brazos River and its tributaries (Clear Fork Brazos River, Salt Fork Brazos River and Double Mountain Fork Brazos River) upstream of Lake Possum Kingdom. This watershed is largely free-flowing and characterized by shallow, sandy, and braided stream channels. The Salt Fork Brazos River (SFBR) is fed by numerous Permian brine springs that at times lead to salinities greater than the Gulf of Mexico and very clear waters. The White River, a tributary of the Salt Fork, was once fed by the fresher Ogallala Aquifer and was impounded in 1963 with the construction of White River Reservoir. Leakage from the dam forms a small trickle and groundwater pumping for irrigation has dried up nearly all springs fed by the Ogallala in the Salt Fork watershed (Brune 2002). Lake Alan Henry, constructed in 1993, impounds the Double Mountain Fork Brazos River (DMFBR) before its confluence with the North Fork Double Mountain Fork Brazos River (NFDMFBR). Portions of the DMFBR are also underlain by the Ogallala (Brune 2002). The Clear Fork Brazos River supports habitat for native fishes and supplies water to the lower portion of the Brazos River mainstem supporting critical habitat for Smalleye and Sharpnose shiners.

Reservoir construction and operation, groundwater pumping and surface water diversions, and the invasion of the Brazos River landscape by salt cedar, among other impacts, have altered the Brazos River and its riparian and aquatic communities (Mayes et al. 2019). A long-standing invasion of salt cedar (*Tamarix* spp.) has contributed to channel-narrowing and deepening (Blackburn et al. 1982) with potential consequences on hydraulic habitat and use.

Since its introduction to the Brazos River watershed in the first half of the 1900s, salt cedar has expanded and is typically found in high density stands along the river’s edge; new growth is often found in the river channel. Salt cedar colonizes stream floodplains and terraces, armoring river terraces and reducing the ability of a stream to meander. As the channel narrows, stream depth increases and temperature decreases.

The native fishes of the Upper Brazos River NFCA are structured by spatial and temporal variations in environmental conditions such as salinity and hydraulic habitat as well as isolating constraints from downstream dams. In the saline reaches, such as most of the Salt Fork Brazos River, salt-tolerant Red River Pupfish *Cyprinodon rubrofluviatilis* and Plains Killifish *Fundulus zebrinus* dominate assemblages, while in fresher reaches (NFDMFBR, DMFBR and the Brazos River) fish species richness is greater due to the presence of numerous cyprinids. Of note are the minnows in the pelagic, broadcast-spawning reproductive guild which require long reaches of free-flowing riverine habitat (Smalleye Shiner *Notropis buccula*, Sharpnose Shiner *N. oxyrhynchus*, Chub Shiner *N. potteri* and Plains Minnow *Hybognathus placitus*). The Sharpnose Shiner and Smalleye Shiner were both listed as endangered by the USFWS in 2014 due to dramatically reduced distributions and ongoing impacts, looming threats, and effects of drought (Mayes et al. 2019). The USFWS also designated most of the upper Brazos River watershed as critical habitat for these two endangered species.

#### 4.3.2 Surface Water Rights and Return Flows

In the Great Plains portion of the upper Brazos River watershed, there are about 154 surface water rights for diversion totaling 230,855 ac-ft/year. Most of these diversion rights (99) are for irrigation use and total 16,740 ac-ft/yr. Municipal rights (20) account for 103,000 ac-ft/yr. Six rights for industrial use account for 18,190 ac-ft/yr; 11 multiple uses for 78,710 ac-ft/yr; 7 mining use for 7,410 ac-ft/yr; and 10 recreation use for 7,050 ac-ft/yr. Permits for diversions and their volumes are summarized by watershed unit (i.e., HUCs that contribute to the Upper Brazos River NFCA) in Table 6.

Table 6. Water right permits within the Upper Brazos River watershed

|  |  |  |
| --- | --- | --- |
| HUC name | Number of Rights | Volume (ac-ft/yr) |
| Clear Fork | 62 | 101,390 |
| Middle Brazos/Millers Creek | 14 | 7820 |
| Paint Creek/California Creek | 11 | 16,490 |
| Double Mountain Fork Brazos River | 13 | 43,000 |
| North Fork DMFBR | 8 | 49,940 |
| Salt Fork Brazos River | 9 | 1480 |
| White River | 5 | 6090 |
| Running Water Draw | 30 | 4340 |
| Blackwater Draw | 2 | 305 |
| Yellowhouse Draw | 0 | 0 |
| TOTALS | 154 | 230,855 |

The City of Lubbock discharges water from its wastewater treatment plants into the North Fork DMFBR which supplies base flows to downstream reaches though all seasons.

#### 4.3.4 Groundwater Management

The Upper Brazos River NFCA is underlain by the Ogallala, Seymour and Edwards-Trinity (Plateau) major aquifers and the Dockum, Blaine and Trinity-Edwards (High Plains) minor aquifers. Across the Upper Brazos River NFCA, groundwater use varies by county. There are five counties with an average annual groundwater use of less than 10,000 ac-ft and five with an average annual groundwater use greater than 10,000 ac-ft. Lubbock County uses the most groundwater with an annual average use of 247,148 ac-ft followed by Crosby County with an average annual use of 123,524 ac-ft.

County wide trends in groundwater well depletion from 2000 to present vary by county. Of the five counties with use less than 10,000 ac-ft, three show stable trends and two show decreasing trends. Of the five counties with use greater than 10,000 ac-ft, three show stable trends and two show decreasing trends.

There are six groundwater conservation districts (GCD) in the Great Plains portion of the upper Brazos River watershed: High Plains, Garza County, Clear Fork, Wes-Tex, Rolling Plains, and Gateway GCDs.

#### 4.3.5 Reservoirs and Re-operations

Major water supply reservoirs include Alan Henry Reservoir on the Double Mountain Fork Brazos River, White River Lake on the White River, Lake Davis, Millers Creek Reservoir on Miller Creek, Lake Stamford, and at the downstream end of the NFCA, Lake Possum Kingdom on the mainstem Brazos River. A series of dams was constructed on the North Fork Double Mountain Fork to capture a portion of City of Lubbock return flows.

#### 4.3.6 Land Use Management

Efforts to manage the invasion of salt cedar in the Upper Brazos River NFCA are being led by TPWD and USFWS. From 2016 to 2018, partners treated 10,400 acres (4209 hectares) of salt cedar in the Salt Fork, North Fork DMFBR, and DMFBR watersheds; treatments were conducted in 2019 and are being planned for 2020. Ongoing monitoring efforts are designed to assess post-treatment effects on hydrology, instream habitat, and riparian habitat. Hydrologic modeling (see Mayes et al. 2019) in the DMFBR indicates modest gains in water yield (up to 344,000 L/ha at 75% reduction in salt cedar [~0.7 ac-ft/acre]). Since 2013, the City of Lubbock has treated salt cedar upstream of Lake Alan Henry. The USGS (Harwell et al. 2016) simulated effects of salt cedar control on water yield in the upstream watershed and predicted an increase of 5700 ac-ft/yr. The U.S. Department of Agriculture-Natural Resources Conservation Service and the Texas AgriLife Research and Extension have also released salt cedar beetles to assist in control efforts.

#### 4.3.7 Analysis of Opportunities

Results of attainment frequency analysis of hydrology-based flow targets indicate that most gages in the Upper Brazos River NFCA have been only slightly altered. Attainment frequencies of some metrics at some locations have increased relative to pre-1980 numbers. This is particularly true for the Double Mountain Fork Brazos River at Aspermont, TX and the Brazos River at Seymour, TX. This suggests that, while water transactions to augment summer subsistence and base flow should certainly be evaluated, the primary strategy in this portion of the basin should be flow protection. To ensure successful recruitment and persistence of Smalleye Shiner, Sharpnose Shiner, and other native fishes in the Upper Brazos River NFCA it will be important to pursue strategies to maintain flows during the summer/spawning months. These strategies could include such actions as flow protections as components of future water management projects (e.g., use of former return flows for other purposes in Lubbock), flow agreements as part of regional or other water planning, and transaction strategies focused on maintaining current flows rather than augmentation.

Streamflow gages in the Clear Fork Brazos River are highly altered including the Clear Fork Brazos River near Roby, TX (USGS Gage #08083100) and Clear Fork Brazos River near Hawley, TX (USGS Gage #08083240). Near Roby, base flow deficits range from 22–50 ac-ft/yr while subsistence flow deficits are 22–45 ac-ft/yr across seasons. Given these deficits, flow restoration strategies are most suitable in this watershed. The following activities represent potential environmental flow protection and restoration strategies for the Upper Brazos River NFCA:

##### Flow Protection Strategies for the Upper Brazos River NFCA

* Preserve return flows to the extent possible
* Clear Fork River flows need to be protected to support critical habitat
* Enforcement of water rights, diversion restrictions and volumes
* Avoid fragmentation in critical habitat
* Inclusion of the necessary infrastructure to supply releases from multiple levels to protect water quality conditions and to accommodate releases of low and high flows as part of a natural flow regime in new reservoirs
* Minimize pumping/drilling from Seymour and other aquifers that contribute flows to the NFCA

##### Flow Restoration Strategies for the Upper Brazos River NFCA

* Clear Fork flows need to be restored to support Smalleye Shiner and Sharpnose Shiner critical habitat in the Brazos River
* Surface water rights transactions for restoration and future flow needs.
* Reservoir reops where available and feasible
* Management of salt cedar in the upper Brazos NFCA and the HUCs that contribute flow to the NFCA should be continued and expanded in geography down to Lake Possum Kingdom.
* Playa lake management to restore or enhance recharge to the Ogallala and other aquifers
* Restore fragmented reaches by mitigating/removing barriers to fish movement
* Improvements in agriculture irrigation efficiencies

Further analysis using projections of the effects of proposed future environmental flow management strategies on flows could be used to evaluate potential increases in attainment frequency of ecology-based flow targets.

### 4.4 Upper Colorado River Native Fish Conservation Area

#### 4.4.1 Basic Description of NFCA

The Colorado River begins near Lamesa in the High Plains and Southwest Tablelands ecoregions and flows in a south east direction into the Gulf of Mexico. The hot semi-arid climate produces an annual average precipitation of 14 to 21 inches (Kos and Shafer 2017). Perennial streams are typified by low flows and most tributary streams are ephemeral or intermittent. The soils in the region can have elevated minerals and salts and some streams contain high levels of chloride and sulfates (TCEQ 2012). In contrast, some streams like the South Concho River are spring fed and have exceptional water quality (TCEQ 2012).

Rivers in the Great Plains portion of the Central Edwards Plateau River (CEPR) NFCA include the Concho River watershed and the Colorado River between O.H Ivie Reservoir and the San Saba County line. Fifty-four native freshwater fishes are found in the Central Edwards Plateau Rivers NFCA; 15 of which are Species of Greatest Conservation Need (SGCN fishes). The Concho and Colorado rivers supports several species of concern including the recently federally delisted Concho water snake *Nerodia paucimaculata*, state threatened Texas pimpleback *Quadrula petrina and* Texas fatmucket *Lampsilis bracteata*, Guadalupe Bass *Micropterus treculii* (SGCN), the spring-dependent Colorado Roundnose Minnow *Dionda* sp. 3, and the broadcast spawning cyprinids Shoal Chub *Macrhypobsis hyostoma* and Plains Minnow *Hybognathus placitus*. Threats to these and other native species include loss of habitat, habitat fragmentation due to reservoir construction, flow regime alteration including loss of springflow and baseflows, and the introduction of non-native species.

#### 4.4.2 Surface Water Rights and Reservoir Operations

The CEPR NFCA in the study area contains 11 streamflow gages that indicate hydrology has been altered using hydrology-based flow targets for base and subsistence flows. Six gages are located on streams in the NFCA and five gages are located on streams that contribute to the NFCA. Of those in the NFCA, four are located in the headwaters of the Concho River (North Concho River near Carlsbad, TX; Middle Concho River above Tankers, TX; South Concho at Christoval, TX and Pecan Creek near San Angelo, TX) and two are on the Concho River mainstem (Concho River at San Angelo, TX and Concho River at Paint Rock, TX). The headwaters of the Concho River are comprised of three forks: North, Middle and South Concho Rivers. Each fork feeds water supply reservoirs constructed near San Angelo.

Within the NFCA there are 246 permitted surface water rights with a total annual volume of 335,780 ac-ft. In general, the water rights are for agriculture, municipal, mining, and recreation uses. Five large reservoirs divide the NFCA into three distinct areas. Twin Buttes Reservoir, Lake Nasworthy and O.C. Fisher Lake separate the headwaters of the North, Middle, and South Concho rivers from the mainstem and O.H. Ivie Reservoir separates the Concho River from the mainstem of the Colorado River. O.C. Fisher Lake is located on the North Concho River and Twin Buttes Reservoir is located at the confluence of the Middle and South Concho rivers. Data on flow alteration, deficits, and water rights were assessed at the HUC 8 scale corresponding to each of the three Concho watersheds. Streamflow in the North and Middle Concho rivers is moderately to highly altered across seasons. Seasonal flow deficits range between 16 - 80 ac-ft for the North Concho and 43 – 312 ac-ft for the Middle Concho River. The North Concho River serves seven water rights used for irrigation and recreational purposes, totaling 611 ac-ft/yr that achieve moderate to low reliability. The Middle Concho River serves three irrigation water rights, totaling 189 ac-ft/yr that achieve low reliability. The South Concho watershed is comprised of four gaged tributaries which collectively yield more water and supports more water development than the other forks. Two of the four streams, South Concho River (Upper) and Pecan Creek have altered hydrology and flow deficits. In the greater South Concho watershed there are 106 water rights totaling 10,090 ac-ft/yr. Water diverted for irrigation purposes occurs on the gaged tributaries Spring Creek, Dove Creek and South Concho River, but not on Pecan Creek. Large municipal water rights are located at the confluence of these streams at Twin Buttes Reservoir and Lake Nasworthy. Downstream of O.C. Fisher Lake and Lake Nasworthy, the North and South Concho rivers form the Concho River at San Angelo.

The mainstem of the Concho River is bounded by the headwater reservoirs described previously and O.H. Ivie Reservoir. At the Concho River at San Angelo, TX gage, seasonal baseflows and subsistence flows are moderately to severely altered, resulting in a subsistence seasonal flow deficit range from 71-210 ac-ft and baseflow seasonal flow deficit range from 0-2000 ac-ft. The Paint Creek gage shows negligible to severe alteration of seasonal baseflows, resulting in a baseflow seasonal deficit range from 0-602 ac-ft. Within the HUC 8 watershed associated with the Concho River there are 74 water rights summing to 89,200 ac-ft/yr. Most of the water rights are located on the mainstem and irrigate agricultural lands.

The mainstem of the Colorado River downstream of O.H. Ivie Reservoir and within the GPLCC makes up the third distinct area discussed here. The stream gage for this section lies outside of the GPLCC boundary and therefore has been excluded from this analysis. Nonetheless, the contributing streams, the Concho River and the Colorado River near Ballinger, exhibit altered streamflow. Within the HUC 8 watershed associated with the Colorado River downstream of O.H. Ivie Reservoir there are 43 water rights with an annual permitted use summing to 121,030 ac-ft. Most of the permitted amount is for O.H. Ivie Reservoir with 113,000 ac-ft/yr use and 554,340 ac-ft of storage dedicated to municipal use. Permits for diversions and their volumes are summarized by watershed unit (i.e., HUCs that contribute to the CEPR NFCA) in Table 7.

Table 7. Water right permits within the upper Colorado portion of the Central Edwards Plateau Rivers NFCA watersheds.

|  |  |  |
| --- | --- | --- |
| HUC name | Number of Rights | Volume (ac-ft/yr) |
| Upper Colorado | 24 | 64,624 |
| Middle Colorado-Elm | 108 | 10,703 |
| South Concho | 131 | 110,418 |
| Middle Concho | 3 | 189 |
| North Concho | 7 | 611 |
| Concho | 74 | 89,196 |
| Middle Colorado | 43 | 121,030 |
| TOTALS | 390 | 396,770 |

#### 4.4.3 Groundwater

The upper Colorado River portion of the Central Edwards Plateau Rivers NFCA is underlain by several aquifers - the major Ogallala and Edwards Trinity Plateau and the minor Dockum, Lipan, Hickory and Ellenburger-San Saba aquifers. Across the NFCA groundwater use varies by county. Average annual groundwater use is less than 10,000 ac-ft for all counties except Reagan and Tom Green counties. Reagan County located in the western portion of the NFCA uses 27,000 ac-ft, with the majority used for irrigation. Tom Green County’s average annual groundwater use is 79,000 ac-ft, with the majority used for irrigation and municipal water use (TWDB 2016).

Trends in groundwater well depletion from 2000 to present within the NFCA vary by county. The counties with most wells considered stable are Irion, Crockett, Schleicher, Tom Green and Concho. The counties with a majority of wells considered decreasing are Reagan and Runnels. In Reagan County the percentage of wells decreasing, increasing, or stable are 82%, 12% and 6%, respectively. In Runnels County the percentage of wells decreasing, increasing, or stable are 67%, 0% and 33%, respectively.

##### 4.4.4 Land Use Management

There are several active brush control programs in the region, including the City of San Angelo’s program for brush removal from Twin Buttes and O.C. Fisher reservoirs and CRMWD’s program for salt cedar removal at Lake Spence. Other water providers have partnered with the Texas State Soil and Water Conservation Board (TSSWCB) on brush removal projects in the past. However, brush management must be an ongoing strategy to continue to realize water savings. This strategy is a potentially feasible strategy for operators and users of the CRMWD system, San Angelo system, Concho River, and Lake Brownwood. Feasibility studies have been conducted in several watersheds in the study area and brush control is identified in the 2016 Region F Water Plan (Freese and Nichols, Inc. and LBG-Guyton Associates 2015) for Tom Green County.

##### 4.4.5 Analysis of Opportunities

Strategies for maintaining running waters should focus on restoring flows in altered streams and protecting flows in less altered streams. Priority should be given to the habitat of focal species of concern and streams in the NFCA that contribute water to the NFCA. Flowing water is needed in the upper Colorado River Basin to maintain water quality and reduce impacts of dry spells and droughts. Although water development such as dams and water extraction have fragmented habitat and altered streamflow, they also present opportunities to restore streamflow. In streams where the volume of permitted water rights meets or exceeds flow deficits, opportunities exist for voluntary environmental water transactions. The stream reaches in the South Concho River watershed, the mainstem of the Concho River, and the Colorado River upstream and downstream of O.H. Ivie Reservoir should be viable options for water right purchases, conversions and dedications, as well as reservoir re-operations and dam releases. Beyond water right transactions, reduction in flow deficits may be achieved through preserving return flows, groundwater management and land use management. The following activities represent potential environmental flow protection and restoration strategies for the upper Colorado River portion of the Central Edwards Plateau Rivers NFCA:

###### Flow Protection Strategies for the upper Colorado River portion of the Central Edwards Plateau Rivers NFCA

* Preserve return flows to the extent possible
* Enforcement of water rights including environmental provisions
* Inclusion of the necessary infrastructure to supply releases from multiple levels to protect water quality conditions and to accommodate releases of low and high flows as part of a natural flow regime in new reservoirs
* Minimize pumping/drilling in aquifers that contribute flows to the NFCA

###### Flow Restoration Strategies for the upper Colorado River portion of the Central Edwards Plateau Rivers NFCA

* Surface water rights transactions
* Reservoir reoperation where available and feasible
* Management of salt cedar and other invasive riparian species
* Restore fragmented reaches by mitigating/removing barriers to fish movement
* Improvements in agriculture irrigation efficiencies

### 4.6 Matrix of Flow Restoration and Protection Strategies

The preceding information, based on analyses using the GP EFIT Hydrologic Dashboard, was used to create a matrix of opportunities and environmental flow management strategies to protect and restore environmental flows in the Southern Great Plains Native Fish ConservationAreasof Texas (Tables 8, 9, 10, 11). A map of opportunity areas is provided in Figure 3 and a list of potential partners is in Appendix 3.

Table 8. Potential environmental flow management strategy types for the Upper Brazos River Native Fish Conservation Area (NFCA) in the Texas Great Plains. Yes indicates that HUC 8 scale components are in place to craft a viable voluntary strategy. No indicates that components may not be available within the HUC 8.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| HUC 8 # | Sub Basin  HUC 8 | Surface Water Transactions | Reservoir Operations | Land Management | Groundwater Management |
| 12050002 | Blackwater Draw | No | No | No | No |
| 12050003 | North Fork Double Mountain Fork Brazos | Yes | Yes | Yes | No |
| 12050004 | Double Mountain Fork Brazos | Yes | No | Yes | No |
| 12050006 | White | No | No | Yes | Yes |
| 12050007 | Salt Fork Brazos | No | No | Yes | No |
| 12060101 | Middle Brazos-Millers | Yes | No | No | No |
| 12060102 | Upper Clear Fork Brazos | Yes | Yes | No | No |
| 12060103 | Paint | Yes | No | No | No |

Table 9. Potential environmental flow management strategy types for the Upper Canadian River Native Fish Conservation Area (NFCA) in the Texas Great Plains. Yes indicates that HUC 8 scale components are in place to craft a viable voluntary strategy. No indicates that components may not be available within the HUC 8.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| HUC 8 # | Sub Basin –  HUC 8 | Surface Water Transactions | Reservoir Operations | Land Management | Groundwater Management |
| 11080006 | Upper Canadian-Ute Reservoir | Yes | Yes | Yes | No |
| 11090101 | Middle Canadian-Trujillo | Yes | Yes | Yes | No |
| 11090102 | Punta de Agua | No | No | No | No |
| 11090105 | Lake Meredith | Yes | Yes | Yes | No |
| 11090106 | Middle Canadian-Spring | Yes | Yes | No | Yes |
| 11090201 | Lower Canadian-Deer | No | No | No | No |
| 11100102 | Middle Beaver | No | No | No | No |
| 11100103 | Coldwater | No | No | No | No |
| 11100104 | Palo Duro | No | No | No | No |
| 11100201 | Lower Beaver | No | No | No | No |
| 11100202 | Upper Wolf | No | No | No | No |
| 11100203 | Lower Wolf | No | No | No | No |
| 11130301 | Washita Headwaters | No | No | No | No |

Table 10. Potential environmental flow management strategy types for the Upper Colorado River portion of Central Edwards Plateau Native Fish Conservation Area (NFCA) in the Texas Great Plains. Yes indicates that HUC 8 scale components are in place to craft a viable voluntary strategy. No indicates that components may not be available within the HUC 8.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| HUC 8 # | Sub Basin  HUC 8 | Surface Water Transactions | Reservoir Operations | Land Management | Groundwater Management |
| 12080008 | Upper Colorado | Yes | Yes | Yes | Yes |
| 12090101 | Middle Colorado-Elm | Yes | Yes | Yes | Yes |
| 12090102 | South Concho | Yes | No | Yes | Yes |
| 12090103 | Middle Concho | No | No | Yes | Yes |
| 12090104 | North Concho | No | No | Yes | Yes |
| 12090105 | Concho | Yes | Yes | Yes | Yes |
| 12090106 | Middle Colorado | Yes | Yes | Yes | No |

Table 11. Potential environmental flow management strategy types for the Upper Red River Native Fish Conservation Area (NFCA) in the Texas Great Plains. Yes indicates that HUC 8 scale components are in place to craft a viable voluntary strategy. No indicates that components may not be available within the HUC 8.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| HUC 8 # | Sub Basin  HUC 8 | Surface Water Transactions | Reservoir Operations | Land Management | Groundwater Management |
| 11120101 | Tierra Blanca | Yes | Yes | No | No |
| 11120103 | Upper Prairie Dog Town Fork Red | No | No | No | No |
| 11120104 | Tule | No | Yes | No | No |
| 11120105 | Lower Prairie Dog Town Fork Red | No | No | No | No |
| 11120201 | Upper Salt Fork Red | Yes | Yes | No | No |
| 11120202 | Lower Salt Fork Red | No | No | No | No |
| 11120304 | Elm Fork Red | No | No | No | No |
| 11130101 | Groesbeck-Sandy | No | No | No | No |
| 11130102 | Blue-China | No | No | No | No |
| 11130103 | North Pease | No | No | No | No |
| 11130104 | Middle Pease | No | No | No | No |
| 11130105 | Pease | No | No | Yes | Yes |
| 11130201 | Farmers-Mud | No | No | No | No |
| 11130204 | North Wichita | No | No | No | No |
| 11130205 | South Wichita | No | No | No | No |
| 11130206 | Wichita | No | No | No | No |
| 11130207 | Southern Beaver | No | No | No | No |
| 11130209 | Little Wichita | No | No | No | No |

Figure . Opportunity Areas for flow protection and restoration strategies within the Native Fish Conservation Areas in the Great Plains in Texas.



## 5.0 Discussion and Conclusion

Restoration and protection of environmental flows is a critical conservation issue for native freshwater fishes that requires the use of interrelated data sources to better understand and address. The GP EFIT is designed to serve information, data, and analyses to facilitate collaborative, voluntary environmental flow conservation efforts. Using GP EFIT, end-users can access georeferenced ecological data and flow-response metrics; flow alteration data derived from streamflow gages/naturalized flow datasets; ground and surface water right and usage information; and other spatial data layers (e.g. conservation areas, invasive species locations, land use). With this information, an end-user can explore various conservation scenarios and gain the needed information to craft environmental flow strategies catered specifically towards their unique needs and perspectives. Within the context of the prior appropriation system for surface water rights and the rule of capture for groundwater withdrawal, opportunities for flow preservation and restoration are limited. Identifying streams where altered streamflow, species of concern, and water rights intersect is a key first step for directing intervention efforts.

As demonstrated in Section 4 of this report, the GP EFIT can be used to identify these intersecting areas and evaluate potential environmental flow protection or restoration strategies appropriate for a given area or stream reach. For example, while voluntary reservoir reoperation may have the most potential for providing flows to the Canadian River, developing efficient and effective voluntary flow restoration strategies such as the sale, donation, or leasing of existing water rights; dedication of return flows; dam re-operation; dry year options on irrigation use; water conservation; and improved land use management may be better for portions of the Brazos River basin in the Great Plains.

The GP EFIT is expected to be a “living” tool with the ability to ingest new data, science, and technologies as they become available. The GP EFIT will undergo a regular process of review, updates, and end-user communication to ensure GP EFIT information is current and reliable. Technological advances may require the deployment of a new interface and occasional maintenance to insure continued operability and the GP EFIT is designed to allow for changes to features or system modifications as needed. In addition, TCS (2019) and TNC (2019) recommended next steps and refinements for some of the data layers incorporated in the GP EFIT. These refinements, such as developing synthetic naturalized daily streamflow datasets for ungaged streams, extending the period of record for gages with fragmented flow records, or adding focal species for analysis, will be components of future GP EFIT efforts.

Building upon the work of developing the GP EFIT, TPWD secured funding to expand the EFIT to the rest of Texas. Initially, the statewide EFIT will focus on hydrology-based flow targets using the same data as found in the Hydrology Dashboard. Due to the heterogeneity of Texas’ ecosystems, stream networks, climate and water demands, the state EFIT may require regional adjustments and considerations to more accurately address local conditions. In addition, different types of data may be necessary to create viable flow restoration and protection strategies for other parts of the state. From a technical standpoint, improvements in aspects of storing and serving GIS and other data may lead to refinements in the overall look and feel of the EFIT. Development of a statewide EFIT is underway and expected to be completed by September 30, 2020.

The potential for funding from a variety of sources to enable pursuit of a full suite of environmental flow strategies elevates the need for an environmental flow decision support system. The GP EFIT was conceived and designed to provide disparate information to flow practitioners in an easy to understand format to aid them in determining locations where flow restoration strategies will have the greatest potential for success based on hydrologic, ecologic, infrastructure, and water use data. The EFIT can provide not only spatial but also temporal information which could be useful in drafting strategies to meet defined objectives (e.g. provide spawning flows for pelagic minnows; increase summer flows to prevent mussel beds from desiccation; direct riparian restoration efforts to benefit flow and water quality).

The GP EFIT will enable environmental flow practitioners and stakeholders to communicate and collaborate more effectively to achieve voluntary environmental flow protection and restoration strategies. The ability of the tool to extend to a broader scale allows for consideration of a range of strategies from communities to watersheds to the State of Texas. Pioneering efforts such as the GP EFIT show that the integration of technology, instream flow science and communication tools within a web-based geospatial platform can provide information important for developing strategies that enable water resource management that addresses environmental streamflow needs and native fish conservation.

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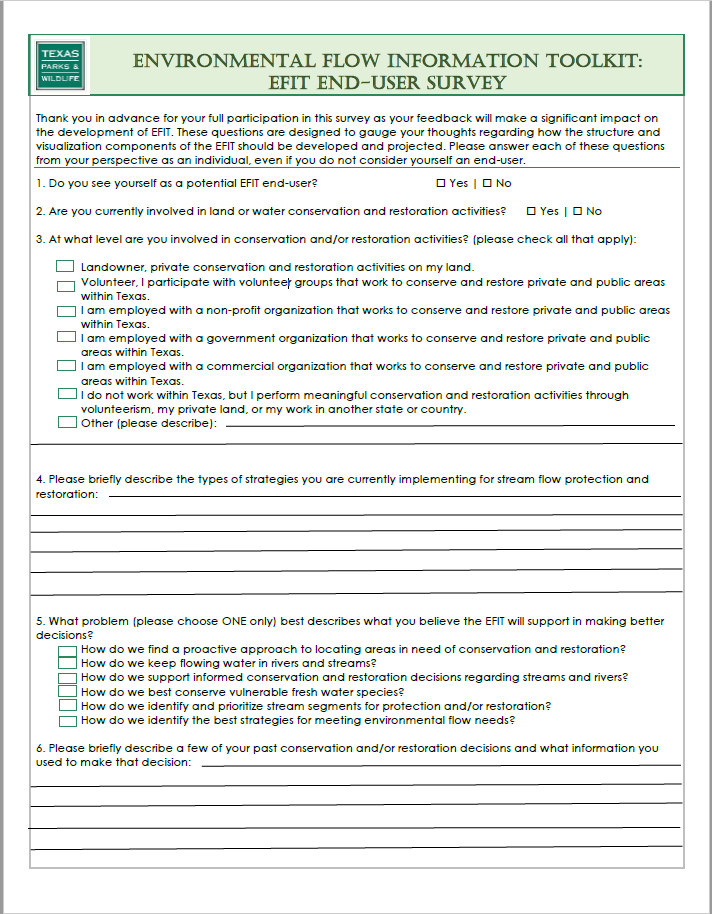
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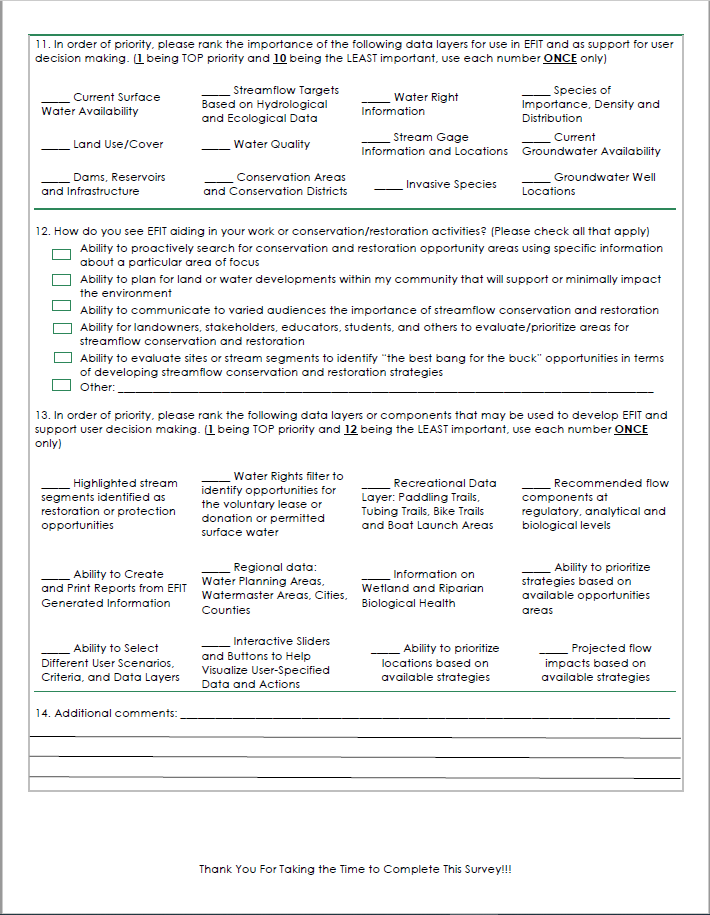
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## Appendix 1. End-User Survey





## Appendix 2. Supporting Data Layers

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| --- | --- | --- |
| **Data Layer Description** | **Raw Data Source(s)** | **Categorized Data Type Focus** |
| Fish collection data referenced by species and collection date/location | Museums, Agencies, Universities and Researchers | Ecological |
| Focal species’ nativity range at HUC8 | Fishes of Texas, University of Texas-Austin | Ecological |
| NHD Streamlines | USGS National Hydrologic Dataset (NHD) | Hydrologic/Geographical |
| Great Plains LCC Texas Boundary | Texas Parks and Wildlife | Geographical |
| The Nature Conservancy (Texas Chapter) priority conservation areas | The Nature Conservancy (Texas Chapter) Water Explorer | Ecological |
| Native Fish Conservation Areas (NFCA) prioritization layer | Texas Parks and Wildlife as shared by the Great Plains Fish Habitat Partnership | Ecological |
| USFWS identified Critical Habitat | U.S. Fish and Wildlife Services | Ecological |
| Groundwater point data monitoring observation well trends | The Nature Conservancy (Texas Chapter) Water Explorer data shared by Texas Water Development Board | Hydrologic |
| Percentage of groundwater wells declining by county | The Nature Conservancy (Texas Chapter) Water Explorer data shared by Texas Water Development Board | Water Planning |
| Projected water use by county | The Nature Conservancy (Texas Chapter) Water Explorer data shared by Texas Water Development Board | Water Planning |
| Estimated groundwater pumping by aquifer and county | The Nature Conservancy (Texas Chapter) Water Explorer data shared by Texas Water Development Board | Water Planning |
| Dam and fish barrier locations | National Dam Inventory, Southeast Aquatic Resources Partnership | Hydrologic |
| Mussel distributions | Texas Department of Transportation | Ecological |
| Stream fragmentation and habitat patches | The Nature Conservancy (Texas Chapter) Water Explorer data shared by Texas Water Development Board | Hydrologic |
| Reservoir locations | Texas Water Development Board | Hydrologic |
| Salt cedar locations | Texas Parks and Wildlife, Early Detection and Distribution Mapping System | Ecological |
| Playa locations | Playa Lakes Joint Ventures | Hydrologic |
| Major Rivers of Texas | Texas Water Development Board | Hydrologic/Geographical |
| River Basins of Texas | Texas Water Development Board | Hydrologic/Geographical |
| Spring Locations | Texas Water Development Board | Hydrologic |
| Waste water outfall locations | Texas Commission for Environmental Quality | Water Planning |
| Aquifers (major and minor) | Texas Water Development Board | Hydrologic |
| Impaired Reservoirs | Texas Commission for Environmental Quality | Ecological/Water Planning |
| Water rights data-diversion locations and use type | Texas Conservation Science as shared by Texas Commission for Environmental Quality | Ecological/Hydrologic |
| Regional Water Planning Areas | Texas Water Development Board | Water Planning |
| Priority Groundwater Management Areas | Texas Water Development Board | Water Planning |
| Groundwater Conservation Districts | Texas Water Development Board | Water Planning |
| Watershed Boundaries at HUC08,10 and 12 | Texas Parks and Wildlife and Texas Conservation Science (HUC08) | ALL Types |
| USGS Gage Locations (present and historical) without Streamflow Recommendations | U.S. Geological Services | Hydrologic |
| Texas Border | Texas Parks and Wildlife | Geographical |
| Flow standards | Texas Commission for Environmental Quality | Water Planning |
| BBEST flow recommendations | Texas Parks and Wildlife | Water Planning |

## Appendix 3. List of potential partners for water acquisition, leases, or other voluntary incentive-based programs in the Great Plains region of Texas.

Summary information from the EFIT will support efforts by various entities to restore and protect environmental flows. There are several groups working on issues related to environmental flows. The development of voluntary flow restoration and protection strategies will involve conservation groups and organizations that are active in the Great Plains and across Texas and will also require communication and coordination with holders of water rights, reservoir owners and operators, landowners and others. In addition, funds to incentivize transactions and individuals/organizations with experience in conservation financial practices will be needed. The following table identifies potential partners for developing and implementing water acquisition, leases, or other voluntary incentive-based programs in the Great Plains region of Texas.

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| --- |
| Audubon Texas |
| Brazos River Authority |
| Canadian River Compact Commission |
| Canadian River Municipal Water Authority |
| City of Abilene |
| City of Amarillo |
| City of Lubbock |
| City of San Angelo |
| Colorado River Land Trust |
| Colorado River Municipal Water District |
| Ducks Unlimited |
| Earth Genome |
| George and Cynthia Mitchell Foundation |
| Meadows Foundation |
| Natural Resources Conservation Service |
| Natural Resources Conservation Service |
| Playa Lakes Joint Venture |
| Red River Authority |
| Red River Compact Commission |
| Texas Land Conservancy |
| Texas Parks and Wildlife Department |
| Texas Parks and Wildlife Foundation |
| Texas State Soil & Water Conservation Board |
| Texas Water Trade |
| The Conservation Fund |
| The Nature Conservancy - Texas |
| United States Fish and Wildlife Service |
| Upper Colorado River Authority |