SALT BAYOU WATERSHED RESTORATION PLAN

Prepared by:

Salt Bayou Marsh Workgroup

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SALT BAYOU MARSH WORKGROUP MEMBERS

Ducks Unlimited

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- Engineering Department
- Jefferson County Drainage District No. 6

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- National Marine Fisheries Service:
  - Habitat Conservation Division
  - Restoration Center

Texas General Land Office:

- Coastal Erosion Planning and Response Act (CEPRA) Program
- Natural Resource Damage Assessment Program

Texas Parks and Wildlife Department (TPWD):

- Wildlife Division
- Coastal Fisheries Division
- Environmental Assessment, Response, and Restoration Program

Texas Water Development Board:

- Coastal Water Resources Group

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U.S. Fish and Wildlife Service (USFWS):

- McFaddin National Wildlife Refuge
- Coastal Program

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INTRODUCTION

The purpose of this document is to present a brief summary describing the importance of the ecological functions of the Salt Bayou system, to discuss natural and man-made causes of decline, and to propose a plan of action that would maintain ecological functions and values or reverse their decline. This document was developed in collaboration with a technical stakeholder group that has met yearly since 2000. This document reflects the Salt Bayou Workgroup’s understanding and knowledge of this ecosystem. It also represents a consensus of the workgroup members on a strategy or plan forward to collectively improve conditions in the Salt Bayou system.

The Salt Bayou ecosystem contains the largest contiguous estuarine marsh complex in Texas (Figure 1). This ecosystem is approximately 139,000 acres in size within a Chenier Plain landscape that includes freshwater to estuarine marsh, coastal prairie grasslands, tidal flats, creeks and basins and associated aquatic vegetation (Figures 2 and 3). This diversity of communities creates an extremely productive complex for an array of fish and wildlife resources. This system provides a wide variety of benefits for people of the area including outdoor recreation and storm protection. The Salt Bayou system is widely recognized for its fishing, hunting, and wildlife viewing opportunities. The area is extremely important for commercial and recreational fisheries productivity and for wintering and migratory bird habitat. The area is one of the largest extant wetland areas in the entire state and sustains a very high level of productivity.

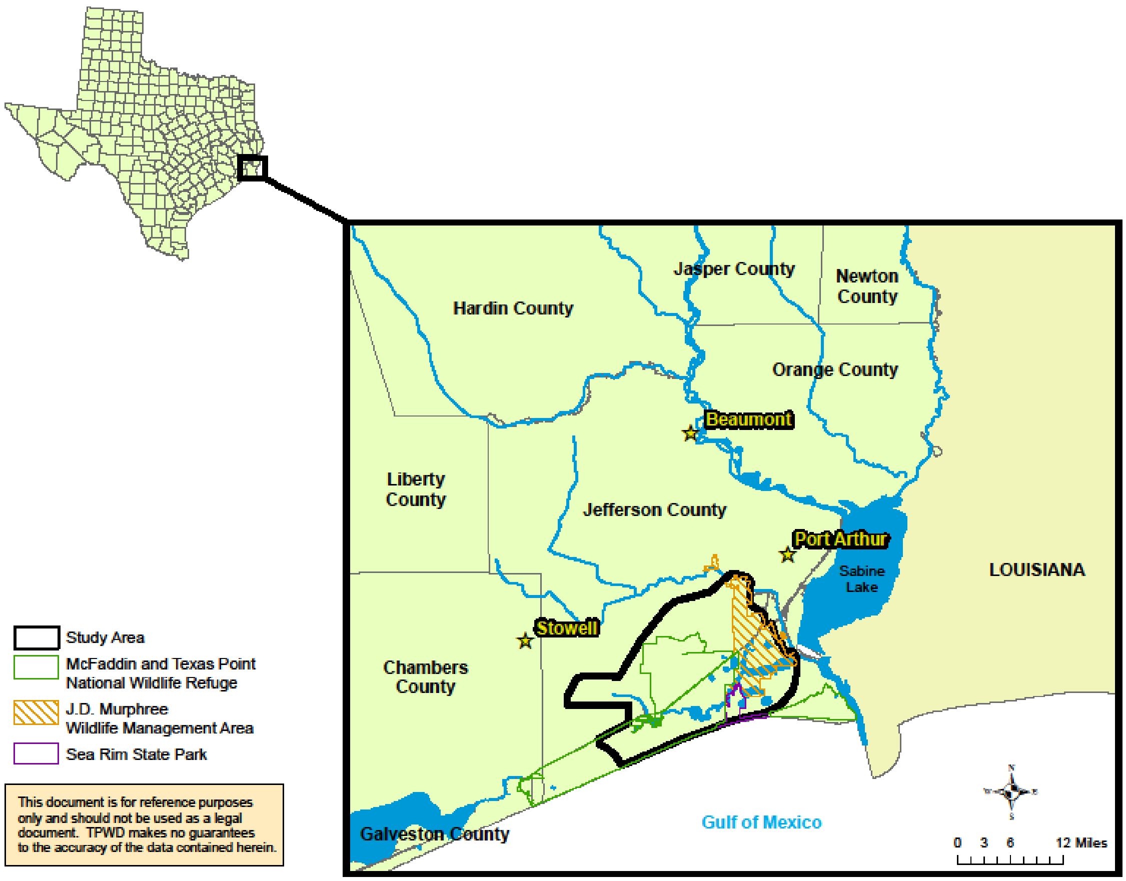

Figure 1. Location and extent of Salt Bayou Marsh study area.

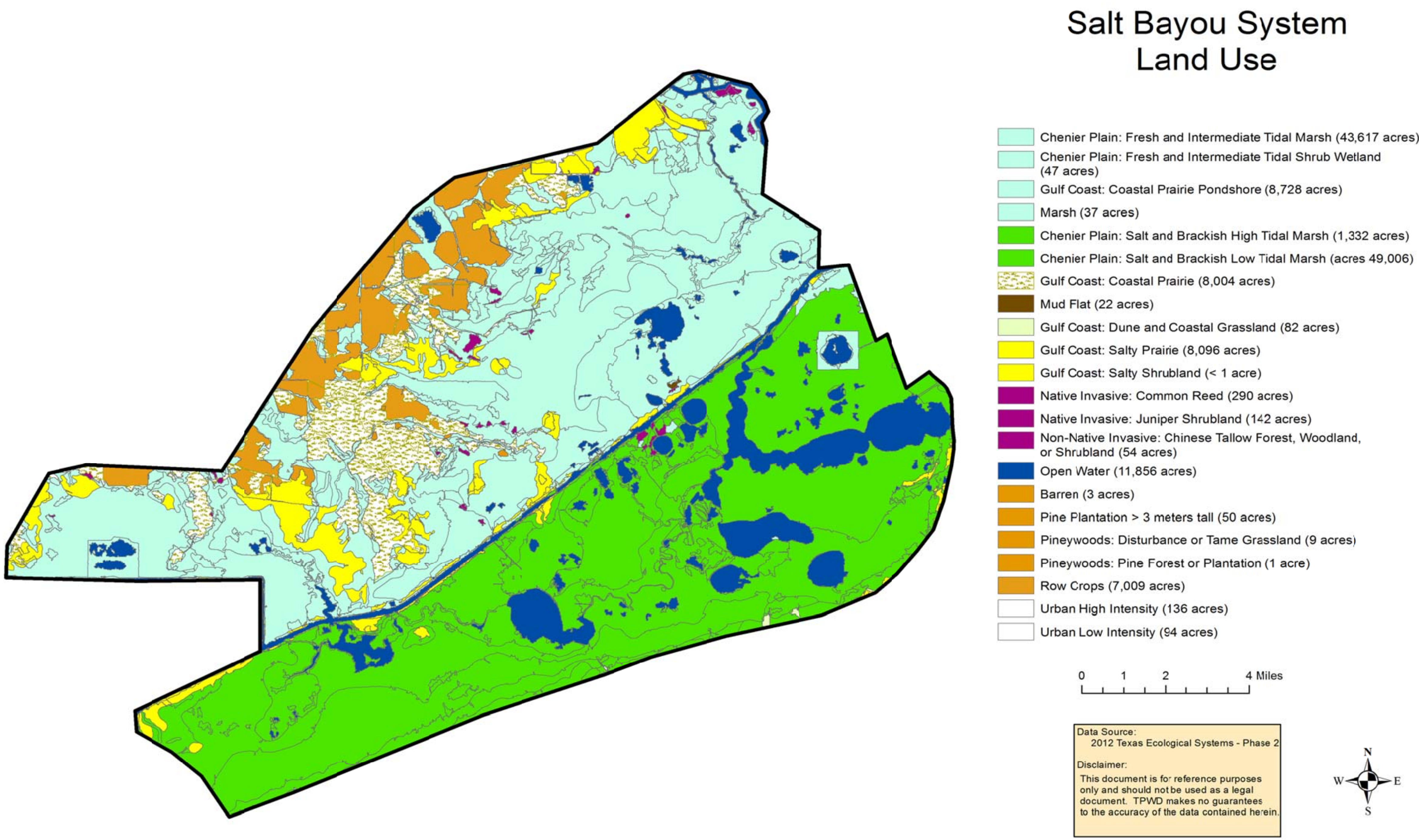

Figure 2. Texas Parks and Wildlife vegetation classification of the Salt Bayou System.

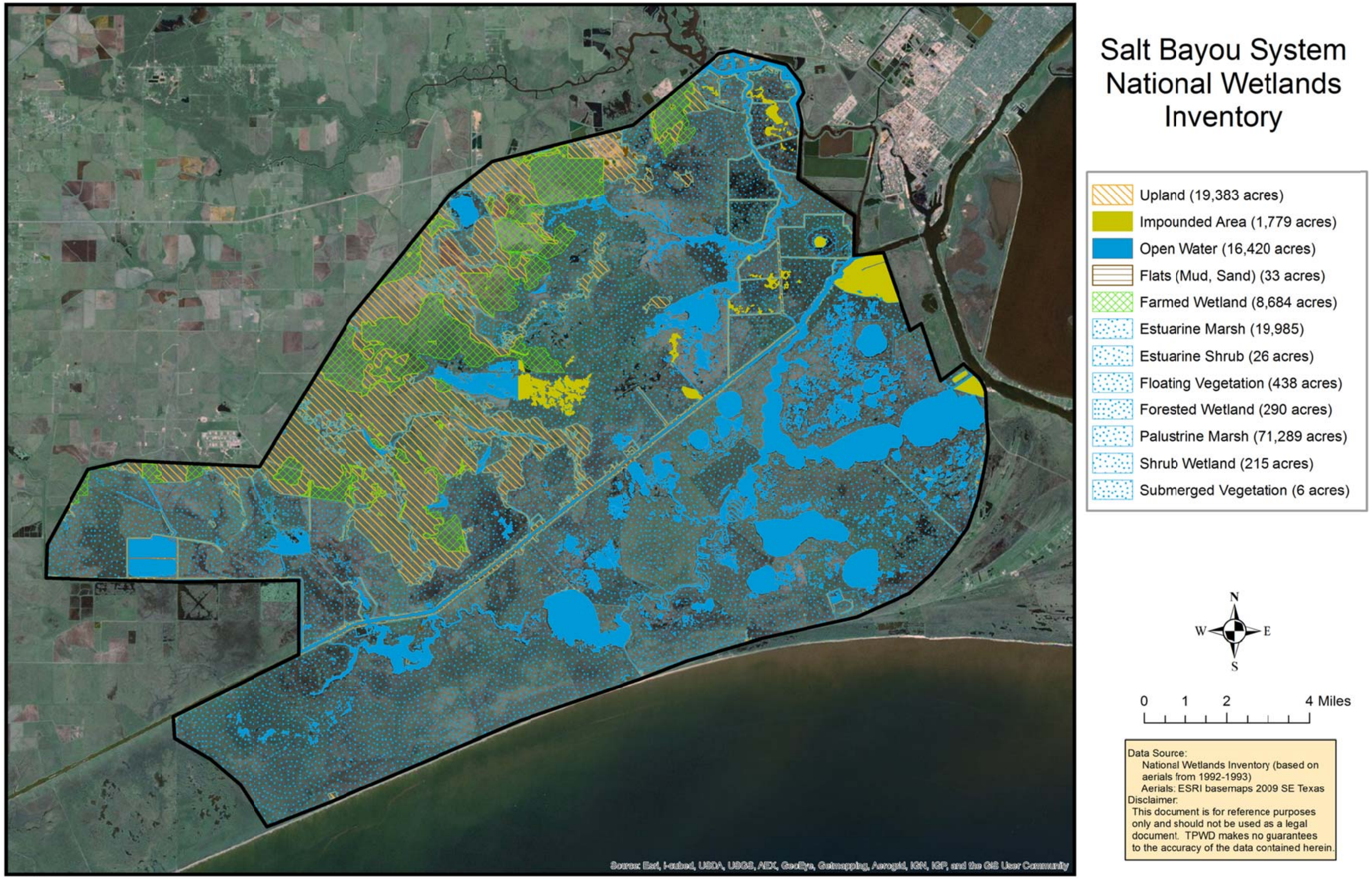

Figure 3. Wetland area as determined by the National Wetlands Inventory in the Salt Bayou Area.

DEVELOPMENT OF THE SALT BAYOU SYSTEM AND CURRENT STATUS

The Salt Bayou system is part of the Chenier plain that was formed by the reworking of riverine sediments. The Mississippi River provided the main sediment source that formed the coastal landscape in Louisiana and in southeastern Texas. The Chenier plain was developed by lateral oscillations of the Mississippi River over long periods of time and the reworking of sediments that were deposited during these shifts. Mudflats were formed along the shoreline by the fine grained sediments from the Mississippi River. These sediments were pushed west by longshore transport and were ultimately deposited along the shoreline through nearshore currents (Britsch and Dunbar 1993). Eastward shifts in the course of the Mississippi River resulted in a decline of the westward sediment transport. This decline in sediments resulted in coastal processes reworking and eroding the sediments along the shore. These coastal processes concentrated the coarse, large-grained sediments forming higher ridges or cheniers (Britsch and Dunbar 1993).

When the Mississippi River oscillated westward again, new sediments were deposited along the existing shoreline, and the cycle of ridge and mudflat formation began again. Repetition of sediment accretion and erosion from coastal processes over time created the alternating ridges separated by marshlands, which is now called the Chenier plain (Britsch and Dunbar 1993). The higher ridges support woody vegetation, while the mudflat areas which are isolated from the Gulf waters support diverse freshwater coastal habitat (USFWS 2008). Today the Chenier plain stretches approximately 125 miles from southwest Louisiana to southeast Texas and runs parallel to shore (Penland and Suter 1989).

The Salt Bayou system is part of the Texas portion of the Chenier plain. The system covers approximately 139,000 acres in Jefferson County, Texas (Figure 1) and is protected as public lands in large part by McFaddin National Wildlife Refuge (57,000 acres), J.D. Murphree Wildlife Management Area (25,000 acres), and Sea Rim State Park (3,000 acres). "Although this system is but a remnant of what was once a much larger watershed extending north as far as Beaumont and as far west as Stowell, Texas, it is still a large wetland complex composed of hydraulically connected shallow lakes and small bayous" (Pothina and Guthrie 2009).

Essential Functions

The Salt Bayou system is rich in natural resources and is a valuable economic resource for Texas. Historically, the system consisted of fresh (0-0.5 ppt) to intermediate (0.5-3.5 ppt) salinity marshes with some brackish (3.5-10 ppt) to saline (>10 ppt) inclusions near where saltwater from Sabine Lake would enter the system (TPWD and USFWS 1990, Stutzenbaker 1999). The plant communities in these marshes were highly productive, and supported a large number of vertebrate and invertebrate species. In fresher regions, the emergent marsh community was dominated by Jamaica sawgrass (*Cladium jamaicensis*), cutgrass (*Zizaniopsis milaceae*), maidencane (*Panicum hemitomon*), lotus (*Nelumbo lutea*), najas (*Najas guadalupensis*), arrowheads (*Sagittaria* spp.), and banana waterlily (*Nymphaea mexicana*). Intermediate and brackish zones were dominated by marsh hay cordgrass (*Spartina patens*), seashore paspalum (*Paspalum vaginatum*), saltgrass (*Distichlis spicata*), and salt marsh bulrush (*Schoenoplectus robustus*) with widgeongrass (*Ruppia maritima*) in open water areas. In more recent times, these marshes have been subjected to increasing salinities with a reduction in extent of fresh to intermediate marsh and associated changes in species diversity, abundance, and productivity. However, the system remains a very important habitat for fish and wildlife and still maintains much of the historic diversity and productivity.

The remaining freshwater and low-salinity marshes provide excellent habitat for a variety of wildlife. The Salt Bayou system is recognized in the North American Waterfowl Management Plan (2004) as an important waterfowl habitat. This area supports hundreds of thousands of individuals of most species within the Central Flyway during winter months. It also provides year-round habitat for mottled ducks (*Anas fulvigula*), rails (Rallidae), bitterns (Ardeidae), stilts (Recurvirostridae), and many other marsh birds. The Texas Upper Coast has produced large populations of muskrat (*Ondatra zibethicus*) and nutria (*Myocastor coypu*) over the years. Historically, the fur industry provided early settlers and inhabitants through the 1970's with dynamic and abundant fur resources. Trappers have traditionally produced high quality harvests of muskrat, mink and river otter pelts from south Jefferson County marshes. The now extirpated red wolf (*Canis rufus*) once inhabited this area. Other mammals, including coyote (*Canis latrans*), bobcat (*Lynx rufus*), opossum (*Oposum virginianus*), and raccoon (*Procyon lotor*) also thrive in these marsh habitats. Two invasive exotic species, feral hogs (*Sus scrofa*) and nutria are problematic in these coastal marsh habitats.

Several species of reptiles are also found commonly throughout the system including various species of snakes (e.g., Colubridae and Viperidae), turtles (e.g., Kinosternidae, Emydidae, Chelydridae and Trionichidae) and the American alligator (*Alligator mississippiensis*). Likewise, amphibians can be found when conditions within the system are favorable (i.e., salinities are not too high). These may include several species of amphibians (e.g., Hylidae, Ranidae and Microhylidae), toads (e.g., Bufonidae) and the Amphiuma (*Amphiuma tridactylum*).

This area is an important nursery for marine and estuarine fishery species, including several that are important to the local economy. Recreational fishing in the area focuses on speckled trout (*Cynoscion nebulosus*), redfish (*Sciaenops ocellatus*), Southern flounder (*Paralichthys lethostigma*), and other species. These game fish forage on the smaller fish and shellfish species that are abundant within the marsh. Commercially valuable species that share a similar dependent attachment to this marsh include brown shrimp (*Farfantepenaeus aztecus*), white shrimp (*Litopenaeus setiferus*), blue crab (*Callinectes sapidus*), black drum (*Pogonias chromis*), gulf menhaden (*Brevoortia patronus*), Southern flounder, and various bait fish. Although not of commercial interest in the Sabine Lake system, reefs formed by the Eastern oyster (*Crassostrea virginica*) in the Salt Bayou marsh system provide essential fish habitat, with large shell beds of the Atlantic rangia (*Rangia cuneata*) also providing several ecosystem services. A number of past investigators have studied species abundance and distribution in the Salt Bayou Marsh besides TPWD - Coastal Fisheries (1986 – Present) which include works by Bob Fish (TPWD-Sea Rim State Park, data summarized in Stelly (1980), Hartman et al. (1987), and Simon (1996).

Marshes provide essential functions that maintain the productivity of the system. They filter pollutants, provide essential nutrients and food, and provide refuge from predators. These marshes are also highly effective at decreasing impacts from storm surges. The Army Corps of Engineers estimates that for each 2.7 miles of emergent marsh present, one foot of storm surge can be reduced. Although this is a widely used estimate, an accurate prediction of storm abatement must take into account landscape position, storm intensity, storm track, speed at which the storm is moving, slope from sea floor to coastal marshes, degree of bottom friction on the surge, and condition of the marsh (Masters 2011). The portion of the Salt Bayou system covered by this plan is up to 20 miles wide and is effective at protecting nearby municipalities from a high frequency of severe storms that occur in the area (Table 1).

Table 1. Hurricanes and tropical storms that have affected the Keith Lake - Salt Bayou system. All events were recorded from the National Weather Service and National Hurricane Center.

Date	Tropical Storm or Hurricane Event
September 13, 1865	Hurricane landfall along Texas/Louisiana border, storm surge inundates Calcasieu Lake and Grand Chenier.
July 15, 1866	Tropical storm landfall at Port O'Connor.
1871	Three hurricanes land on the Texas coast: June 2-3, June 9, September 30-October 2.
September 15-17, 1877	Hurricane landfall on Texas coast.
August 22-23, 1879	Hurricane landfall along upper Texas coast.
September 14, 1882	Tropical storm landfall at Sabine Pass.
June 14, 1886	Tropical storm landfall near Sabine Pass that flooded the coast several miles inland and inundated Sabine Pass with 7 ft of water.
October 12, 1886	Hurricane (Category 2) near Sabine Pass that flooded the coast up to 20 miles inland.
July 5, 1888	Hurricane landfall at Galveston.
July 13, 1891	Hurricane landfall near Sabine Pass.
October 6, 1895	Tropical storm landfall at Bolivar Peninsula.

September 13, 1897	Hurricane (Category 1) landfall in western Louisiana. Sabine Pass rice fields in Taylor Bayou were inundated with 6ft of water.
September 28, 1898	Tropical storm landfall at Bolivar Peninsula.
September 9, 1900	Hurricane (Category 4) landfall Galveston Island.
August 17, 1915	Hurricane (Category 3) landfall west of Galveston Island.
August 14, 1932	Hurricane (Category 4) landfall south of Galveston Island.
August 14, 1938	Hurricane (Category 1) western Louisiana produced high tides on upper Texas coast.
August 7, 1940	Hurricane (Category 2) east of Sabine Pass with a storm surge reaching 21.1 ft.
September 15, 1941	Tropical storm landfall west of Sabine Pass.
August 21, 1942	Hurricane (Category 1) landfall near Galveston with a storm surge reaching 7 ft at High Island.
July 27, 1943	Hurricane (Category 1) landfall at Bolivar Peninsula. Beaumont recorded 17.76 of rain.
June 16, 1946	Tropical storm landfall east of Sabine Pass.
August 24, 1947	Hurricane (Category 1) landfall at Galveston Island produced a 3.6 ft tide at Sabine Pass.
June 27, 1957	Hurricane Audrey (Category 4) landfall east of Sabine Pass with storm surge of 8-10 feet.
August 9, 1957	Tropical Storm Bertha landfall east of Sabine Pass.
July 24, 1959	Hurricane Debra (Category 1) landfall east of Freeport.
September 11, 1961	Hurricane Carla (Category 4) landfall near Port Lavaca with storm surge of 7-8 feet.
September 17, 1963	Hurricane Cindy (Category 1) landfall near High Island.
September 15, 1970	Tropical Storm Felice landfall north of Galveston.

July 2, 1979	Tropical Storm Claudette landfall near Sabine Pass. Port Arthur records 13 inches of rain
September 5, 1980	Tropical Storm Danielle landfall near Galveston. Port Arthur records 17 inches of rain.
August 17-18, 1983	Hurricane Alicia (Category 3) landfall Galveston Island with a storm surge just over 5 feet.
September 11, 1982	Tropical Storm Chris landfall near Texas/Louisiana border.
June 26, 1986	Hurricane Bonnie (Category 1) landfall west of Sabine Pass with a storm surge of 6-7 feet.
August 9, 1987	Unnamed tropical storm landfall near Texas/Louisiana border.
August 1, 1989	Hurricane Chantal (Category 1) landfall at High Island caused beach erosion with storm surge of 4-5 feet.
October 16, 1989	Hurricane Jerry (Category 1) landfall at Galveston with storm surge of 4-5 feet.
September 11, 1998	Tropical Storm Frances landfall at Corpus Christi creates a storm surge of 5.4 ft at Sabine Pass.
September 24, 2005	Hurricane Rita (Category 3) landfall at Sabine Pass creates a storm surge of 10 feet.
September 13, 2007	Hurricane Humberto (Category 1) landfall at McFaddin NWR with storm surge of 4-5 feet.
September 13, 2008	Hurricane Ike (Category 2) landfall at Galveston Island creates a 14 foot storm surge across Salt Bayou.

SIGNIFICANT CAUSES OF ENVIRONMENTAL CHANGE

The vast resources discussed previously are rapidly degrading due to a variety of changes in the system. The rate of decline in recent years has increased dramatically as a result of management actions in combination with natural processes. Below, the human-induced and natural processes that have affected the Salt Bayou system are described.

History of Significant Anthropogenic Influences

The ecological functions of the Salt Bayou system have been significantly affected by a long history of land development which started in the mid-1800s (Table 2; Figure 4). Individually, many of the land alterations were minor, however, when combined with more significant alterations, the effects have been devastating.

Historically, the Salt Bayou watershed was predominantly a freshwater to intermediate system. However, by 1900, development of a rail line connecting Beaumont to Sabine Pass and the dredging of a 6 ft deep channel from Sabine Pass to Taylor Bayou resulted in farmers noticing salinity in their irrigation fields. The railroad berm also caused flooding west of Sabine Pass by inhibiting sheetflow and increased the duration of flooding to the detriment of the marsh community.

By the 1930s, the Gulf Intracoastal Waterway (GIWW) and the Sabine-Neches Waterway (SNWW) had been constructed. The GIWW cut off overland freshwater flows that drained from the northern to the southern portion of the watershed, thereby eliminating nearly half of the watershed of Salt Bayou. Additionally, the GIWW provided a large conduit for saltwater to travel to portions of the system which rarely experienced any tidal influx. Extended exposure to saltwater killed many salt intolerant plants. In some areas, more salt tolerant plants replaced those that died while in many locations vegetated marshes converted to open water. During this same time period, oil and gas production near the Clam Lake area began. The withdrawal of subsurface fluids caused a fault line to become active and resulted in land subsidence and a conversion of marsh to open water (White and Tremblay 1995).

Table 2. Events that directly or indirectly have affected the hydrological and ecological conditions of the Keith Lake - Salt Bayou system (modified from TPWD and USFWS 1990).

Date	Event
pre-1860	System is relatively undisturbed. No natural connection exists between Little Keith Lake and Sabine Lake, but this area is suitable for a man-made connection. Sheetflow flows from Salt Bayou to Taylor Bayou to Sabine Lake.
1861	Eastern Texas Railroad Company constructs a rail line on an earthen berm connecting Beaumont, Port Arthur and Sabine Pass (Handbook of Texas Online). The berm prevents sheetflow from going into Sabine Lake.
1862	In response to complaints of flooding in Salt Bayou by local residents the railroad cuts the berm and attempts to imitate sheet or relieve flooding flow between Little Keith Lake and Sabine Lake.
mid-1870s	Mr. Keith opens a row boat canal from Little Keith Lake to Sabine Lake, possibly utilizing the existing cut through the railroad berm (J. Sutherlin, *pers. comm*.).
1870-1880	Congressional appropriations were made for the survey of possible Texas harbors, and improvements were made at Sabine Pass (Handbook of Texas Online).
1898	Port Arthur Canal and Dock Company, Kansas City Railroad, and Gulf Railroad connect the Port Arthur Canal to the Sabine Channel (Alperin 1977) Dredge spoil closes the entrance to the existing boat canal between Little Keith Lake and Sabine Lake (J. Sutherlin, *pers. comm*.).
1901	Rice growers on Taylor's Bayou report saline water in irrigation system used for rice fields (Alperin 1977).
1908	SNWW dredged to 100 ft wide by 9 ft deep (Alperin 1977).
1911	A salt water guard lock in the Sabine-Neches Canal downstream from the mouth of the Neches River was authorized (Wilson 1981).
1914	Construction of a lock and salt water barrier on Taylor Bayou by the Beaumont Navigation District of Jefferson County, later replaced with a relocated barrier in 1935 (Wilson 1981).

1916	SNWW dredged to 25 ft deep (Alperin 1977).
1922	SNWW widened to 125 ft (Alperin 1977).
1924	Severe drought and peat fires convert areas of marsh in Salt Bayou to open water (Lay and O'Neill 1942).
1925	Removal of the saltwater guard lock in the Sabine Neches Canal downstream of mouth of the Neches River was authorized by the River and Harbor Act of March 3, 1925. A bypass channel was constructed around the lock, and the lock was later removed in fiscal years 1952-53 (Wilson 1981).
1927	SNWW dredged to 150 ft wide by 30 ft deep (Alperin 1977). Dredging activities along the SNWW likely hastened the reconnection with Little Keith Lake (J. Sutherlin, *pers. comm*.).
1933	Gulf Intracoastal Waterway (GIWW) dredged across Jefferson County, separating Salt Bayou from its upper watershed and confluence with Taylor Bayou and Sabine Lake.
1930-1933	Water control structures are installed on the GIWW at Star Lake and Salt Bayou. A water control structure is installed between Little Keith Lake and SNWW. A second water connection (canal) is developed using dynamite to improve boat access between Keith Lake and Little Keith Lake (USDA/SCS 1976, J. Sutherlin, *pers. comm*.).
1946	SNWW dredged to 400 ft wide by 36 ft deep (Alperin 1977).
1947	Clam Lake Oil Field is developed and begins production. Construction of Clam Lake Road changes hydrologic patterns within the marshes.
Early 1950s	Dam B (B. A. Stienhagen Reservoir 1951) is constructed on the Neches River at Town Bluff. White's levee, Perkin's levee, Back Ridge Cattlewalk and numerous small boat trails and small wooden weirs were constructed throughout the marsh. Lost Lake and Round Lake were impounded by ring-levee systems.

1957	TPWD acquires land for a wildlife management area (J.D. Murphree WMA). Hurricane Audrey (1957) makes landfall. The storm likely damages existing water control structures along the GIWW and Little Keith Lake.
1958	Shell Lake Oil Field developed and begins production. Construction of Shell Road changes hydrologic patterns within the marshes.
1961	Hurricane Carla (1961) makes landfall and likely further damages the existing water control structures along the GIWW and Little Keith Lake. By this time, these structures likely no longer prevented the free exchange of tidal waters.
1964	The USACE built a containment levee around Little Keith Lake and filled the lake with dredged materials from the SNWW (TPWD and USFWS 1990).
1965	Impoundment of the Angelina River (Neches River Basin) and construction of Lake Sam Rayburn reservoir. Dredging began to deepen the SNWW to 40 ft (completed in 1972, Alperin 1977) 1969 Toledo Bend reservoir.
1969	Toledo Bend reservoir construction was completed.
1971	TPWD purchases Sea Rim State Park.
1977	Keith Lake Fish Pass is dredged.
1981	USFWS acquires McFaddin NWR.
1985	TPWD acquires 5,000 acres North of Keith Lake, including Lost Lake. These acres eventually become part of the Salt Bayou Unit of J. D. Murphree WMA.
1995	Salt Bayou structure is constructed at the eastern intersection with the GIWW.
1997	11,000 acres of Sea Rim State Park transferred to the J. D. Murphree WMA and are combined with the 5,000 acres purchased in 1985 to make up the Salt Bayou Unit.
1998	Tropical storm Frances reduced the elevation of the beach ridge.
2003	LNVA completes a permanent salt water barrier on the Neches River above Beaumont.

2005	Hurricane Rita severely damages the beach ridge. Beach ridge elevation is no longer high enough to protect marshes. There are widespread impacts.
2007	Hurricane Humberto makes landfall and causes minor damage to marsh vegetation.
2008	Hurricane Ike makes landfall and creates over 800 acres of open water from emergent marsh by scouring vegetation from the marsh within the J D Murphree WMA. The storm also affects remaining beach ridge and internal hydrologic patterns by depositing debris and sediment in existing ditches and channels.
2010	Needmore Diversion Ditch is started, which will affect hydrologic patterns within the watershed north of the GIWW upon completion.
2006-2012	Beneficial Use efforts using grant funding from NOAA Fisheries (Hurricane Ike Recovery), industrial partnerships and 404 mitigation within the Salt Bayou Unit of the J. D. Murphree WMA totals enhancement to approximately 2,100 acres of emergent marsh since 2006. (J. Sutherlin *pers comm*.).
2011	A year long drought of record results in a lack of freshwater inflows and rainfall resulting in exacerbated salinity levels above 20 ppt through-out the Salt Bayou Watershed for much of the year. (J. Sutherlin *pers comm*.).

Figure 4. Major man-made structures that have resulted in significant hydrologic alterations.

Prior to dredging of the GIWW, the Salt Bayou system drained to the north through Salt Bayou into Taylor Bayou and then Sabine Lake. This route was truncated when the GIWW was dredged, with the system draining into the GIWW through a water control structure. As a result, aquatic estuarine dependent organisms had a shorter distance to get in and out of the system. Little Keith Lake also had a connection to the shipping channel through a drainage ditch dug by the railroad to alleviate the flooding mentioned earlier. This ditch remained until the USACE filled Little Keith Lake with dredged material in 1966. After the filling of Little Keith Lake, the only access point for estuarine organisms and tidal waters was through the confluence of the GIWW and Salt Bayou. This resulted in a decline of the estuarine function of the wetlands along with a decline in recreational and commercial fishing (TPWD et al. 1976).

In 1977, the Keith Lake Fish Pass (KLFP) was opened to connect the SNWW to Keith Lake in order to enhance recreational fishing in Sea Rim State Park. The opening of this cut provided a direct conduit for saltwater to access the system. As a result, the area was impacted by higher levels of salt influx than had ever occurred before (TPWD and USFWS 1990). According to Pothina and Guthrie (2009):

> Over time, tidal action widened and deepened the Fish Pass so that by 1988, the Fish Pass had expanded [in some locations] to 300 ft wide and 10 ft deep (Fisher 1988). This allowed the salinity gradient to impact interior marshes upstream of Keith Lake, which included marshes near Johnson Lake, Salt Bayou, Shell Lake, Salt Lake, Fence Lake and Knight Lake (TPWD and USFWS 1990) and areas further west. Today, the predominant source of saltwater to the system enters via the Fish Pass (Fisher 1988), with consequences to freshwater conditions in the eastern portion of the watershed.

Over the years, water control structures that were built to prevent saltwater intrusion fell into disrepair and are no longer functional today. The water control structure at the eastern confluence of the GIWW and Salt Bayou was replaced with a new structure in 1995. Berms and levees created during dredging of channels and for water management inhibited sheet flow and funneled water out of the system via narrow channels, many of which were developed as access for hunting and trapping. Under flood conditions (fresh or salt water), this caused a longer residence time and increased waterlogging stresses, conditions which can lead to plant death and land loss. Constructed waterways including the GIWW, SNWW, and KLFP have been subject to erosive forces eroding the banks of these channels, leading to loss of emergent marsh along the banks. Over the last 100 years, the SNWW has been widened and deepened several times, further increasing the amount of Gulf of Mexico (GOM) waters entering the system.

Natural processes

Beyond the aforementioned human-induced activities that have reduced marsh area, relative sea-level rise, severe disturbances (e.g. hurricanes, droughts), and the natural reworking of coastal sediments are also contributing to habitat degradation. Relative sea-level rise is a major factor in the rate of land loss. The Salt Bayou system has a high vulnerability to sea-level rise. Two different studies have established high rates of sea-level rise in this area ranging from 6.45 mm/yr (1958-1999) (USFWS 2008) to 5.66 mm/yr (1958-2006) at Sabine Pass (Paine et al. 2011). In comparison, global sea-level rise was 1.7 mm/year (Church and White 2006). Various sea-level rise scenarios were modeled to determine the extent of potential inundation in the Salt Bayou system (Figure 5). Model scenarios estimated that by 2100, estuarine open water could increase from at least 9% up to 252%. Irregularly flooded marsh is predicted to decrease between 4-97% and fresh marsh is expected to increase slightly (1-6%) or to decrease by 37% depending on the model scenario (Warren Pinnacle Consulting, Inc. 2011).

Changes in the location of the Mississippi River have also influenced the areal extent and geography of the Salt Bayou system. Currently, this system is suffering from substantial shoreline erosion and retreat, which has resulted in land loss comparable to that of coastal Louisiana. The historic barrier/beach dune system has degraded severely on both the Texas Point and McFaddin National Wildlife Refuges (NWR) (USFWS 2008). On average, the shoreline in Jefferson County has been retreating 9.2 ft/year and land loss rates have averaged 35.7 acres/year (Paine et al. 2011).

The large-scale perturbations discussed previously act to lower the resiliency of the marsh, making it more vulnerable to large, acute disturbances such as hurricanes. For example, Hurricane Ike, which made landfall approximately 65 miles to the southwest, resulted in land loss of 14.8 km^2 (5.7 mi^2.; Barras et al. 2010).

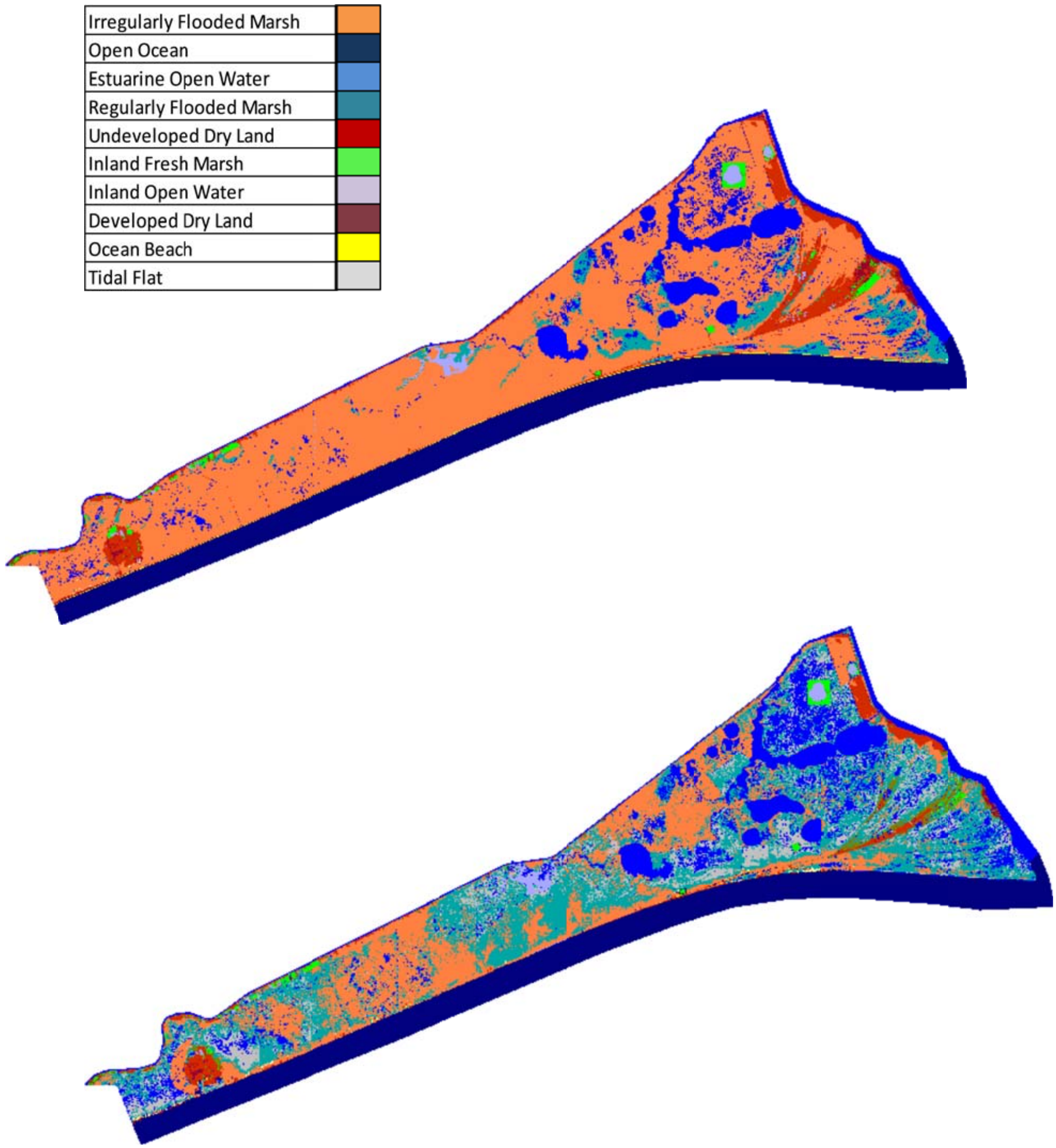

Figure 5. SLAMM 6 (Sea Level Affecting Marshes Model) visual representation of the (a) current condition of the southern portion of the Salt Bayou and the (b) predicted habitat change with the 1m of sea level rise scenario in the year 2100 (Warren Pinnacle Consulting Inc. 2011).

IMPACTS DUE TO ENVIRONMENTAL ALTERATIONS

Following the reopening and restructuring of the KLFP in 1977, the system has slowly and episodically transitioned towards estuarine conditions with negative consequences to its diverse wetland habitats. Salt intolerant plant communities are dying and subsequently the organic soils are dissolving and eroding, resulting in increasing expanses of shallow open water. As expanses of open water exceed 75-80 % relative to vegetated marsh, production of brown and white shrimp and blue crabs has been shown to decrease (Minello and Rozas 2002).

In response to the overall increase in salinity, increased frequency of high salinity events, and continued marsh loss, several changes have occurred in the system. Areas of open water are increasing at the expense of other nearby habitat types. Plant communities have shifted so that only the more salt tolerant species remain, and/or additional areas of open water were created in areas where plants died due to harsh environmental conditions. Additionally, many of the historic reptiles and amphibians that were present have decreased or disappeared. Muskrats, nutria, and river otters, once common, have declined dramatically (TPWD and USFWS 1990). Sightings of these mammals within the Salt Bayou system are now rare. The number of waterfowl using the system is declining even though the numbers for the state have not changed significantly over the last 20 years or more (Kevin Kraaii – TPWD Waterfowl Program Leader, personal communication March 9, 2012). The change in numbers reflects a shift in where waterfowl are spending the winter months, with more of them spending increasingly more time further inland in more preferable freshwater habitats (Kevin Kraaii – TPWD Waterfowl Program Leader, personal communication March 9, 2012). Hunting opportunities remain plentiful today but the quality of opportunities is likely to decrease as the habitat continues to degrade.

Increased salinities have accelerated wetland plant loss while enhancing access of some estuarine marine fisheries including gulf menhaden, blue crabs, brown shrimp, and spotted seatrout (*Cynoscion nebulosus*), all valuable fisheries species. This accelerated increase in fisheries production will reverse as marsh loss continues, undercutting the foundation of the food web and its associated nursery habitat function (Boesch, et al., 1994; Minello and Rozas 2002). Plant viability, longevity, and reproductive success will decrease because seawater in flooded wetland soils leads to the conversion of sulfate to hydrogen sulfide, a compound toxic to marsh plants. Some plant species may be replaced by more tolerant species. However, conversion of marsh to open water can also be an outcome of this process if surface soils are lost and the area is inundated to a depth incompatible with establishment and growth of plants. Substantial marsh loss has already occurred in this system (German and O'Brien 2002). This process of increased salinity and increased frequency of salinity spikes will continue to lead to a degraded ecosystem with reduced fisheries productivity, reduced use by migratory birds and mammals, elimination of most reptile and amphibian species, and reduction in abundance of the macroinvertebrate community (USFWS 2010; Haas et al. 2004).

Coastal marshes are able to reduce or suppress storm surge (Masters 2011; Resio and Westerink, 2008; Wamsley et al. 2009). Because this ability is directly related to the areal extent, vegetation type and density, and condition of marsh between the Gulf and upland areas as well as condition of marsh vegetation, changes within the Salt Bayou system could have direct effects on storm impacts, both physically and economically (Costanza et al. 2008). An additional 4 to 9.5 miles of freshwater to intermediate marsh are found between the GIWW, Port Arthur's storm levee and SH 73, and are integral to the effectiveness of storm surge suppression along the coast. Should the marshes within the Salt Bayou system continue to degrade or disappear completely, the reduction in effectiveness would significantly increase risks of storm damage and economic losses in this area.

STRATEGY FOR SALT BAYOU SYSTEM

In order to sustain the functions of the Salt Bayou system, the Salt Bayou Workgroup has discussed and agreed upon some general principles that should be considered for future restoration projects in the area. The overall goal of this Plan is to facilitate:

> *Conservation of the Salt Bayou system to ensure its continued benefits for wildlife, fisheries, and the community.*

The workgroup formed with the original goal of reducing the negative impacts of hydrologic modifications by reducing the volume of GOM water coming through KLFP. Soon after the work group formed, they chose 5 conservation actions to use in determining the success of any modification to KLFP. These conservation actions were:

1. Modify the cross section of the pass sufficiently to allow a maximum salinity at the interchange between Johnson's Lake and Keith Lake of 10 ppt (under any conditions excluding tropical low pressure events and extreme drought).
2. Re-establish isohaline gradients within the Salt Bayou system to allow intermediate emergent marsh with freshwater inclusions to grade into brackish marsh (waters) at the Keith Lake/Johnson's Lake interchange.
3. Reduce the rate at which the Salt Bayou marshes de-water when a weather front from out of the North causes a tidal blow-out. Current conditions allow rapid de-watering (about 12 hours) resulting in increased organic soil suspension and loss during tidal blow-outs. Blow-out low tides should be slowed to a rate which minimizes suspension and loss of organic soils (e.g. 48 hours).
4. Slow or reverse the present/on-going trend of marsh deterioration whereby salt intolerant emergent plants are being lost, resulting in accelerated erosion of organic soils.
5. Restore soil accretion through vegetative production and reduced current velocities throughout the Salt Bayou marsh system.

Scrutiny of the entire watershed by the group revealed a set of existing and emerging alterations to the system that have the ability to drastically change the hydrologic and biological characteristics of the marshes. The alterations are many, but could be grouped into two main categories. The first relates to human-induced and natural changes to hydrology that altered the historic hydrologic pattern either by reducing the amount of freshwater entering the system or by increasing the amount of saltwater entering the system. The second category relates to surface subsidence from loss of organic surface soils, subsidence from fluid extraction, or a combination of both. It is perhaps these two groups of perturbations that are having the greatest effect on the characteristics of the marshes in Salt Bayou, and the two that the group has placed most effort in addressing.

Alteration of historic hydrologic patterns

Changes to the hydrologic pattern are a grave threat at this time because its impacts are widespread and continuous. It is also a major driver of land loss and loss of elevation within the emergent marsh. Freshwater inputs have been severed from the northern part of the watershed by the GIWW, and cannot be restored without a structural solution. Saltwater is now entering from at least two major locations within the watershed where it had not during predevelopment times, and soon may be intruding from multiple other locations. Without adequately addressing all of the actual and potential alterations to the hydrologic flows into the watershed, marsh loss will continue at an accelerating rate.

Keith Lake Fish Pass is a major, man-made cut that altered hydrology and is having a drastic impact to the system. Since its excavation, the fish pass has eroded to over 3 times its original depth (5.5 feet) and twice its original width (150 feet). The current cross section allows large volumes of saltwater to rapidly exchange between the Sabine Neches Waterway and the Salt Bayou marsh. The rapid exchange of seawater from the shipping channel greatly stresses the *Spartina patens* dominated emergent marsh. Review of aerial photography of this area shows that over several decades the marsh has been breaking up internally (German and O'Brien, 2002) in a manner described for marshes in the Louisiana Chenier Plain (Delaune, et al., 1994; Nyman et al., 1993). Estimates of the rate of conversion from emergent vegetation to surface water are as high as 0.69 % per year (German and O'Brien 2002).

A more recent entryway for saltwater with impacts at least equaling those of KLFP is loss of the beach ridge along the GOM. This ridge prevented Gulf seawater from directly entering the marshes within what is now McFaddin NWR under all but storm tides. Today, water from the Gulf overtops the eroded ridge several times a year and directly impacts thousands of acres of fresh to intermediate marsh and submerged aquatic vegetation with each overtopping event. The high rate of shoreline erosion along this stretch of coast makes rebuilding a stable ridge difficult and expensive. However, without addressing this source of salt water intrusion the loss of marsh between the current shoreline and GIWW is imminent.

A third source of saltwater is from potential breaching of the earthen banks of the GIWW. This would open a third front that would allow near constant influx of saltwater into the system, with impacts that could equal those from the KLFP or overtopping from the Gulf in extent and severity.

In order to address the problems associated with increases in salinity, the following goals and objectives were developed:

Goal: To the maximum practical extent, restore the hydrologic pattern of the Salt Bayou system to pre-development conditions.

> **Objective**: Reduce volumes of saltwater flowing through KLFP such that salinity at the junction of Johnson and Keith lakes does not exceed 10 parts per thousand during 80 % or more of a year with typical rainfall and river flows (excludes years with tropical storms or drought).
>
> **Objective**: Return freshwater inputs from north of the GIWW to re-establish isohaline gradients through the watershed which resemble those historically found in the watershed.
>
> **Objective**: Create a sustainable shoreline that resembles in function the historic ridge and dune system to protect fresh to intermediate marshes located between the Gulf and the GIWW that accounts for potential sea level rise.

Objective: Prevent additional points of entry for saltwater from forming within the watershed along shipping channels and other locations.

Loss of emergent marsh through loss of soils and elevation

Within marshes of the Chenier plain, two typical patterns of marsh loss are commonly observed. In the first, loss of living root networks or erosion of organic soils below the root network cause the peat layer to collapse and form small patches of open water in a scattered pattern (Nyman et al., 1993). This collapse then allows ponding within the affected area that precludes future plant growth ultimately leading to marsh loss. Through time, as the peat layer is eroded further, these small ponds converge and create a large area of surface water in which emergent vegetation does not re-establish.

The second pattern of marsh loss is described as "marsh loss hotspots." They are large areas of marsh experiencing rapid conversion to open water embedded within a larger area of marsh experiencing a much lower rate of marsh loss. Peat collapse appears to be the primary mechanism of hotspot formation (DeLaune et al., 1994, Nyman et al., 1994). The inability of the marsh to accrete soils with components that are organic, mineral, or both leads to flooding stress and ponding within large areas of emergent vegetation. Within a marsh, loss may occur by both of these processes simultaneously.

Within the Salt Bayou watershed, examples of both of these processes are found. The formation of hotspots is most prevalent within areas with active or abandoned oil and gas wells where the surface subsided as extraction occurred. After fluid removal operations ended, subsidence returned to background rates (White and Tremblay 1995) and is believed to continue at those rates. However, the elevation of the soil surface in these areas is below mean sea-level and these areas are nearly constantly inundated. The scattered ponding pattern is evident in areas of the marsh not associated with mineral extraction activities but that are under flooding stress with saltwater. These areas cannot support an emergent plant community without additional inputs of sediments. Effective restoration of the soil accretion process within the watershed will require addressing waterlogging by saltwater as well as restoring the physical conditions (e.g. elevation, flow patterns, wet/dry cycles, etc.) that promote vigorous growth of vegetation and accumulation of organic material. Addressing the loss of emergent marsh will require consideration of the rates of surface subsidence in relation to marsh soil accretion such that proposed actions will promote accretion at a rate sufficient to keep up with subsidence and relative sea-level changes.

In order to address the problems associated with surface subsidence, the following goals and objectives were developed:

Goal: Slow or reverse the current trend of emergent vegetation converting to open water through loss of marsh soils and elevation.

> **Objective**: Promote the beneficial use of dredge material to stabilize degrading marsh and restore elevations sufficient to support emergent marsh vegetation.
>
> **Objective**: Stabilize seasonal salinity patterns to reduce or eliminate rapid changes within the system that lead to conversion of vegetated marsh to shallow open water.
>
> **Objective**: Reduce stress to emergent marsh plants from extended exposure to waterlogging, high salinity, or hydrogen sulfide that leads to plant death and conversion to open water.

Goal: Create conditions that promote formation of marsh soils having both mineral and organic components at a rate capable of keeping pace with relative sea level rise.

> **Objective**: Develop ways to deliver beneficial use dredge material across the watershed to accrete marsh soils and supply nutrients to marsh vegetation.
>
> **Objective**: Re-establish hydrologic conditions that support primary productivity within the emergent marsh plant community sufficient to allow accretion of organic soil components at a rate to match or exceed relative sea level rise.

RECENT ACCOMPLISHMENTS OF WORKGROUP MEMBERS

Since the year 1990, members of the Salt Bayou Workgroup, independently or through partnership, have accomplished several efforts aimed at long-term solutions to restore and maintain the ecosystem.

These include:

- Installation of the Star Lake water control structure. It is managed to maximize availability of fresh water inflows into the 5 Mile and Clam Lake portions of the Salt Bayou system.
- Construction of a new Salt Bayou water control structure to replace the deteriorated water control structure at the eastern confluence of Salt Bayou and the GIWW. This structure is managed to restore the historic hydrologic functions of the Salt Bayou system.
- Installation of the Wild Cow Bayou water control structure. The structure is managed to meet marsh objectives and to restore hydrologic functions in the Wild Cow Bayou Management Unit of the Salt Bayou system.
- A model evaluating the hydrologic nature of the Salt Bayou ecosystem.
- A hydrologic model to evaluate different designs to reduce the KLFP cross-sectional flows.
- A model to evaluate how different tidal reduction designs for KLFP might affect larval fisheries.
- Development of siphon designs across the GIWW to restore freshwater inputs into the system.
- Feasibility assessment of McFaddin Beach Ridge alignments and ridge restoration options.
- Located an offshore source of sand for beach nourishment along McFaddin National Wildlife Refuge.
- Design and construction of the clay core artificial ridge associated with the McFaddin Beach Ridge.

- Applications of beneficial use of dredged material from the Sabine Neches Ship Channel and GIWW at several locations in the system.
- Erosion control and marsh restoration along the GIWW.

Recommendations

Dialogue and efforts have continued with members to implement fundamental projects necessary for long-term sustainability of this ecosystem. Currently (April 2013) four major projects to address the fundamental problems are being pursued. They are:

1. Restoring the historic beach ridge where it is missing from High Island to Sabine Pass. The first phase of clay core berm construction will begin in early 2013. When fully completed, this beach ridge barrier system will minimize the frequency of high tide overwash events to a periodicity of multiple years (between 5 and 10 years). This would allow the marsh ecosystem to stabilize after high salinity events and provide a productive vegetation community and habitat that supports freshwater dependent species.
2. Reducing the ability of Gulf waters from the Sabine Neches Ship Channel to feed directly into the ecosystem via the KLFP. Reducing the tidal flux through this pass will reduce the frequency and duration of high salinity events in the ecosystem.
3. Increasing freshwater inputs to the Salt Bayou System by installing siphons across the GIWW and mimicking some of the historic freshwater inflow back into the system. These siphons would also provide the opportunity for freshwater delivery during critical periods such as drought or after tropical storm surge flooding.
4. Beneficially using dredge material to restore elevation to eroding marsh in Salt Bayou Unit, J. D. Murphree Water Management Area. This project is being done through collaboration between Texas Parks and Wildlife Department and private industry, and is acting as an example of how private and public sectors can combine seemingly disparate needs to create a project that benefits public lands and natural resources. Through 2012, approximately 2,300 acres of marsh within the WMA has been enhanced or restored using dredged soil materials.

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