MATAGORDA BAY FRESHWATER INFLOW NEEDS STUDY

Lower Colorado River Authority
Texas Commission on Environmental Quality
Texas Parks and Wildlife
Texas Water Development Board

August 2006

EXECUTIVE SUMMARY

Matagorda Bay
Freshwater Inflow Needs Study

Introduction

The primary purpose of this study is to reassess the freshwater inflow needs for Matagorda Bay based on more than eight years of new data collected since the completion of the 1997 Freshwater Inflow Needs Study. The earlier study was based on five years of data collected after the U.S. Army Corps of Engineers (USACE) opened a diversion channel in 1991 from the Colorado River into Matagorda Bay to increase freshwater inflows entering into the bay. The current study also reviews and modifies some of the 1997 study methodologies and assumptions. The results of this study indicate that higher freshwater inflows are needed to achieve the Target and Critical inflow needs than indicated in the 1997 study. This is largely due to the availability of additional, more variable data collected over a longer period of time.

Both the 1997 study and the current study represent a joint effort of the Lower Colorado River Authority (LCRA), the Texas Parks and Wildlife Department (TPWD), the Texas Water Development Board (TWDB), and the Texas Commission on Environmental Quality (TCEQ). Each study partner was represented on the study advisory committee and guided by a joint memorandum of agreement and scope of work (See Appendix A). A representative of the Lavaca-Navidad River Authority also attended the advisory committee meetings. The advisory committee meetings were open to the public and development of the study involved public meetings and workshops, a stakeholder process and public review and comment on the draft study.

Improvements in the Current Study

The current study builds and improves upon several areas of the 1997 study. Flow, salinity, and biological productivity data have been extended beyond what was used in the1997 study and are

applied here. This includes the availability and use of independent fisheries data collected by TPWD rather than the reliance on commercial harvest data. As a result, improved equations have been developed for relating flow to salinity and to productivity. Biological equations for shrimp have also been improved resulting from more careful consideration of the influence of inflows on shrimp during the juvenile life stage. Sensitivity analyses were conducted on the TXEMP optimization model to provide better insight on the influence of constraints and other factors on the model results. As a result, limits on inflow and biological constraints were revised from the 1997 study. In addition to developing Critical and Target Flows as in the 1997 study, the current study presents options for use of TXEMP model results to develop intermediate flow solutions for use as a transition between the Critical and Target inflow needs. Model calibration of the TXBLEND hydrodynamic and salinity transport model benefited from additional data, and multi-year simulations were conducted in this study and provide better confidence in the model behavior.

The 1997 report identified a number of areas that would benefit from additional study. However, some areas could not be extended in this study due to lack of additional new data, including nutrients (related to primary productivity, offshore concentrations, loadings, and sediment), benthic dynamics and sedimentation needs of Lavaca Bay and East Matagorda Bay. In addition to the need to continue developing additional data and analysis, more information is needed on existing habitat conditions and their relationship to biological productivity. A comprehensive assessment of factors that may affect the overall ecological health of the bay is also being conducted as a part of the LCRA-SAWS Water Project (LSWP) Bay Health Study. The improvements and modifications to the State Methodology being done for this study in combination with the more comprehensive look at overall bay health and productivity by the LSWP Bay Health Study are expected to contribute to the development of improved methods and tools for assessing freshwater inflow needs for Matagorda Bay.

Target Flows and Critical Flows

Beginning with the 1997 study, two freshwater inflow needs (FINS) have been identified: the "Target" freshwater inflow need based on the application of the State Methodology; and the "Critical" freshwater inflow need. The "Target" freshwater inflow need seeks to optimize selected estuarine species productivity; the "Critical" freshwater inflow need is intended to provide a fishery sanctuary habitat during drier periods from which finfish and shellfish species are expected to recover and repopulate the bay when more normal weather conditions return.

The monthly Target flow needs estimated by the current study by source are summarized in Table ES.1. Monthly Target flows range from 480,100 acre-feet in May to 111,700 acre-feet in August. Compared to the 1997 study results, these results represent a maximum monthly increase of 267,600 acre-feet of freshwater inflows in the month of February to a maximum monthly decrease of 181,500 acre-feet of water in the month of May needed to deliver the Target inflow necessary to optimize selected estuarine species productivity.

Table ES.1 Monthly Target Flow Needs by Source.

Month	Colorado (1,000 ac-ft)	Lavaca (1,000 ac-ft)	Other (1,000 ac-ft)	Total Monthly (1,000 ac-ft)
January	205.6	77.0	37.2	319.8
February	194.5	68.9	44.5	307.9
March	63.2	15.6	42.3	121.1
April	60.4	30.3	51.1	141.8
May	255.4	139.4	85.3	480.1
June	210.5	86.0	80.2	376.7
July	108.4	29.2	66.4	204.0
August	62.0	18.3	31.4	111.7
September	61.9	37.3	107.2	206.5
October	71.3	42.9	100.7	214.9
November	66.5	23.0	47.4	136.9
December	68.0	24.9	35.7	128.7

During the 1997 study, 25 parts per thousand (ppt) was established as the desired maximum salinity level during drought or extended dry periods. This criterion was based on review of species tolerances with particular attention to the Eastern Oyster and its predators. The Eastern Oyster was

chosen not only because it is a commercially important species, but because it cannot migrate to areas with lower salinity ranges to avoid predators. The 25 ppt salinity level is also the approximate dividing line between brackish estuarine waters and more saline marine waters and, thus, an appropriate threshold to use in determining whether estuarine species may become significantly affected.

Based on additional data and analysis, Critical inflow needs for the Colorado River increase from 14,260 acre-feet of water per month to 36,000 acre-feet of water per month over those calculated in the 1997 study. Lavaca-Navidad Critical inflow needs increase from 2,260 acre-feet of water per month to 4,290 acre-feet per month. Corresponding increases would also be needed from the other coastal basins that feed into West Matagorda Bay.

The primary reasons for the increases in Critical and Target inflow needs from the 1997 study include the following:

- More accurate statistical relationships based on additional data collected over a longer period of time since the USACE diversion channel was completed in 1991. For example, data was collected on a more continuous basis and data collection included fewer gaps and was subject to less frequent equipment failures.
- More variability of wet and dry years and corresponding salinities was captured by the statistical relationships; and
- Increased monthly inflow constraints were selected for use in the TXEMP modeling. Historic flows in the 70th percentile replaced the historic monthly mean used in the 1997 study or the monthly median flow (50th percentile monthly or median monthly historic flow), which has been widely used in other Texas estuaries. This constraint increase was necessary to allow the model to be solved without exceeding the selected salinity and biological productivity constraints.

Consistent with the 1997 study, the 2006 update continued to use the same salinity regimes and rationale for Critical and Target inflows, measurement locations, State optimization and hydrodynamic and conservative transport models (TXEMP and TXBLEND), target species (with

one exception), and the relative weighting of species, as the 1997 study. In contrast to the 1997 study, the 2006 study also explored a range of intermediate inflow regimes that may be considered as a transition from Target to Critical inflow regimes.

Both the 1997 and the 2006 studies used the State Methodology, with some modifications. The State Methodology includes the use of the TXEMP model, a general purpose optimization model to find a minimum or maximum function (e.g., biological productivity) that satisfies constraints that are imposed (hydrology, salinity, biological). TXEMP results are bounded by the constraints. The State Methodology also includes the use of the TXBLEND model, a hydrodynamic and conservative transport model specific to water bodies such as lakes or bays. The conservation transport aspect of the model looks at the movement of salt through the water body. The TXBLEND model is used to verify that the inflow regime results identified by the TXEMP model as meeting all constraints will also provide the desired salinity regime throughout the Matagorda Bay system.

While the logic and equations of the optimization model itself are built on mathematical and engineering analyses, application of the model requires the inclusion of operative constraints, limits, and resource management objectives. These objectives are based more on policy than science and engineering. Other policy decisions include: the indicator species to be used, the relative weighting of the species; and the selection of inflow-response equations and inflow constraints (Longley, ed., 1994). Since many of these policy decisions are made by the state agencies responsible under state law for water permitting and planning, the 1997 study as well as this update are based on the existing State Methodology, with some modifications developed in consultation with the state resource agencies. It is expected that these policies and methodologies will continue to evolve based on the recommendations of the SB 1639 (78th Texas Legislature; 2003) Study Commission on Water for Environmental Flows.

It should be recognized that salinity is only one component in assessing the overall health and productivity of the bay. Other components of aquatic habitat such as the hydrodynamic regime, physical structure, food availability, and shelter/predator avoidance are also important. Salinity has

been used as a primary measurement of beneficial inflows because it influences productivity, and it is easy to measure as a hydrologic variable. However, it may have only a secondary degree of influence. The indirect influence of salinity includes food availability (e.g. plankton) that thrive in freshwater – seawater mixtures found in estuaries. Higher productivity in terms of species richness and evenness is usually found in the fluctuating, mesohaline zone of the estuary.

Post-Diversion Productivity

The Colorado River was diverted into the eastern arm of Matagorda Bay in 1991 by the U.S. Army Corps of Engineers (USACE) to create habitat, increase nutrients and moderate salinity in order to improve productivity. Since the diversion, a functional deltaic marsh has developed at the end of the diversion cut that now forms the mouth of the river, creating habitat for many estuarine species. Over time it is expected that the delta marsh will increase productivity in Matagorda Bay because of increased physical habitat, increased nutrients, and moderated salinity. Comparisons of bay-wide biological monitoring data before and after the USACE diversion channel do not indicate a clear relationship between increased inflows and species abundance. However, the TPWD sampling effort in the bay does not directly sample this delta marsh, making it difficult to assess species utilization. Additionally, a major flood in 1992 and a severe drought in 1996 occurred during the post-diversion period, both of which have likely had negative short-term impacts on species productivity.

The current health and productivity of Matagorda Bay is generally good, according to TPWD studies and observations. Matagorda Bay generates approximately $63 million annually in commercial seafood harvests, and contributes toward an additional $115 million annually to the sport fishing industry (Loeffler and Balboa "Colorado Quandry," TWPD, The Outdoor Magazine of Texas, July 2003). Since the completion in 1991 of the USACE diversion channel, hundreds of acres of productive marshes have been created and newly created oyster reefs are flourishing. Id. Therefore, the health and productivity of the bay have been generally very good under the current freshwater inflows being provided to the bay.

Recent State Reviews

Since this update was initiated, the Texas Legislature established the Study Commission on Water for Environmental Flows under Senate Bill 1639 (2003). As a part of its task, the commission appointed a Science Advisory Committee to assess current methodologies and analytical tools for determining freshwater inflow needs. The Science Advisory Committee recommended improvements to the State Methodology, some of which have been incorporated into this study. For example, it criticized the State Methodology's use of commercial harvest data. This study relies on independent monitoring data. The Committee also criticized the State Methodology as relying too heavily on the premise that species abundance is dependent upon inflow and salinity, without adequately considering nutrients, sediments, energy, habitat and other measures of overall ecological health and productivity. In addition, the Study Commission's report recommended an "adaptive management" approach where adjustments to identifying or meeting environmental needs are made as new information and better science becomes available and endorsed the use of a peer review process and stakeholder involvement. LCRA is unique in the State of Texas in using this approach in the periodic review and revision of its Water Management Plan (LCRA, 1999). LCRA is also the only water right holder in the lower Colorado River basin that has specifically committed water for environmental water needs and has incorporated adaptive management principles.

Because of the recent criticism of the State Methodology, the uncertainty of what the legislative response may be to the SB 1639 Study Commission report, and the use of different modeling tools and approaches under the LSWP Bay Health Study, there remains the need to continue the periodic review and reassessment of freshwater inflow needs. Estimates of freshwater inflow needs for Matagorda Bay and the most appropriate means for delivering such flows should be updated and revised when new data, methods, and tools become available. The LSWP is also evaluating many factors that affect the overall ecological health of the bay and should be considered together with the FINS in any future water management decisions. Any lessons learned from other freshwater inflow needs studies being conducted in Texas should also be considered. For example, the Nueces Bay Study indicated that the timing and location of freshwater inflows were more important than an overall increase in the total amount of inflow for improving bay productivity.

Finally, models can predict only what may happen. In reality, only the passage of many years will demonstrate what effects freshwater inflows have on bay health and productivity. Like all coastal systems, Matagorda Bay's productivity is the result of a host of complex factors that are not yet fully understood.

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Acronyms

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CHAPTER 1
Introduction

1.1 Purpose

The purpose of this study is to: (1) better understand the relationships between the volume and seasonal timing of freshwater inflows and important environmental conditions in the estuarine system; (2) better estimate the needs for freshwater inflows to maintain and preserve the bay's aquatic ecology; and (3) update the 1997 Freshwater Inflow Needs of Matagorda Bay System Study in accordance with the 2002 Memorandum of Agreement (MOA), as amended, between the Lower Colorado River Authority (LCRA), the Texas Parks and Wildlife Department (TPWD), the Texas Water Development Board (TWDB), and the Texas Commission on Environmental Quality (TCEQ).

A large part of this study seeks to help answer questions that were raised during the 2002 LCRA Water Management Plan stakeholder process regarding specific aspects of the 1997 Freshwater Inflow Needs Study results for Matagorda Bay. In particular, several stakeholders raised concerns about accuracy of the salinity –inflow relationship near the mouth of the Colorado River. These concerns and related discussions prompted LCRA and the participating agencies to revisit the 1997 Freshwater Inflow Needs Study.

The current FINS study is not intended to determine or suggest how the results may be implemented by any of the study participants. This study may be used by the TPWD, TWDB and TCEQ as a study prepared under Texas Water Code §§11.1491 and 16.058, along with any other relevant studies and information, and by TCEQ in the consideration of water right applications to store, divert or use state water pursuant to Texas Water Code §11.147. In addition, the TWDB may choose to use the study in the development and approval of state and regional water plans under Texas Water Code Chapter 16, subchapter C. The study will also be considered by LCRA in determining whether any changes to its Water Management Plan are needed, as provided under the MOA. This review process will assess the revised FINS with all other water demands, water availability, and with input from all affected interests. The review will also include the consideration of the Bay Health Study

being performed as part of the feasibility study for the Lower Colorado River Authority-San Antonio Water System Water Project and any other relevant information and studies.

1.2 Study Components – State Methodology for Determining Freshwater Inflow Needs

The Target freshwater inflow needs for this update were estimated following as closely as possible the process developed by the TWDB and TPWD in their study of the Guadalupe Estuary (Longley, ed., 1994). This process involves a number of separate functions (Figure 1.1). The first major element is the development of statistical relationships for the varied and complex interactions between freshwater inflows and important indicators of estuarine ecosystem conditions. The key estuarine indicators considered were salinity, species productivity and nutrient inflows. Each of these indicators is related to inflows to the bay, which are developed in Chapter 2, Hydrologic Characteristics of Matagorda Bay. Chapter 3, Biology describes the species selected for use in this study and develops the equations relating abundance of these species to inflows. A description of the salinity characteristics of the bay is provided in Chapter 4, Matagorda Bay Salinity. This information is applied toward developing salinity-inflow relationships in Chapter 5, Development of Salinity Inflow Relationships for Use within TXEMP. Chapter 6, Nutrient Requirements of Matagorda Bay, describes the nutrient characteristics of Matagorda Bay and develops minimum nutrient requirements for later use in the analysis. A summary of the datasets used in these analyses is included in Appendix B.

The second essential process involves using statistical functions to compute optimal monthly and seasonal freshwater inflow needs. This is accomplished using the TWDB's TXEMP Model (Longley, ed., 1994). The TXEMP model estimates the freshwater inflow needs of an estuary by representing mathematically the interactions between freshwater inflows and salinity, species productivity and nutrient inflows. Sediment inflow constraints are excluded in TXEMP due to a lack of data concerning the volume of sediment needed to balance erosion and subsidence in the Colorado River and Lavaca River delta. Chapter 7, Estimation of Freshwater Inflow Needs, describes the application of the salinity, productivity, and nutrient information developed earlier in the report in TXEMP to develop Target and Intermediate inflows.

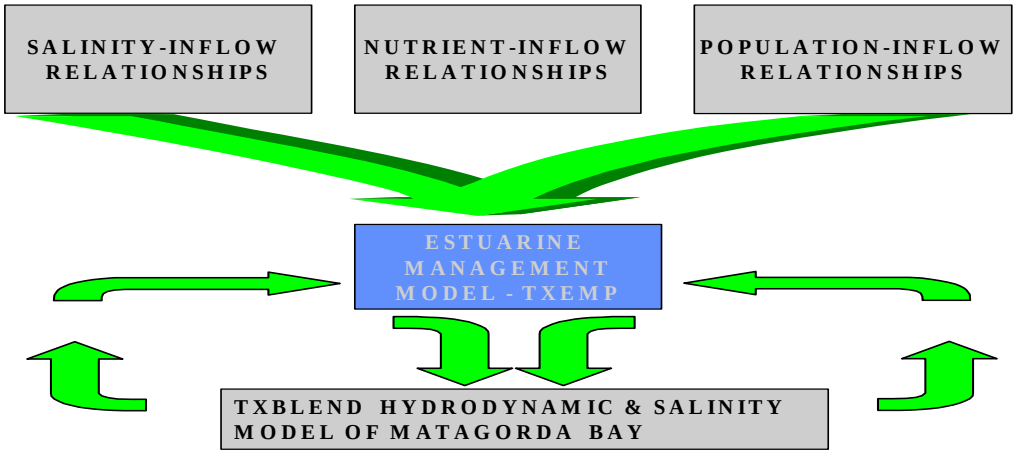


Figure 1.1 Process for Determining Freshwater Inflow Needs.

The third major component of the process of developing inflow needs is the simulation of the salinity conditions throughout the estuary using the TXBLEND model developed by TWDB and modified by LCRA. The simulated salinity is then compared to desired salinity ranges over broad areas of the estuary. If salinity is not within those ranges, then constraints in TXEMP are modified to achieve the desired salinity. Target flows developed in Chapter 7 are applied as inputs to TXBLEND in Chapter 8, Hydrodynamic and Salinity Transport Model, to evaluate the resulting salinity distribution throughout the bay. Chapter 9, Development of Critical Freshwater Flow Estimates describes the development of Critical Flows or flows required during low flow conditions in which the management goal is to provide sanctuary for species until more normal conditions return.

1.3 Improvements in the Current Study

The current study improves upon several areas of the 1997 study. Flow, salinity, and biological productivity data have been extended beyond what was used in the1997 study and are applied here. As a result, improved equations have been developed for relating flow to salinity and to productivity. Biological equations for shrimp have also been revised resulting from more careful consideration of the influence of inflows on shrimp during the juvenile life stage. Sensitivity analyses were conducted on the TXEMP optimization model to provide better insight on the influence of

constraints and other factors on the model results. In addition to developing Critical and Target inflows as in the 1997 study, the current study presents options for use of TXEMP model results to develop intermediate flow solutions. Model calibration of the TXBLEND hydrodynamic and salinity transport model benefited from additional data, and multi-year simulations were conducted in this study and provide better confidence in the model behavior.

The 1997 report identified a number of areas that would benefit from additional study. However, some areas could not be extended in this study due to lack of additional new data, including nutrients (related to primary productivity, offshore concentrations, loadings, and sediment), benthic dynamics and sedimentation needs of Lavaca Bay and East Matagorda Bay. In addition to the need to continue developing additional data and analysis on nutrients, more information is needed on existing habitat conditions and their relationship to biological productivity.

1.4 Background

1.4.1 The Ecological Importance of Freshwater Inflows to Matagorda Bay

Bays and estuaries are critically important to the well-being of most marine shellfish and finfish species on the Texas coast and are vital to the state's commercial and sport fishing industry. Between 75 to 80 percent of the fishery species in the Gulf of Mexico are dependent upon estuaries during some portion of their life cycle. Many species are not permanent residents of the estuaries but migrate to them during different times of their lives. These migrations occur seasonally and are usually related to spawning cycles. Larval and juvenile organisms move from the ocean into estuarine marsh lands to find food and to seek the protection of lower salinity water. The young of many fishery species can tolerate lower salinity than their predators and parasites. When they mature to young adults, the individuals migrate back to the Gulf.

The life cycles of estuarine-dependent species require differing seasonal migratory patterns. Redfish, for example, spawn in the fall, and the young migrate into estuarine marshes shortly afterward to feed and grow. Estuaries are the permanent homes for many indigenous species that do not migrate. The most well-known of these is the oyster. The juveniles anchor upon natural reefs or

other solid objects and remain in the same spot through their adult lives. This lack of mobility makes the oyster particularly susceptible to changes in water conditions. Oysters cannot tolerate freshwater (i.e. less than 5 ppt salinity) for more than a few days. On the other extreme, very salty water (i.e. over 25 ppt) for a prolonged period of time combined with high temperatures allows parasites (*Perkinsus marinus*) and oyster drills (*Thais haemostoma*) to attack the oysters, often destroying entire oyster reefs.

Many complicated interactions govern the biological productivity of Texas bays and estuaries other than the quantity of freshwater inflows. However, freshwater inflows and their associated nutrients and sediments are recognized by most estuarine biologists as one of the primary factors in estuarine productivity. Studies have demonstrated that these contributions from the freshwater inflows allow economically important fish and shellfish species to survive, grow and reproduce abundantly (LCRA, 1997).

Researchers have also discovered that periodic river floods inundate delta marshes, transport nutrients and other organic materials (food sources), and remove or limit many pollutants, parasites, bacteria and viruses harmful to estuarine-dependent organisms (LCRA, 1997). However, too much freshwater can stress or even severely damage these living coastal systems if their environment loses its marine character.

1.4.2 The Economic Value of Matagorda Bay

At approximately 350 square miles, the Matagorda Bay system is the second largest of Texas' seven major bay systems (Galveston Bay is the largest; other significant bay systems include Sabine Lake, San Antonio Bay, Aransas/Copano Bay, Corpus Christi, Nueces Bay and Upper and Lower Laguna Madre). This system is also known as the Lavaca-Colorado estuary, and its largest single body of water is Matagorda Bay. Major secondary bays in the estuary include Lavaca, East Matagorda, Keller, Carancahua, and Tres Palacios (Figure 1.2).

The current health and productivity of Matagorda Bay is good, according to TPWD studies and observations. The bay, with its estuaries nourished by freshwater inflows from the Lavaca and Colorado rivers as well as numerous, smaller streams and creeks, has been described as a "mother

dynamo of sea life production." (Jim Anderson, "The Ocean's Nursery," TPWD, The Outdoor Magazine of Texas, July 2002) The abundant production of finfish and shellfish make this environmentally sensitive area important not only as an ecological resource, but also as a source of economically significant commercial and sports fisheries (Loeffler and Balboa, "Colorado Quandary," TPWD, The Outdoor Magazine of Texas, July 2003). Palacios calls itself "The Shrimp Capital of Texas," and is the home port to more than 400 shrimp trawlers. The Gulf of Mexico produces more than 40 percent of the total U.S. seafood harvest, and commercial boats based around Matagorda Bay bring in a major portion of the bounty, generating about $63 million annually. Id. The booming sportfishing industry on the bay generates $115 million annually. Id. "It's a healthy, diverse system now," according to TPWD biologist Bill Balboa, based at the Palacios Field Station. "The menhaden [a key forage fish] are thriving, shellfish surveys are up and new wetlands have formed." Id.

The economic importance of estuaries is shown in the value of estuary-dependent fish and shellfish. Commercial fishermen in Texas landed an estimated 95.2 million pounds of fish, shrimp, crabs and oysters in 1999. Shrimp are the most valuable resource along the Texas coast, accounting for 81 percent of the harvest and 88 percent of the dockside value in 1999 (Auil-Marshalleck et al., 2001). The dockside value of the shrimp catch was worth an estimated $219 million (in 1999 dollars). The economic impact of the industry is estimated at $330 million annually, which supports 30,000 full-time jobs (Texas Center for Policy Study, 2002).

Matagorda Bay has an important role in commercial fishing among Texas bays, especially with regard to shrimp. Commercial shrimpers in the Matagorda Bay system landed one-fourth of the total shrimp catch from all Texas bays, representing 27 percent of the dockside value, on average, from 1995 to 1999. Commercial crab landings from the Matagorda Bay system accounted for about 15 percent of the statewide catch and value. Gulf landings from ports located in the Matagorda system are important to the local and state economies. Palacios and Port Lavaca have gained major port status with the National Marine Fisheries Service. Major port status is assigned to a port with more than 5 million pounds of seafood landings per year. Palacios, in particular, has consistently been classified as a major port and ranked second among Texas ports for shrimp landings in 2000.

Texas A&M University modeled economic output for several Texas bays in 1995. The A&M study estimated that the statewide impact from commercial fishing (gulf and bay) for the Matagorda system was 1,847 jobs and $71.86 million in total output (Tanyeri-Abur et al., 1998). Increases in landings and value data indicate that this impact has grown over time. For example, Palacios landings recorded 6 million pounds of seafood worth $21 million in 1995; by 2002 that number increased 15 million pounds worth nearly $31 million.

Estuaries also provide important recreational benefits. The Texas coast provides abundant opportunities for fishing, wildlife and bird watching and other nature recreation. Marsh wetlands surrounding the estuaries are vital habitat for migrating waterfowl. The U. S. Fish and Wildlife Service estimated that expenditures for wildlife-related activities in Texas were $5.4 billion in 2001 (Underwood, 2003). Fishing and other nature tourism are dependent on healthy estuaries with adequate freshwater inflow.

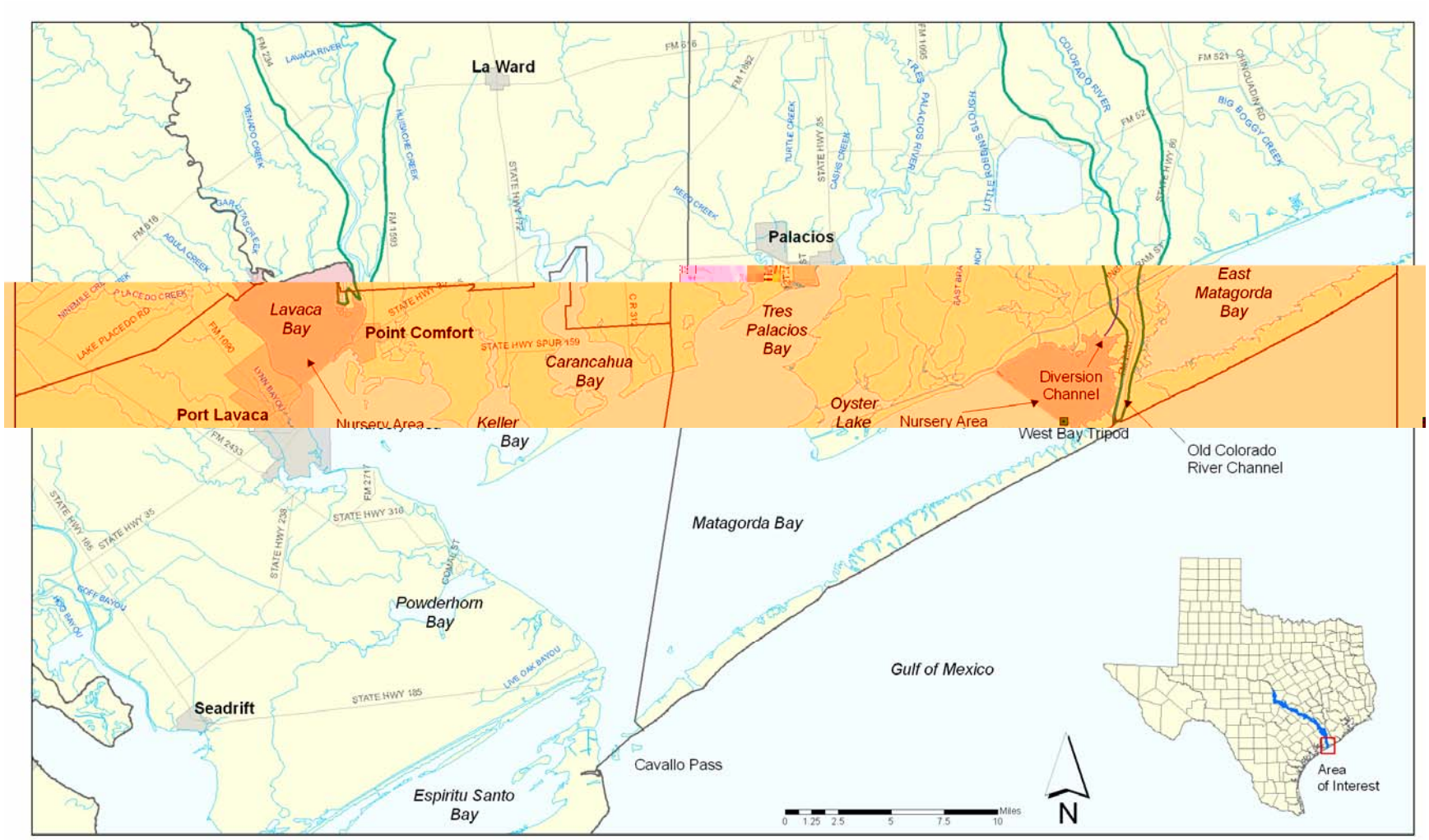


Figure 1.2 Matagorda Bay.

1.4.3 Historical Changes in Inflows

Natural as well as manmade changes have had a significant impact on the amount and pattern of freshwater inflows into Matagorda Bay. For centuries, the Colorado River emptied into Matagorda Bay, which then included what is now known as East Matagorda Bay. But tremendous floods during the past two centuries slowly created an obstacle of logs and debris that extended for several miles upstream of the mouth of the river. Several unsuccessful attempts were made to clear the log jam or build channels around it. Finally, in 1929, a great flood cleared this massive log jam and blew centuries of accumulated silt and debris into Matagorda Bay, building a new delta. This delta continued to grow until it finally cut the bay in half, separating Matagorda Bay from East Matagorda Bay (Figure 1.3). A channel was cut through this land bridge in 1935, allowing the Colorado River to flow directly to the Gulf of Mexico.

Federal maintenance of the river channel began in 1937, authorized under the U.S. Army Corps of Engineers maintenance authority for the Gulf Intracoastal Waterway (GIWW). The GIWW intersects the Colorado River just above the bay near the town of Matagorda through which some of Colorado River flow exchanges between East Matagorda Bay and Matagorda Bay. The GIWW also has affected the historical inflows to the bay, particularly from the smaller, upper bay tributaries.

In 1991, the Corps of Engineers dredged a diversion channel so that water from the Colorado River would once again flow into Matagorda Bay. The purpose of the diversion channel was to provide more freshwater inflows into the bay to reduce salinities, increase nutrient inflows and develop emergent marshlands to increase biological productivity and diversity. While emergent marshlands continue to develop, more years of data are needed to evaluate the relationship between altered flows and productivity. There is also some local concern that because of the amount of sediment being deposited, the diversion channel will cause that end of the bay to turn into a vast, shallow marshland, which will have an impact on recreational navigation and fishing (Underwood, 2003).

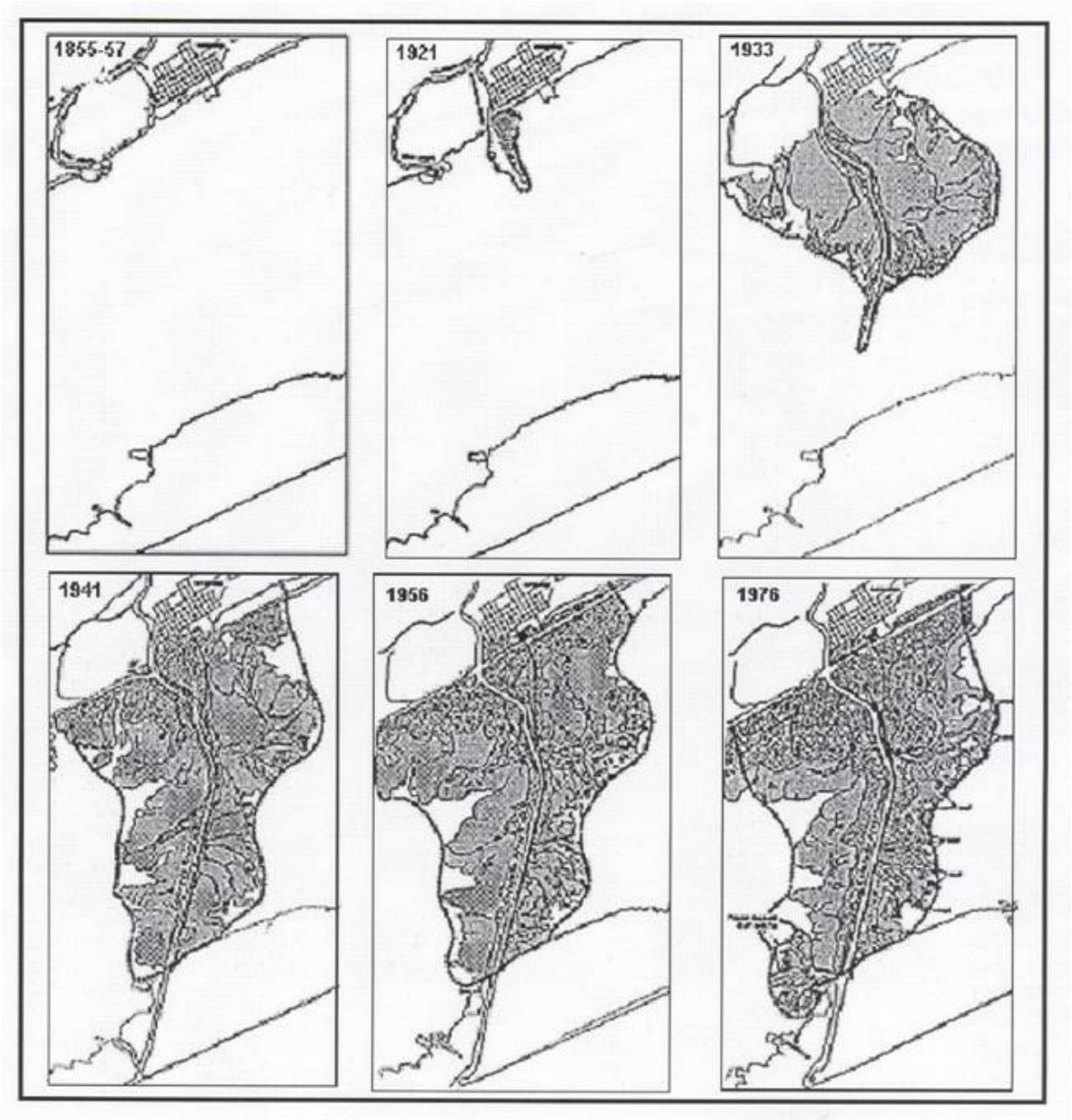


Figure 1.3 Development of Colorado River Delta[1].

1. Reference: Delta Development – Mouth of Colorado River Project Assessment Report, Coastal Technology Corporation (Adapted from USGS, Tobin & Kargl), 1980.

1.4.4 State Policy on Freshwater Inflow Needs for Bays and Estuaries

Water management in Texas has become increasingly more complex as population and economic growth continues at a rapid pace and environmental needs for water are becoming fully recognized. The use of freshwater for municipal, industrial, agricultural and other activities is often in direct competition with estuarine freshwater inflow needs. This competition of needs has generated much public interest in the water planning and permitting process over the past several decades.

Prior to the 1985 conservation and environmental amendments to the Texas Water Code, the State of Texas generally did not consider or provide for the assessment or protection of environmental water needs. Since most water rights in Texas were issued prior to 1985, most were issued without conditions for the protection of environmental water needs. In river basins that are fully or over appropriated, unused water rights and return flows are the primary sources of water for environmental flow needs, especially during dry periods. (Jordan, 1995) Therefore, a number of innovative strategies, both regulatory and non-regulatory, will be needed to fully meet environmental flow needs. Id.

In 1985 the Legislature amended Texas Water Code Section 11.147 to require consideration of freshwater inflows to bays and estuaries during water rights permitting decisions. Available studies to support these permitting decisions regarding freshwater inflows are limited. Further weight to be given to various factors in considering freshwater inflow needs during permitting decisions has been subject to considerable dispute over the appropriate environmental management goals and how water should be allocated to meet these goals while considering all other competing demands for water.

Presently, Texas law does not clearly define environmental management goals nor mandate protection of specific levels of freshwater inflows. However, state policy does require the state to "consider and provide for the freshwater inflows necessary to maintain the viability of the state's bays and estuary systems while balancing all other interests in the granting of permits" (Water Code §11.0235, enacted by SB1639). The first recognition of effects of permit issuance on estuaries came in 1975, with the passage of SB 137 by the 65th Texas Legislature. Later enactment of Texas Water Code §16.1331 requires that five percent of the firm yield of any state reservoir within 200 river

miles of the coast that was built after September 1, 1985, be reserved for instream uses and estuarine inflow releases. The authorization of any new major new reservoirs will face significant challenges because of cost, environmental issues, lack of appropriate sites and availability of sufficient, unappropriated water. Id. In addition, for new water use permits within 200 river miles of the coast, "the commission shall include in the permit to the extent practicable when considering all public interests and the studies mandated [by law], those conditions considered necessary to maintain beneficial inflows to any affected bay and estuary system." (Texas Water Code §11.147, 1985)

It is relatively easy to quantify the water needs for municipal, industrial, agricultural and other human uses of water. However, the influence of water on the complex interactions in estuaries is difficult to quantify. To more fully understand the implications of changes in freshwater inflows to estuarine ecosystems, state and federal agencies began studies of Texas' bays and estuaries in the 1960s.

In 1985, the Texas Legislature directed TPWD and TWDB to continue studies of the estuaries and determine sufficient information so that the need for freshwater inflows to the estuaries could be considered in the allocation of the state's water resources. These studies originally were to be completed by December 31, 1989. However, due to funding reductions, changes in priorities, the complexity of estuarine systems not fully understood at this time, and other factors, they were significantly delayed.

LCRA's ability to more effectively manage the Highland Lakes to meet the region's existing and future water needs, including the protection of environmental flow needs, was directly affected by the delay in completing these studies. LCRA was required by the Texas Water Commission, a predecessor of the TCEQ, to seek amendments to the LCRA Water Management Plan for its lakes Buchanan and Travis water rights to consider freshwater inflow needs of the Matagorda Bay from the Colorado River. Thus, establishing the freshwater inflow needs from the Colorado River is vital to LCRA's management of its lakes Buchanan and Travis water rights in the Colorado River basin for all beneficial purposes. LCRA is aware of its responsibilities in meeting competing water needs

all along the river so that the Matagorda Bay system will receive adequate freshwater inflows and continue to be productive in its natural role.

1.4.5 The 1997 Matagorda Bay Freshwater Inflow Needs Study

To expedite the state's freshwater inflow needs study of the Matagorda Bay system, and to comply with requirements of its water rights, LCRA entered into a cooperative agreement with TPWD, TWDB and the Texas Natural Resource Conservation Commission (TNRCC) (a predecessor agency to the TCEQ) in 1993 to initiate a freshwater inflow needs study for Matagorda Bay. In 1997, the cooperating agencies (LCRA, TWDB, TNRCC, TPWD, and LNRA) completed their study of freshwater inflow needs of the Matagorda Bay system pursuant to the Memorandum of Agreement, the results of which are contained in a report titled, "Freshwater Inflow Needs of Matagorda Bay." In the study, LCRA adapted existing methods used by the TPWD and TWDB and applied those methods to estimate freshwater inflow needs for the estuary. The participating state agencies provided timely technical assistance to LCRA in completing the study.

The 1997 study focused on the estuary west of the Colorado River (Matagorda Bay) in quantifying the freshwater inflow needed from the Colorado and Lavaca rivers and adjacent coastal basins. To the extent possible, the impact of freshwater inflows on the environmental conditions in East Matagorda Bay was to be evaluated; however, full analysis of East Matagorda Bay was contingent on adequate external funding and sufficient additional data. The results of the study were subsequently considered during the 1999 revisions to the LCRA Water Management Plan.

Two freshwater inflow needs (FIN) were identified in the 1997 study – the "Target" freshwater inflow need, based on application of the State Methodology, and the "Critical" freshwater inflow need. The Target FIN seeks to optimize selected estuarine species productivity within various hydrological and biological constraints; the Critical FIN is intended to provide a fishery sanctuary habitat during the most severe drought from which finfish and shellfish species could be expected to recover and repopulate the bay when more normal weather conditions return.

At the time of the 1997 study, the use of a Critical inflow management strategy was a pioneering concept not yet generally adopted by the state. The purpose of this strategy was to balance the

impacts of environmental water needs with other competing demands for water during times of water shortage. Also, the Target flow cannot always be met, even in the naturalized flow time series. The Critical FIN for Matagorda Bay was based on maintaining a salinity level of 25 ppt in an area of the bay (at the West Bay Tripod) near the mouth of the diversion channel from the Colorado River into Matagorda Bay (Figure 1.2). The area of this refuge is approximately 10,000 acres. The Critical salinity value was chosen to protect oysters, a commercially important species in Matagorda Bay, from the significant predation and mortality from parasites that occurs when salinities exceed 25 ppt and other conditions such as higher temperatures are present (Chu and La Peyre, 1993; King, 1989; Shumway, 1996). This salinity level was also chosen because oysters are stationary and cannot migrate in response to salinity changes. This salinity level is also an approximate dividing line between brackish water needed for bay species life cycle events and more saline marine water. Juveniles of other species are less tolerant to elevated salinity but are mobile and can move to less saline areas such as the mouths of rivers and creeks.

The salinity reference location for the oyster reefs is at the West Bay Tripod, 3.5 miles from the delta of the Colorado River near the southern shoreline (Figure 2.2), and almost as far away from the nearest oyster reefs which lie along the northern shoreline. The West Bay Tripod and the nearest oyster reefs are nearly equidistant from the river mouth. Inflow regression equations were used to estimate the inflows necessary to maintain desired salinity levels at the West Bay Tripod, and by implication, at the oyster reefs.

A salinity measuring device for the Lavaca River delta was also attached to an existing structure (Port Lavaca Causeway) located approximately 3 miles from the delta of the Lavaca River. The Lavaca River refuge or sanctuary encompasses about 13,000 acres. Including the Colorado River delta refuge area (10,000 acres), the total available refuge area is about 10 percent of the 353 square mile area within the Matagorda Bay estuary.

The 1997 report identified a number of areas that needed further study to verify the processes used and to develop improved relationships between freshwater inflows and important indicators of estuarine conditions. These included collection of more salinity data, re-examination of the salinity-inflow equations, and continued collection of secondary productivity data. These are addressed in

this updated study. The 1997 report also called for more information/data collection on nutrients (related to primary productivity, benthic dynamics) and additional studies of sedimentation needs of Lavaca Bay and East Matagorda Bay. Efforts to obtain additional data through partnerships between the study agencies, federal agencies and academic institutions will continue to be undertaken.

1.4.6 The 2001 LCRA Water Management Plan Revision Stakeholder Group

During the LCRA Water Management Plan revision process[2] in 2001, some members of the Water Management Plan Stakeholder Group believed that LCRA should adopt a revised Critical FIN (36,700 acre-feet per month) to reflect the revised salinity-inflow relationship that was developed based on additional data gathered since the 1997 study. However, other stakeholders voiced concerns over adopting a new Critical freshwater inflow needs figure, raising questions about the methodology and the potential impacts of how such needs might be addressed in light of other competing demands for water. After considering this stakeholder input, LCRA technical staff identified eight specific concerns with adopting new FIN criteria, including:

1. Drought bias in the Colorado River salinity-inflow equation data set;
2. The need to update the Lavaca River inflow salinity equation;
3. The need to update the productivity equations for the nine target species;
4. The need to update the relationships between inflows from the Colorado River, Lavaca-Navidad River system, and ungaged flows (such as those entering the bay system through runoff from the irrigation districts);
5. The need to update the hydrodynamic model to account for sedimentation in the bay;
6. The need to factor in nutrients and algal production;
7. The location of the salinity measuring location relative to the stream gage; and
8. The need to consider other variables that may affect salinity such as water depth, wind and tidal flux.

2 The WMP revision process began in 2001. The LCRA Board accepted staff's recommendations regarding the WMP revision in 2002. The revised WMP was submitted to the TCEQ in 2003.

Given these concerns, in its March 13, 2002, memo to the LCRA Board of Directors relating to recommended changes to the Water Management Plan, LCRA staff recommended against any revisions at that time to the WMP based on new salinity-inflow calculations. In its memo, staff explained there were significantly more issues to be considered besides a single salinity threshold. The memo stated that the 1997 FIN study used a very preliminary salinity limit of 25 ppt as the critical threshold value based solely on limited information about oyster impacts. "It was never recognized as being a rigorous biological criterion for achieving conditions that would be truly critical for all the key plant and animal species in the bay near the mouth of the river." The memo also stated that there was a clear intent to develop a much more complete set of criterion whenever the study was revised in the future. "To revise the critical FIN now using only the improved salinity-inflow relationship would be an incomplete revision. Such a revision would not produce accurate freshwater inflow needs." The memo further recommended that developing the improved criteria for critical inflow needs could be a part of the revision of the 1997 FIN study. The memo adds that the TPWD, TNRCC and TWDB had expressed an interest in working with LCRA to revise the study.

As a result, the LCRA Board accepted staff's recommendation to maintain the existing Critical and Target FIN values contained in the 1999 Water Management Plan but to continue to refine the inflow reassessments. The Board also moved forward to incorporate a new Intermediate flow regime into the proposed Water Management Plan to ease the transition between Target inflows and Critical inflows. The proposed plan calls for Intermediate flows of 1.5 times the Critical inflow when storage in the Highland Lakes is between 50% and 80% of capacity on January 1. The LCRA Board also directed staff to conduct a comprehensive review and update of the 1997 FIN study with the assistance of the three state resource agencies. Updates based on new data and information collected since 1997 were to address all but item (5) of the eight specific concerns identified by LCRA staff and the Water Management Plan Revision Stakeholders Group. However, little additional data that may facilitate inclusion of nutrients and algal production, as suggested in item (6), has been collected in Matagorda Bay. Finally, additional information that might be useful in setting somewhat less arbitrary Intermediate flow goals and criteria is presented in this study for consideration in future revisions of the Water Management Plan.

1.4.7 Initiation of the Current Study

The 2002 MOA (Appendix A) between the LCRA, TPWD, TWDB, and TCEQ was entered into as a result of LCRA Board direction to work with the three agencies to review and revise the 1997 study. Using additional data and developing the appropriate biological criteria and resulting Critical and Target inflow needs to the bay are among the expressed objectives outlined in the MOA.

The MOA also provides that LCRA will adapt "or modify" existing methods to compute updated freshwater inflow needs. The scope of work attached to the MOA also provides that LCRA will use state optimization models including TXEMP and TXBLEND "or alternative methods if deemed appropriate" to compute monthly and seasonal inflow needs. If any party to the MOA disagrees with the final draft report, the MOA provides that LCRA must include a rebuttal statement in the final report. Also, there will be no recommendations in the draft or final report unless there is unanimous agreement among the four agencies.

To the extent the four agencies consider it appropriate based on the findings of the study, LCRA agrees under the MOA to initiate a process for amending its Water Management Plan within six months of completion of the study. However, the MOA does not prescribe whether or how the LCRA would revise the Water Management Plan in response to the results of the study and how any revised freshwater inflow needs should be balanced with other water demands. Under the MOA, the study is not intended to replace the requirements of the state agencies under Texas Water Code §11.1491, but it may be used to fulfill such provisions under this statute.

The MOA set up an advisory committee composed of representatives from each of the participating agencies with the LCRA representative serving as chair. Meetings of the advisory committee were held quarterly and were open to the public, with notice and opportunity for public comment provided. The committee also held several public stakeholder meetings to discuss the data, methods, status and results of the study and to receive comment.

1.4.8 SB 1639 Study Commission on Water for Environmental Flows

Since the initiation of this revision of the 1997 study, a number of events have occurred that could affect the use of the study results. In 2003, the 78th Texas Legislature passed Senate Bill 1639 establishing a Study Commission on Water for Environmental Flows (Study Commission). The primary goal of the Study Commission was to identify and evaluate options for providing adequate environmental flows and ways to consider environmental water needs in the state's water allocation process. SB 1639 also directed the 15-member Study Commission to conduct public hearings and study public policy implications for balancing the demands on the water resources of the state resulting from a growing population with the requirements of the riverine, bay and estuary systems.

In addition, the Study Commission was directed to evaluate granting permits for instream flows for bay and estuaries dedicated to environmental needs, of the Texas Water Trust, and any other issues that the Study Commission determined to have importance and relevance to the protection of environmental flows. In evaluating the options for providing adequate environmental flows, the Study Commission was directed to take notice of a strong public policy imperative recognizing that maintaining the biological soundness of the state's rivers, lakes, bays and estuaries is of great importance to the public's economic health and general well-being. The Study Commission was also directed to specifically address ways that the ecological soundness of these systems will be effectively addressed in the water allocation process.

The Study Commission appointed a Science Advisory Committee (SAC) to assist the commission in developing technical recommendations on the science and methodology of determining environmental flow needs. As a part of its activities, the SAC performed a peer review of the state methodology, including the use of TXEMP and TXBLEND models. That report was submitted to the Study Commission on October 26, 2004. The Study Commission submitted a report with its recommendations to the Texas Legislature in December 2004.

While recognizing that the State of Texas has pioneered tools to address freshwater inflow needs, the Study Commission's report pointed out limitations to the tools in light of both scientific and public policy evolution. In its report, the Study Commission identified several criticisms of the State Methodology identified by the SAC including:

- Over-reliance on target species abundance rather than an overall sound ecological environment;
- Use of or over- reliance on commercial harvest data rather than independent fisheries data;
- Questionable statistical methods, regression forms and definition of independent variables;
- Optimum flows determined by arbitrary constraints;
- Poor correlations between optimum solutions and harvest data;
- Optimum patterns did not occur in the natural hydrology;
- TPWD verification process is biased toward optimum solutions by comparing Min Q and Max H; and
- Absence of dry year viability flows

The Study Commission's report also recommended an "adaptive management" approach when adjustments to identifying or meeting environmental needs are made as new information and better science becomes available and endorsed the use of a peer review process and stakeholder involvement. LCRA is unique in the State of Texas in using an adaptive management approach in the periodic review and revision of its Water Management Plan. LCRA is also the only water right holder in the lower Colorado River basin that has specifically committed water for the protection of environmental water needs.

Some of the shortcomings of the State Methodology identified by the Study Commission are addressed in this revision of the 1997 Matagorda Bay FINS. For example, the current FINS update uses TPWD independent fisheries data rather than commercial harvest data. In addition, the constraints for Target flows were widened to allow more latitude with model runs and simulations. Also, dry year viability flows are addressed using the Critical FINS management strategy. LCRA also used an "adaptive management" approach and a substantial stakeholder involvement process with peer review by the state resource agencies and outside commenters. However, other concerns raised by the Study Commission are still applicable here.

1.4.9 Legislative Response to the Study Commission Report

In partial response to the Study Commission report, Senate Bill 3, authored by State Senator Kenneth Armbrister, chairman of the Senate Natural Resources Committee, was introduced during the regular session of the 79th Texas Legislature in 2005. Although it did not pass, the bill contained a legislative finding that "… while the state has pioneered tools to address freshwater inflow needs for bays and estuaries, there are limitations to those tools in light of both scientific and public policy evolution. To fully address bay and estuary environmental flow issues, the foundation work accomplished by the state should be improved." The bill went on to propose the establishment of an Environmental Flows Commission, assisted by a Texas Environmental Flows Science Advisory Committee as well as bay stakeholder groups and science advisory teams, to assess the current methodologies and tools and to develop environmental flow regime recommendations to be submitted to TCEQ for adoption and use in water right permitting. A similar bill, SB 15, was re-introduced by Senator Armbrister during the special legislative session called in June 2005. A companion bill, HB40, was filed in the House by State Representative Robert Puente, chairman of the House Committee on Natural Resources. However, these bills were outside the governor's call for the special session and no final action was taken on either bill. State resource agencies are currently reviewing the Study Commission report to determine what may be carried forward under SB 3 within their existing authorizations and budgets and in consultation with the State's legislative and executive leadership.

1.4.10 The Bay Health Study of the LCRA-SAWS Water Project

In 2002, LCRA and the San Antonio Water System (SAWS) entered into an agreement to study the feasibility of the LCRA-SAWS Water Project. The purpose of the LCRA-SAWS Water Project (LSWP) is to help satisfy long-term water needs in both the lower Colorado River basin and the San Antonio area while ensuring good stewardship of the environment. The project would conserve and develop up to 330,000 acre-feet of water per year. Of that, approximately 180,000 acre-feet per year of agricultural and other rural water needs would be met in the Colorado River basin through conservation of agricultural irrigation water, storage of river water, and supplemental groundwater for agricultural use. Up to 150,000 acre-feet per year of river water would be transferred to the San Antonio area for the term of the agreement. Groundwater would not be transferred to San Antonio

as part of the Project. The cost of studying, designing, constructing and implementing the project would be paid by SAWS.

The studies for the project must address a number of legislative requirements to protect the interests and environmental needs of the lower Colorado River basin. They are contained in HB 1639 (77th Tex. Leg. 2001). The approaches for the studies were developed during a public process in 2002 and 2003. Following approval of the study period plan by the LCRA and SAWS boards, studies began in July 2004 to address key issues associated with the project. These issues include water quality, potential environmental effects, cost and implementation of conservation and water supply development methods. During the study period, the water supply potential, construction and operational costs and environmental effects of the proposal will be continually refined and evaluated.

The principal charge for the Matagorda Bay Health Evaluation component of the project is to assess the environmental effects that could result from changes in inflow patterns to the Matagorda Bay system. The study is to respond directly to the requirement in Section 222.030(n)(3) of the Texas Water Code, which codifies the LCRA Act, to "ensure that beneficial inflows remaining after any water diversions will be adequate to maintain the ecological health and productivity of the Matagorda Bay system." The LCRA Act further charges that the analyses use the best science available.

A Framework for Assessing Bay Health has been developed for the LSWP to guide the bay study and help provide answers to how bay health will be maintained after the project. The framework approaches bay health by focusing on three components: inflows and how they will be altered by LSWP; habitat, including salinity, vegetation, substrate and other components; and biology, which will attempt to link changes in inflow and habitat to biological changes. This approach focuses on the different functions of various parts of the bay (open bay, secondary bays, marshlands, deltas) to better determine how they might be impacted by varying inflows. The Bay Health Framework is shown in Figure 1.4.

The State Methodology and the framework are dealing with similar issues, namely bay health and productivity; however, the two approaches are designed to answer fundamentally different questions.

The framework directs a set of studies that will determine the health and productivity of Matagorda Bay today, as well as projecting what the health of the bay will be in the future, both with and without LSWP and in particular during suboptimal inflow conditions.

In contrast, the State Methodology was designed to determine the freshwater inflow patterns needed to optimize the productivity of the entire bay complex. A substantial amount of resources has been expended over the past ten years in applying the State Methodology to Matagorda Bay. Numerous insights about the bay have been developed as a result of those efforts. However, the State's optimization TXEMP (Texas Estuarine Mathematical Programming) model was not developed to answer the questions posed by the Project about the future health of the bay, and, therefore, may not be well-suited to answer the questions that the legislative mandate requires be addressed. The impact of the LSWP on the bay will most likely result from reduced freshwater inflows during higher inflow conditions, and/or changes in the timing of inflows. However, the quantification of such potential impacts and the environmental mitigation measures that would result to address any adverse environmental impacts are unknown at this time. Because the State Methodology cannot be readily adapted to assess the potential impacts on bay productivity resulting from such changed conditions, the framework was developed to help assess these impacts while building on the knowledge gained from prior and ongoing applications of the State Methodology to the Matagorda Bay system.

The framework is centered on an understanding of three primary elements: namely, inflow and modifications thereof, habitat, and biology. Said another way, the route to understanding and quantifying potential environmental effects on the bay system starts with a "driver"—Inflow, which could be affected by the project; continues with an understanding of the effect that inflow changes could have on bay physical, chemical and biological/vegetative makeup (habitat); and concludes with the potential changes in the biology of the bay system. This multi-faceted approach characterizes inter-related elements of the health of the bay, which collectively provide a basis for measuring overall bay health.

It is important to note that inflow is certainly not the sole driver of conditions in the bay. Many other factors, some controllable and others not, are potential drivers of bay health, and will be

accounted for insofar as possible in the evaluation. The major components of the proposed approach are summarized below.

- Habitat provides a powerful framework for viewing the health of the ecosystem.
- Salinity is a fundamental component of habitat, along with many other factors.
- Salinity is driven largely by changes in freshwater inflow, and will be investigated using a hydrodynamic/salinity model.
- The framework also provides for improved understanding of direct relationships between inflow and species productivity and benthic diversity.

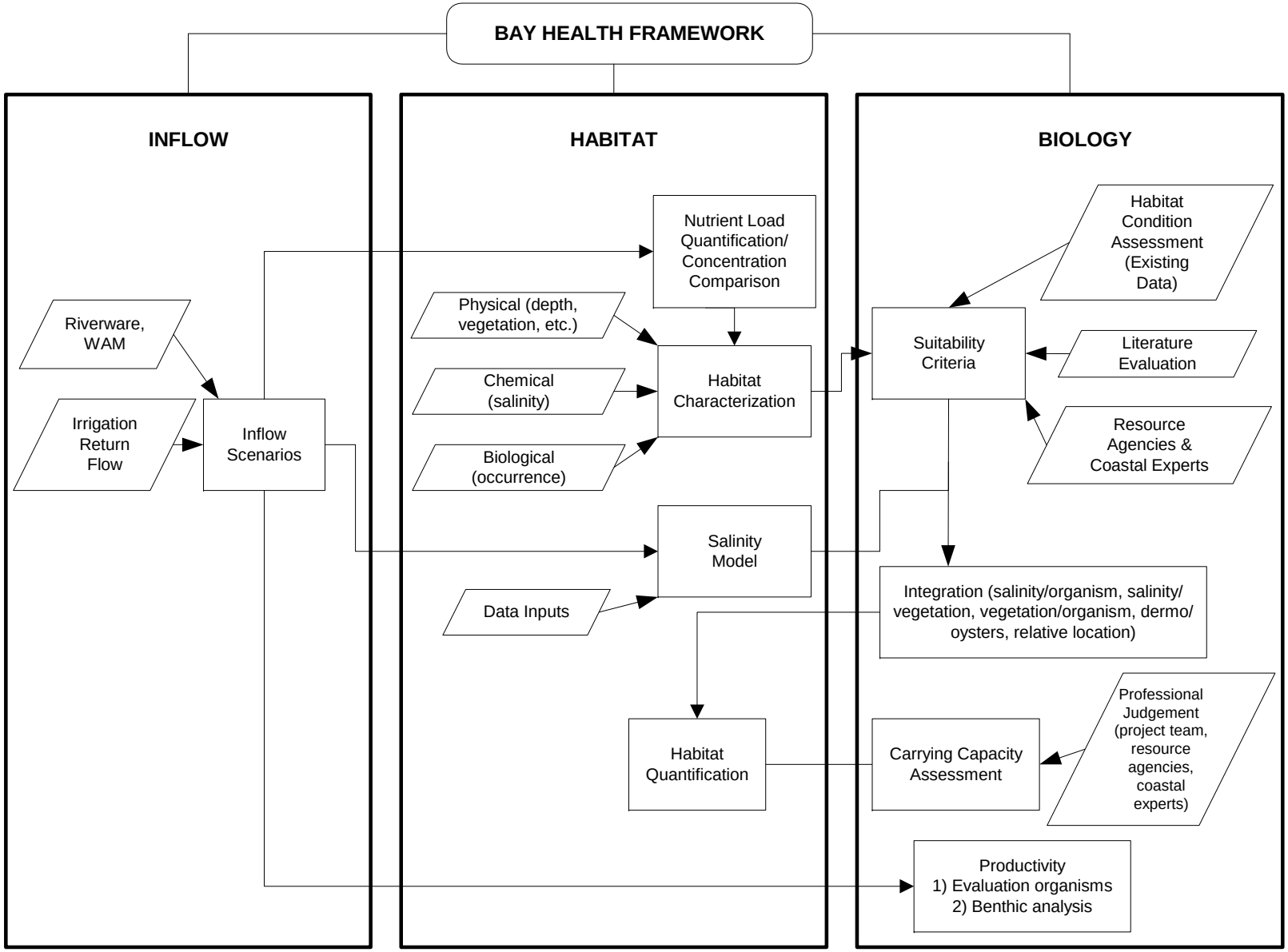


Figure 1.4 Bay Health Framework

The LSWP Matagorda Bay Health Evaluation is expected to be completed in 2007.

1.4.11 Recent Modeling Efforts by U.S. Army Corps of Engineers

The U.S. Army Corps of Engineers Research and Development Center (ERDC), Waterways Experiment Station (WES), recently completed the development of a hydrodynamic model for the Matagorda Bay area (Brown et al., 2003). The model was developed to help the Corps' Galveston District evaluate the effects associated with the potential reopening of Parker's Cut in Matagorda Bay and a potential new opening of Southwest Cut in East Matagorda Bay on currents, salinity and sediment changes. The focus of the model study was to determine if opening any or all of the cuts would improve navigation at the intersection of the Gulf Intracoastal Waterway (GIWW) and the Mouth of Colorado River bypass channel. Local interest groups also recently proposed that a number of other changes be made to the Mouth of Colorado River Project. The model was used to evaluate the existing system configuration and eleven proposed configuration designs to look into alleviating the navigation problems encountered at the intersection of GIWW and the Colorado River. The study included various data collection efforts, including a bathymetric survey of the immediate study area.

At about the same time, the Corps's Galveston District also undertook a modeling study of the Colorado River regarding the jetties, Parker's Cut and Southwest Cut (Kraus et al., 2000). The focus of this regional model study was more on circulation and navigation safety – to help with dredging operations, than on salinity. Multiple alternatives were evaluated in this modeling effort.

The Corps will likely base its decision to make changes to the various navigation cuts by addressing the navigation/transportation and economic benefits for this complex estuarine environment.

1.4.12 Review of State Methodology

As discussed earlier, the Science Advisory Committee of the SB 1639 Study Commission on Water for Environmental Flows has recommended improvements to the state's freshwater inflow methodology and models, which was reflected in the Study Commission's report to the Texas Legislature. A number of these recommendations have been incorporated in this study.

In its evaluation of 27 available hydrodynamic/salinity models including the state TXBLEND model, the LCRA-SAWS Project's Ecological Health Study Group recommended that the U.S. Army Corps of Engineers RMA suite of models be used. TXBLEND was dropped because it did not have the capability to model non-conservative constituents such as organic matter or nutrients.

1.5 Conclusion

This FINS study is intended to be part of an iterative process. When better information and methods become available, this study will also be updated. The USACE diversion channel into West Matagorda Bay, completed in 1991, significantly changed the ecological condition of the bay. Only a relatively short period of time has passed to collect and assess data to determine the impacts created by the channel.

Additional factors other than salinity that explicitly relate to overall biological productivity such as the location and quality of suitable physical habitat are not fully addressed in this study and may need to be further assessed in determining the amount, location and timing of freshwater inflows to effectively maintain and protect the overall ecological health of the bay. The recent example of Nueces Bay — where inflows were redirected to important upper bay marsh areas rather than simply increased to the bay proper, resulting in increased biological productivity (Bureau of Reclamation, 2000) — may provide lessons that can be applied to Matagorda Bay.

A comprehensive assessment of factors that may affect the overall ecological health of the bay is currently being conducted as a part of the LCRA-SAWS Project feasibility studies. The LCRA-SAWS studies should be considered together with the current Matagorda Bay freshwater inflow needs study (FINS) when making future water management decisions. In addition, the models and methodology used to assess freshwater inflow needs are currently being re-evaluated in the State of Texas.

Finally, models can predict only what may happen. In reality, only the passage of many years will enable us to see how changes of freshwater inflows may affect the bay. Like all coastal systems, Matagorda Bay's productivity is the result of extremely complex hydrological, meteorological and biological interactions that are not yet fully understood.

CHAPTER 2

Hydrologic Characteristics of Matagorda Bay

2.1 Purpose

This chapter describes the sources and statistical characteristics of inflow for Matagorda Bay. Total surface inflow is the sum of the inflows entering into Matagorda Bay from the Colorado River basin, Colorado-Lavaca coastal basin, Lavaca River basin, and Lavaca-Guadalupe coastal basin. In this study, total surface inflow is separated into two broad categories – river basin inflows and coastal inflow.

Total surface inflow estimates were obtained from the Texas Water Development Board's (TWDB) Coastal Hydrology database. This database has monthly total surface inflow estimates for the period January 1941 through December 2000. TWDB also has calculated daily inflow estimates for the period January 1, 1977 through December 31, 2003. This study used a combination of the TWDB's data sets, monthly inflow estimates for the period January 1941 though December 1976 and daily inflow estimates for the period January 1, 1977 through December 31, 2003. In these daily and monthly estimates of total surface inflow to Matagorda Bay, the portion from the Colorado River basin prior to June 1990 was based on a method developed by a predecessor agency to the TWDB (Texas Department of Water Resources, 1978).

River basin inflows for Matagorda Bay are estimated using gaged streamflows from the Colorado River basin and Lavaca River basin. Sources of data for gaged streamflows are the United States Geological Survey (USGS) and the Lavaca-Navidad River Authority (LNRA). In the Colorado River basin prior to June 1990, estimated inflow is based on a method of determining the inflow to Matagorda Bay based on gaged streamflow of the Colorado River at Bay City (TDWR, 1978). Beginning in June 1990, estimated Colorado River basin inflow is calculated as gaged streamflow for the Colorado River at Bay City minus diversions at the South Texas Project which is located downstream of the Bay City gage. The streamflow data for the Lavaca River measured by USGS and the streamflow for the Navidad River measured by USGS and LNRA are added together and used directly as estimated Lavaca River basin inflow to Matagorda Bay.

Coastal inflow is calculated in this study as the difference between the total surface inflow and the river basin inflows calculated in this study. The resulting coastal inflow includes gaged and unmeasured streamflows from the Colorado-Lavaca and the Lavaca-Guadalupe coastal basins and unmeasured streamflows from areas of the Colorado River basin and the Lavaca River basin downstream of the USGS and LNRA gage locations (Figure 2.1).

Inflows developed in this chapter are the basis for development of nutrient budgets, development of inflow-salinity and inflow-productivity relationships, development of constraints in TXEMP and calibration and execution of TXBLEND in later chapters of this report. Descriptions of how these data are used are listed in the subsequent chapters.

Future monitoring of meeting freshwater inflow needs would be simplified by using streamflow at commonly measured locations, such as USGS streamflow gages. For this reason, the salinity regression equations described later in this report use estimates of river basin inflows based on gaged streamflow from the Colorado River basin and Lavaca River basin. Since the primary sources of inflow are the Colorado River basin and the Lavaca River basin, the biological productivity regression equations described later in this report also use the estimates of river basin inflows. These regression equations do not explicitly include the other sources of inflow, the unmeasured portions of the river basins and all of the two coastal basins. The decision to use only the river basin inflows for the biological equations was made very early in the study and was agreed to by the cooperating agencies at that time. A significant factor in that decision was that at the beginning of the study, TWDB did not have values for the inflows for the last couple of years. This differs from the 1997 study in which these coastal inflows were explicitly included in the development of the biological productivity regression equations. Omission of the coastal inflow adds some degree of uncertainty to the equations.

2.2 Study Area

The study area for this report includes Matagorda Bay and its secondary and tertiary bays (hereafter referred to simply as Matagorda Bay), as shown in Figure 2.1. The largest sources of freshwater inflow to Matagorda Bay are the Colorado River basin and Lavaca River basin, which includes the Navidad River as a major tributary. Inflow to the bay also comes from the

Colorado-Lavaca coastal basin, with the Tres Palacios River as the major stream, and the Lavaca-Guadalupe coastal basin, with Placedo Creek and Garcitas Creek as major streams (Figure 2.1). There are also a large number of smaller ungaged creeks and streams that feed into the upper bay and marsh areas that provide a nursery and refuge for many species.

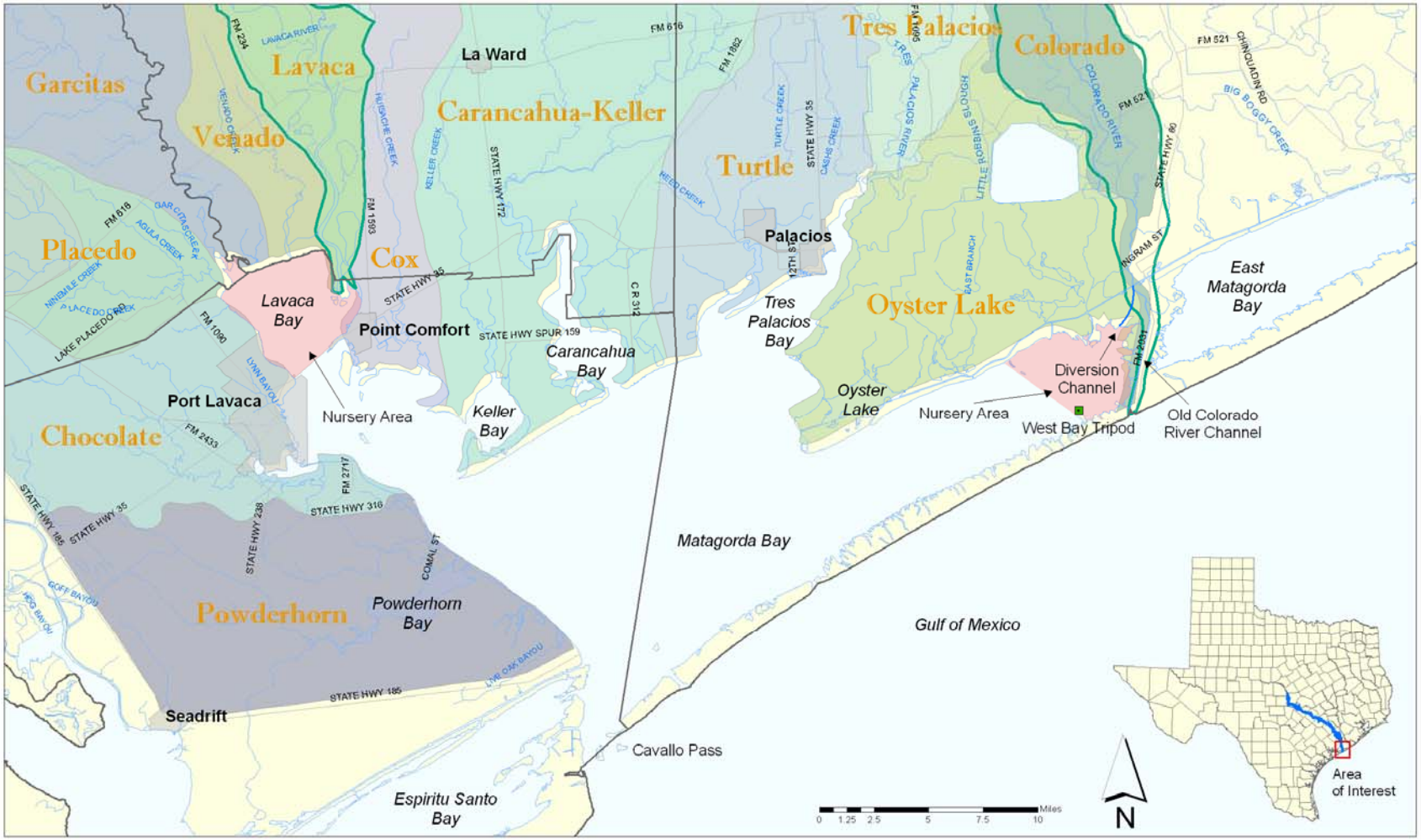


Figure 2.1 Colorado and Lavaca River Basins and Adjacent Coastal Basins.

2.3 Historical Changes

The hydrology of the Matagorda Bay system has undergone major changes. Over the years, log jams have historically occurred on the Colorado River, some of which have extended over many miles in length. Observers in the early 1800s noted an immense log jam that choked the mouth of the river and backed water for miles inland, restricting and diffusing inflows to the bay. Several unsuccessful attempts were made to remove the log jams or to build channels around them. But by 1928, the log jam was 40 miles long. Finally, in 1929, a great flood burst through this log jam and swept centuries of accumulated debris and silt into Matagorda Bay. This created a new peninsula out into the bay that eventually grew into a land bridge reaching to Matagorda Island, effectively cutting Matagorda Bay in half. After the land bridge occurred, some of the freshwater inflow dispersed laterally into the bisected bay and some into the Gulf of Mexico. Then, in 1935, a channel through this land bridge was cut connecting the Colorado River directly to the Gulf of Mexico. This was done to assist navigational access to the Gulf and relieve flooding. The cut, known as Parker's Cut, from the river channel westward to Matagorda Bay was made to allow better access to the oyster reefs in the bay.

Federal maintenance of the river channel near the bay began in 1937, authorized under the U.S. Army Corps of Engineers maintenance authority for the Gulf Intracoastal Waterway (GIWW). The GIWW intersects the Colorado River just above the bay and runs along the upper bay affecting the way inflows had historically entered the bay, especially from the smaller, upper bay tributaries.

The paragraph below describes the pre-diversion project condition, from page IV-1 of TDWR (1978). Tiger Island Cut is also referred to as Parker's Cut.

> *The flow routing and exchange patterns within the Colorado Delta are complex and result from the interaction of two land locked bay tides (both of which are affected by wind stresses), the Gulf of Mexico tide, and the various freshwater inflow patterns of the Colorado River. The avenues of difluence and circulation within the system include the GIWW at Matagorda, Culver Cut between the GIWW and Matagorda Bay, and Tiger Island Cut between the*

Colorado River and Matagorda Bay, as well as the junction of the Colorado River and the Gulf of Mexico. With so many interrelated components, the Colorado Delta represents an extremely complex system with respect to simulation model application.

However, the river channel significantly reduced any remaining inflows into the bay and by the 1970s, the bay's fisheries were suffering. In 1991, about ten years after the Corps of Engineers completed its studies, the Colorado River again flowed into Matagorda Bay through a new diversion channel dredged by the Corps. Many of the anticipated effects of the diversion channel included the increase of freshwater into the bay with resulting beneficial impacts to bay productivity and marsh habitat. Parker's Cut was also closed to prevent freshwater from flowing out of the bay or allowing higher salinity Gulf waters from entering the bay.

2.4 Freshwater Inflows

The following sections describe the methods and data used to determine the total surface inflow to Matagorda Bay, including river basin inflows and coastal basin inflow are described.

2.4.1 Total Surface Inflow

Monthly Total Surface Inflow

TWDB's calculation method for total surface inflow, including streamflow and runoff from all sources, is described below:

Freshwater inflow comes primarily from precipitation over each estuary's drainage basin. Runoff enters streams and rivers, makes its way to the mouth of each watershed, and eventually reaches the estuary. Along the way, some water is diverted for man's use. Diverted water that is not consumed can be returned to the streams.

Flow from larger watersheds and important rivers is monitored by United States Geological Survey (USGS) stream gages. USGS stream gages have historically been located far upstream from the estuary to remove them from the influence of tidal variations in flow and water level.

Downstream of these gages, between the gage and the point where the stream meets the estuary, streamflow is ungaged. In some estuaries, significant runoff originates in these ungaged areas.

Total flow from drainage basin runoff is found by summing flows originating in both gaged and ungaged watersheds. Gaged flows are obtained from USGS streamflow records. Ungaged runoff is the sum of i) computed runoff, using a rainfall-runoff simulation model, based on precipitation over the watershed, ii) flow diverted from streams by municipal, industrial, agricultural, and other users, and iii) unconsumed flow returned to streams.

Thus, total surface inflow reaching the estuary consists of:

Surface Inflow = (1) Sum over all gaged watersheds(USGS Gaged Flow)
+ (2) Sum over all ungaged watersheds(Modeled Flow)
- (3) Sum over all ungaged watersheds(Diverted Flow)
+ (4) Sum over all ungaged watersheds(Returned Flow)[1]

Monthly time series for categories (1) through (4) and for total surface inflow were obtained from the TWDB website for the period 1941 through 2000.

Daily Watershed Surface Inflows

TWDB also calculated more detailed information for the period 1977 through 2003. This consists of daily estimates of surface inflow for each of the 11 watersheds that comprise the total surface inflow to the Matagorda Bay for the period January 1, 1977 through December 31, 2003. The watersheds and their estimated annual average inflow (acre-feet per year, rounded to nearest hundred) for this period are listed below in Table 2.1.

[1] www.twdb.state.tx.us

Table 2.1 Annual Average Flow for 1977-2003 from Watersheds of Matagorda Bay.

Watershed	Annual Average Inflow (ac-ft/year)
Colorado	1,856,200
Oyster Lake	127,500
Tres Palacios	197,600
Turtle Bay	95,500
Carancahua Bay	227,500
Keller Bay	43,800
Cox Bay	40,000
Lavaca Delta	1,066,300
Garcitas Creek	254,400
Chocolate Bay	96,600
Powderhorn Lake	105,900
Total	4,111,300

The monthly and daily data sets have the period 1977 through 2000 in common. The annual average of the monthly total surface inflow for the period from 1977 to 2000 is 4,086,000 acre-feet per year. The annual average of the sum of 11 daily watershed surface inflows for the period from 1977 to 2000 is 4,089,000 acre-feet per year. The very small difference between this average and the corresponding value from the monthly data indicates that the same method was used in these calculations.

The total surface inflow data set used for the analyses in this report is the compilation of the monthly total surface inflow for the period from 1941 to 1976 and the sum of 11 daily watershed surface inflows for the period from 1977 through 2003. Annual total surface inflow for each year is listed in Table 2.2. The annual average for this entire period from 1941 through 2003 is 3,444,000 acre-feet per year.

Table 2.2 Estimated Annual Inflows to Matagorda Bay (acre-feet).

Calendar Year	Total Surface Inflow to Matagorda Bay (TWDB estimates)	Colorado River Basin Inflow*	Lavaca River Basin Inflow (USGS gage and LNRA data)	Coastal Inflow = Total Surface Inflow to Matagorda Bay - Colorado River Inflow – Lavaca River Inflow
1941	6,726,000	3,632,000	1,704,000	1,390,000
1942	2,674,000	1,445,000	540,000	689,000
1943	1,798,000	1,266,000	315,000	217,000
1944	3,937,000	1,740,000	906,000	1,291,000
1945	3,133,000	1,959,000	461,000	712,000
1946	4,682,000	2,139,000	1,207,000	1,336,000
1947	2,039,000	1,332,000	395,000	312,000
1948	1,364,000	600,000	313,000	452,000
1949	3,157,000	1,152,000	667,000	1,338,000
1950	1,317,000	892,000	220,000	205,000
1951	838,000	398,000	168,000	273,000
1952	1,381,000	435,000	497,000	449,000
1953	1,887,000	750,000	363,000	774,000
1954	441,000	274,000	31,000	136,000
1955	1,214,000	820,000	269,000	125,000
1956	448,000	301,000	24,000	123,000
1957	5,794,000	3,833,000	1,279,000	682,000
1958	3,582,000	2,334,000	597,000	651,000
1959	4,076,000	1,963,000	972,000	1,141,000
1960	5,990,000	2,358,000	1,512,000	2,119,000
1961	5,721,000	2,735,000	1,589,000	1,397,000
1962	1,007,000	578,000	279,000	149,000
1963	632,000	341,000	164,000	127,000
1964	1,069,000	283,000	211,000	575,000
1965	2,460,000	1,350,000	915,000	196,000
1966	2,452,000	850,000	571,000	1,031,000
1967	2,193,000	375,000	622,000	1,197,000
1968	5,230,000	2,390,000	1,315,000	1,525,000
1969	3,119,000	1,274,000	1,014,000	831,000
1970	4,016,000	1,729,000	779,000	1,508,000
1971	2,362,000	785,000	589,000	988,000
1972	2,668,000	660,000	914,000	1,094,000
1973	6,040,000	1,919,000	2,436,000	1,685,000
1974	4,204,000	1,922,000	1,276,000	1,006,000
1975	3,255,000	2,107,000	811,000	337,000
1976	3,057,000	1,374,000	980,000	703,000
1977	3,481,000	1,605,000	635,000	1,241,000

* LCRA calculated value based on USGS streamflow (see Section 2.4.2)

Table 2.2 (Cont.) Annual Inflows to Matagorda Bay (acre-feet).

Calendar Year	Total Surface Inflow to Matagorda Bay (TWDB data)	Colorado River Basin Inflow*	Lavaca River Basin Inflow (USGS gage and LNRA data)	Coastal Inflow = Total Surface Inflow to Matagorda Bay - Colorado River Inflow - Lavaca River Inflow
1978	2,297,000	542,000	774,000	981,000
1979	6,111,000	1,528,000	1,564,000	3,019,000
1980	1,727,000	580,000	443,000	704,000
1981	5,558,000	1,918,000	1,543,000	2,096,000
1982	3,066,000	936,000	900,000	1,230,000
1983	3,825,000	904,000	1,122,000	1,799,000
1984	1,740,000	580,000	384,000	776,000
1985	3,478,000	1,122,000	1,016,000	1,339,000
1986	3,095,000	1,515,000	518,000	1,062,000
1987	4,813,000	2,768,000	1,098,000	946,000
1988	726,000	445,000	75,000	206,000
1989	1,146,000	445,000	231,000	469,000
1990	1,250,000	369,000	110,000	770,000
1991	5,345,000	2,463,000	957,000	1,926,000
1992	14,897,000	9,603,000	2,514,000	2,780,000
1993	5,664,000	2,219,000	1,559,000	1,886,000
1994	4,021,000	1,463,000	1,513,000	1,045,000
1995	3,444,000	1,671,000	559,000	1,214,000
1996	1,490,000	595,000	272,000	623,000
1997	10,082,000	4,570,000	2,850,000	2,663,000
1998	7,626,000	3,443,000	2,469,000	1,713,000
1999	1,613,000	858,000	298,000	457,000
2000	1,649,000	718,000	353,000	578,000
2001	4,760,000	2,028,000	1,120,000	1,612,000
2002	5,639,000	2,651,000	1,250,000	1,738,000
2003	2,467,000	1,572,000	539,000	356,000
1941-2003 Average	3,444,000	1,578,000	850,000	1,016,000
1941-2003 Maximum	14,897,000	9,603,000	2,850,000	3,019,000
1941-2003 Minimum	441,000	274,000	24,000	123,000
1941-2003 Median	3,095,000	1,350,000	667,000	981,000
1979-1989 Pre-diversion Average	3,208,000	1,158,000	809,000	1,241,000
1993-2003 Post-diversion Average	4,405,000	1,980,727	1,162,000	1,262,273

* LCRA calculated value based on USGS streamflow (see Section 2.4.2)

2.4.2 River Basin Inflows

U.S. Geological Survey gages were used to calculate river basin inflows. The location of these gages and associated periods of record are listed in Table 2.3. In addition, release records from Lake Texana provided by the Lavaca-Navidad River Authority were used in determining inflow for the Navidad River watershed of the Lavaca River basin.

The streamflow data measured by the gages listed in Table 2.3 can be directly used as equivalent freshwater inflow to Matagorda Bay for the Lavaca River basin. However, prior to the construction of the Mouth of the Colorado River Project by the Corps of Engineers, only a portion of the streamflow in the Colorado River entered Matagorda Bay and the remainder flowed directly to the Gulf of Mexico.

Table 2.3 Measured Streamflow Locations in River Basins.

River Basin	River or Stream	Location	USGS Stream Gage #	Period of Record
Colorado	Colorado River	Wharton	08162000	October 1938 - Present
	Colorado River	Bay City	08162500	May 1948 - Present
Lavaca	Lavaca River	Edna	08164000	September 1938 - Present
	Navidad River	Ganado	08164500	May 1939 - April 1982
	Navidad River	Lake Texana Dam*	-	May 1982 - Present

* The Lavaca Navidad River Authority has measured flow on the Navidad River at the discharge structures for Lake Texana.

In 1978, the Texas Department of Water Resources (TDWR) developed a method of estimating the inflow to Matagorda Bay based on gaged flow of the Colorado River at Bay City (TDWR, 1978). This method makes various assumptions. The first is that the condition of the mouth of the Colorado River varied with streamflow in the river. During extended period of low streamflow in the river, siltation would occur and reduce the cross-sectional area. The second assumption involves the open/close state of the navigation locks. During periods of low streamflow (less than 5,000 cubic feet per second), the locks are assumed to be open with interaction between the river and the GIWW possible.

In a 1978 document (Report LP-79) the Texas Department of Water Resources (TDWR) established a method of estimating inflows from the Colorado River. The methodology seems to result in two simple equations that would calculate the flow from the Colorado River into Matagorda Bay. The equations were derived from a more complicated hydrodynamic model.

Below is an explanation of the methodology:

Q_1: Colorado River Flow above the GIWW;
Q_2: Colorado River Flow below the GIWW;
Q_3: Colorado River Flow entering the Gulf of Mexico;
I_1: Flow Entering Matagorda Bay through Culver Cut;
I_2: Flow Entering Matagorda Bay through Tiger Island Cut (Parker's Cut).

Obtain the flow Q_1 for the Colorado River above the GIWW from the USGS gage streamflow at Bay City.

Q1 and Q2 are related with these equations:

- *If $Q_1 \leq 250$ cfs then $Q_2 / Q_1 = 1.94$*
- *If 250 cfs $< Q_1 <$ 5,000 cfs then*
  $$Q_2 / Q_1 = 1 + (3.03 - 95.45 \cdot X_1 + 80.71 \cdot X_1^2 - 38.43 \cdot X_1^3) / 100$$
  Where $X_1 = \log_{10} (Q_1 / 1{,}000)$
- *If $Q_1 <$ 5,000 cfs then $Q_2 / Q_1 = 1.00$*

I_2 is related to Q_2 with these equations:

- *If $Q_2 <$ 9,000 cfs then $I_2 / Q_2 = (93.05 - 7.067 \cdot 10^{-3} \cdot Q_2 + 3.9015 \cdot 10^{-7} \cdot Q_2^2) / 100$*
- *If $Q_2 \geq$ 9,000 cfs then $I_2 / Q_2 = 0.61$*

The report discusses the flow through Culver Cut, but does not detail a method to determine flow through Culver Cut which is between the GIWW and Matagorda Bay.

This method was used by TWDB to calculate the monthly total surface inflow and the Colorado watershed of the daily watershed inflow data sets for the period prior to the construction of the Mouth of the Colorado River Project.

The same method was used in this study to calculate the daily estimated Colorado River basin inflow for the period prior to June 1990, the construction of the Mouth of the Colorado River Project.

For purposes of this analysis, Colorado River flow measured at the Bay City gage beginning in June 1990 minus diversions by the South Texas Project (STP) is considered to be the inflow that enters the estuaries. Beginning in May 1990, the Corps of Engineers first opened the diversion channel component of the Mouth of the Colorado River Project. This channel connects the junction of the Gulf Intracoastal Waterway and the Colorado River directly with Matagorda Bay (Figure 2.2). From May 1990 through June 1992, flow from the Colorado River entered into Matagorda Bay by means of both the new diversion channel and the existing Tiger Island Cut (Parkers Cut) off of the former Colorado River channel through the Colorado River Delta. In early July 1992, a barrier dam was completed that closed the former Colorado River channel at the junction of the river and the GIWW.

Colorado River flows currently enter Matagorda Bay through either the diversion channel or the GIWW. When the lock gates are closed at the intersection of the GIWW, virtually all of the Colorado River flow enters Matagorda Bay through the diversion. When the lock gates are open, some Colorado River flow can enter the GIWW. These flows can then enter East Matagorda Bay to the north and Matagorda Bay to the south through navigation cuts and to the Gulf of Mexico via the by-pass channel. The consensus of agencies that work in the area is that the majority of Colorado River water enters Matagorda Bay, rather than East Matagorda Bay, either through the GIWW or the diversion channel. The dynamics of the split in flow is an opportunity for more research. Ongoing sedimentation, delta formation, dredging, and gate operating procedures are likely to influence the split. The exact nature of the split is not known, however, it was not of fundamental importance to the regression equations developed in this study effort because the statistical relationships were based on the measured flows at Bay City, salinity and productivity.

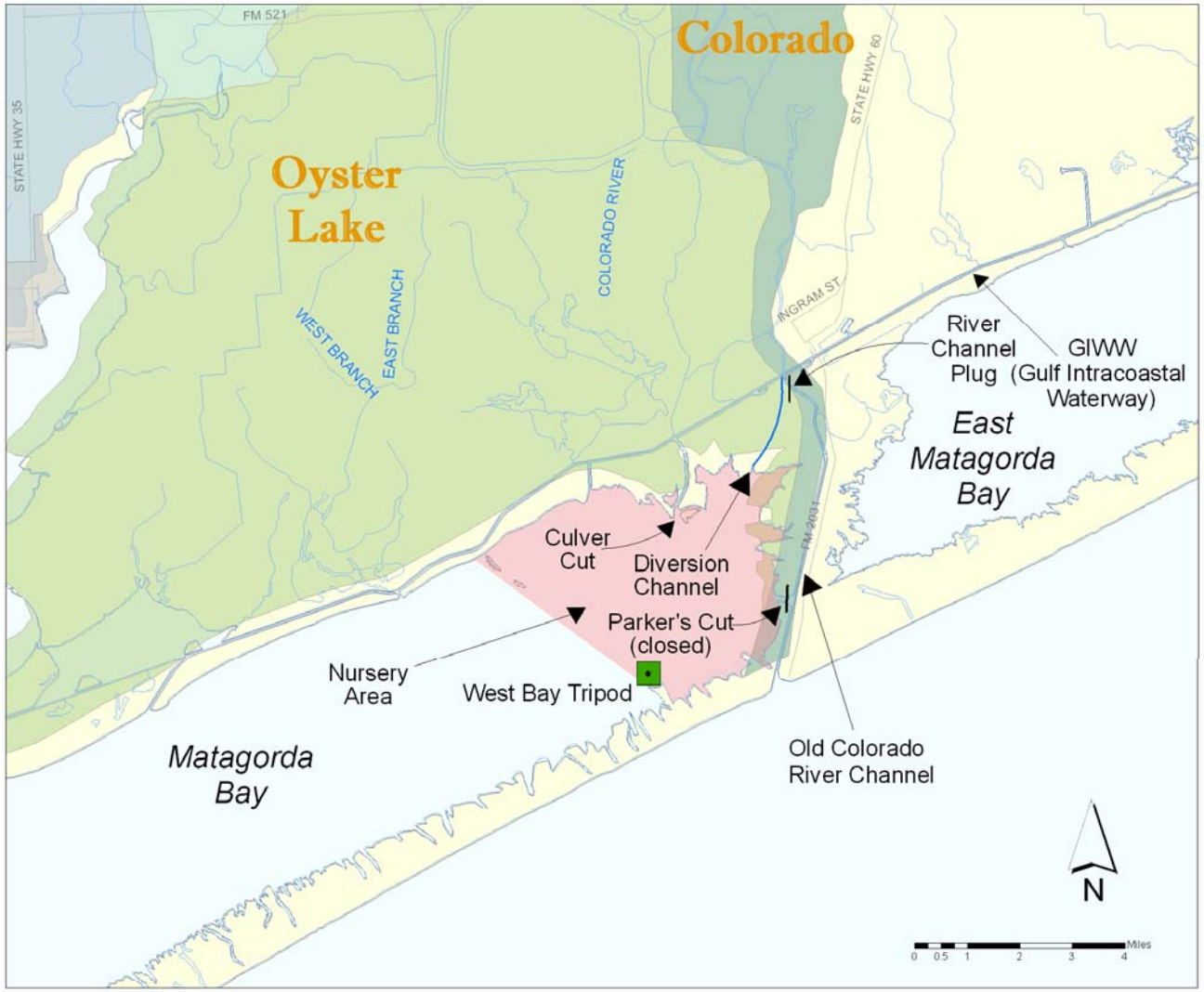


Figure 2.2 Location of the USACE Diversion Channel to Matagorda Bay.

Daily River Basin Gaged Streamflows and Estimated Inflows

Daily Colorado River basin streamflow was based on measurements from the Bay City gage from May 1948 to June 2005. This study does not use the period after December 2003 in any analyses. Data from the Wharton gage was adjusted to fill in the record prior to this period from January 1941 through April 1948 before the Bay City gage was installed. Over the 55-year period of whole calendar years for which streamflow was measured at both the Bay City gage and Wharton gage from 1949 through 2003, less 1992, the ratio of Bay City to Wharton flows from March through September (irrigation season) was 0.885. The similar ratio for the October through February period was 1.070. The flow at Wharton was adjusted by these ratios to provide estimated streamflow at Bay City prior to May 1948. The year 1992 was omitted from the calculation of these ratios as an outlier that would inappropriately skew the ratio. In 1992, the stream flow at Bay City was 9.61 million acre-feet and at Wharton it was 7.27 million acre-feet. Both these numbers were the largest recorded annual value at each of these locations. Their ratio of 1.32 is much larger then the next largest annual ratio of 1.21.

Lavaca River basin flows are comprised of flows from the Lavaca River and Navidad River. Flows on the Lavaca River are measured by a USGS gage near Edna (#08164000). The period of record used in this study for the Lavaca River gage near Edna is from September 1938 through June 2005.

Navidad River streamflow is estimated by LNRA using outflow from Lake Texana beginning in May 1982. Prior to the construction of that dam, June 1939 through April 1980, flows are based on the USGS gage near Ganado (#08164500) multiplied by the drainage area ratio of that gage to the Lake Texana, which is 1.322.

During the 24-month period of construction of Palmetto Bend Dam which impounds Lake Texana from May 1980 through April 1982, the Navidad River streamflow was estimated by using the Lavaca River near Edna gage multiplied by 1.532 as an estimate for streamflow near Ganado, and then multiplied by the drainage area of 1.322 as an estimate for streamflow at Lake Texana.

Monthly Distribution of River Basin Streamflows

Streamflow in the Colorado and Lavaca river basins varies seasonally. Figures 2.3 and 2.4 show the historical monthly distribution of streamflows in these major basins, respectively. The monthly distribution of streamflow is shown for the mean and 30th through 70th percentiles. The distribution of monthly streamflows shows the least variation during the late summer months, especially in August. The distribution is the greatest for both basins during the spring months. These figures demonstrate that there is a wide range of historical inflow that is contributed from each basin to the bay throughout the year.

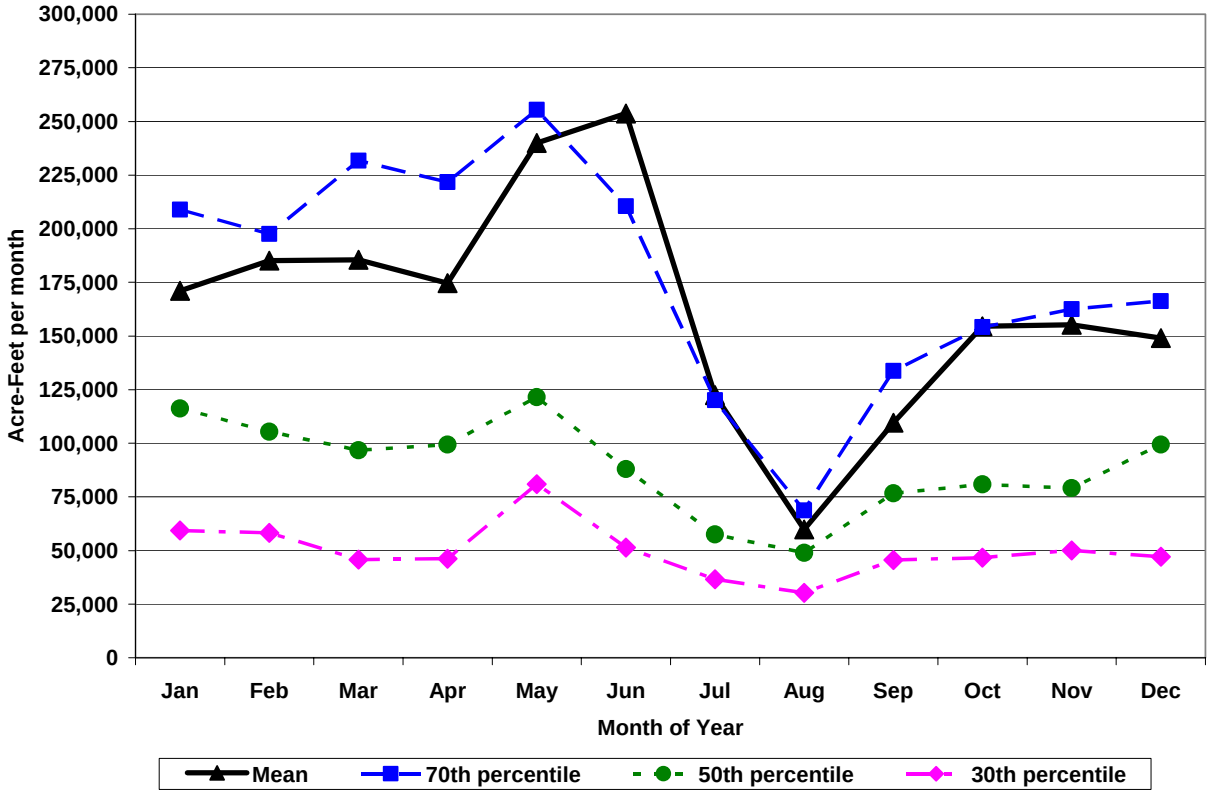


Figure 2.3 Distribution of Monthly Streamflow for the Colorado River Basin for 1941 to 2003.

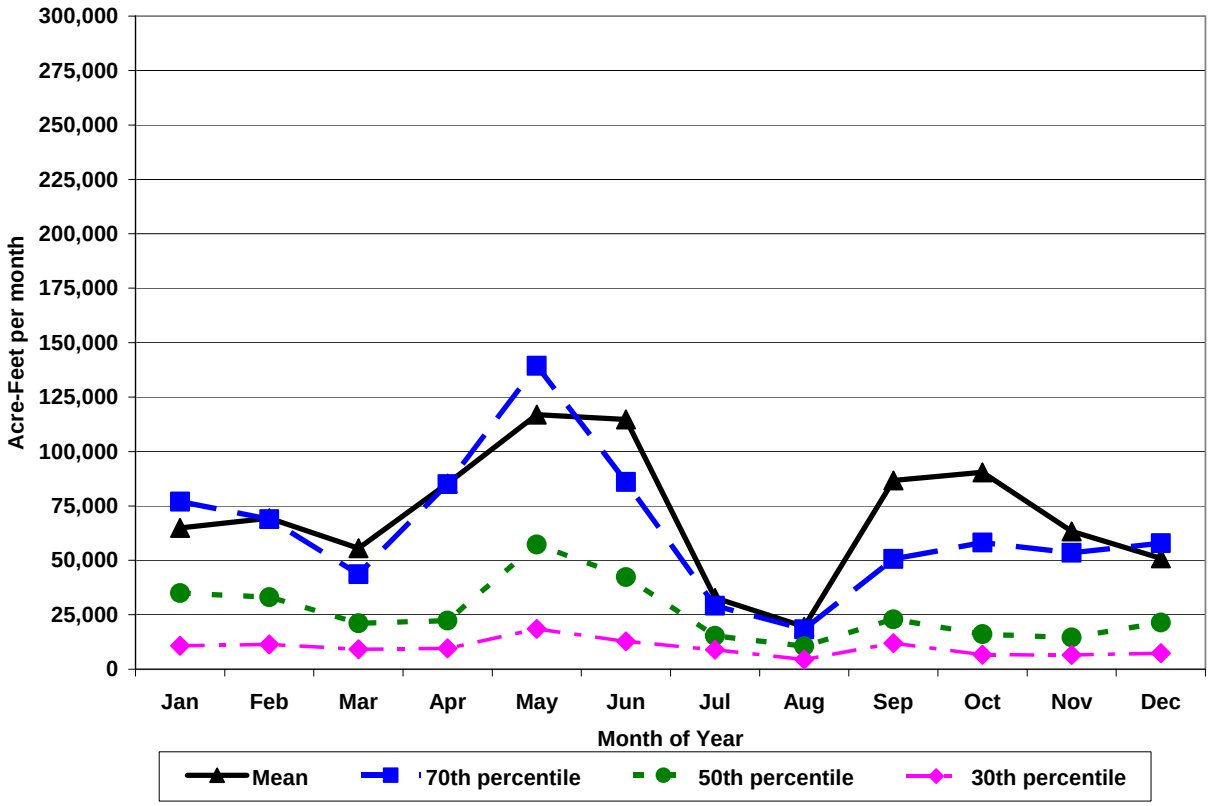


Figure 2.4 Distribution of Monthly Streamflow for the Lavaca River Basin for 1941 to 2003.

2.4.3 Coastal Inflow

In this analysis, the coastal inflow is defined as the unmeasured portions of the two major river basins (Colorado and Lavaca) and all of the coastal basins. The value of coastal inflow is calculated in this study as the difference between total surface inflow and the sum of the two river basin inflows.

The study area shown in Figure 2.1 includes the following four portions of the coastal inflow:

- Colorado River basin, unmeasured portion
- Colorado-Lavaca coastal basin
- Lavaca River basin, unmeasured portion
- Lavaca-Guadalupe coastal basin

The average estimated inflow from the unmeasured portion of Colorado River basin, for January

1977 through December 2003 is 37,200 acre-feet per year. This is the difference between the TWDB daily data for the "Colorado" watershed and the Colorado River basin estimated inflow calculated in this study.

The average estimated inflow from the Colorado-Lavaca Coastal basin, for January 1977 through December 2003 is 731,900 acre-feet per year. This includes the TWDB daily data for the following watersheds: Oyster Lake, Tres Palacios, Turtle Bay, Carancahua Bay, Keller Bay and Cox Bay.

The average inflow for the unmeasured portion of Lavaca River basin, for January 1977 through December 2003 is 78,600 acre-feet per year. This is the difference between the TWDB daily data for the "Lavaca Delta" watershed and the Lavaca River basin estimated inflow calculated in this study.

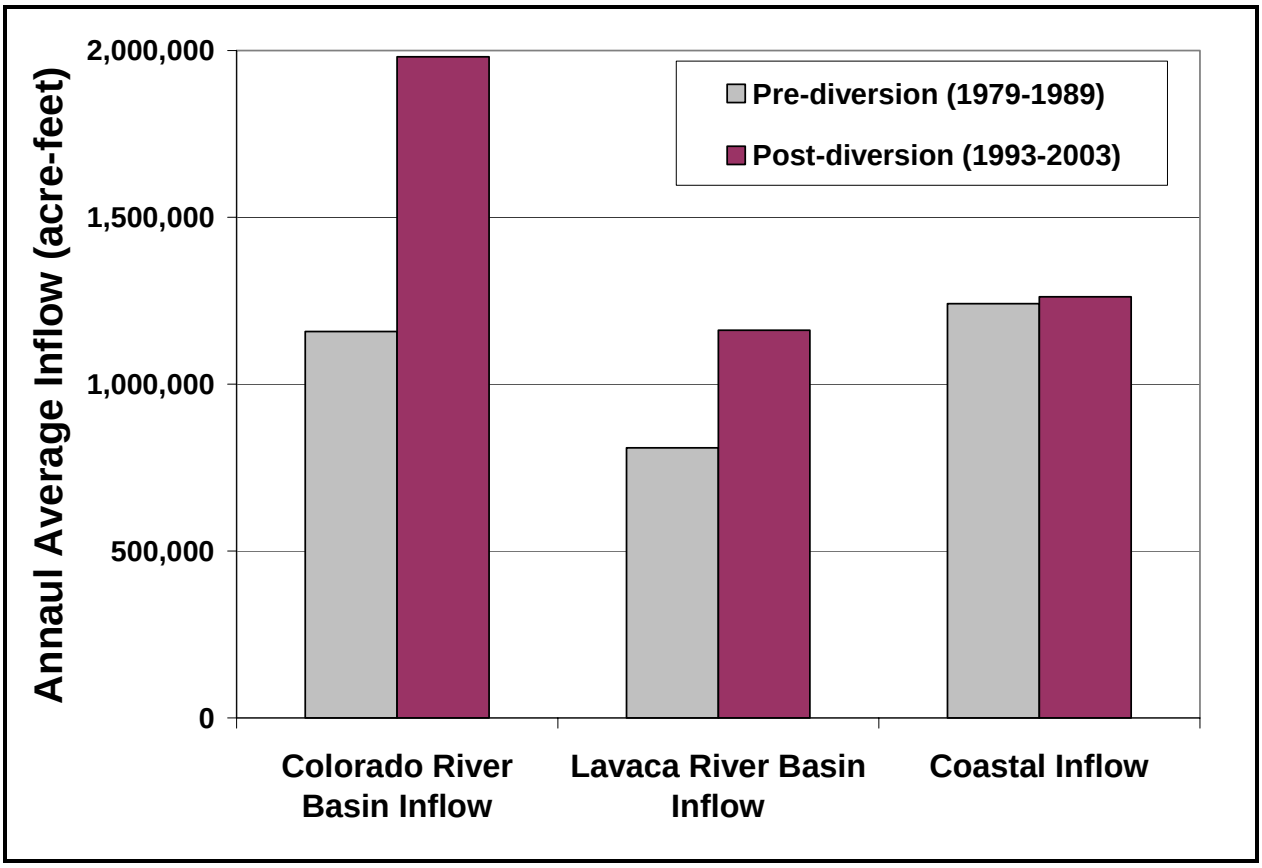
The average estimated inflow from the Lavaca-Guadalupe Coastal basin, for January 1977 through December 2003 is 456,900 acre-feet per year. This includes the TWDB daily data for the Garcitas Creek, Chocolate Bay and Powderhorn Lake.

2.5 Hydrologic Changes Following Diversion Project

Following completion of the Corps of Engineers diversion channel project in 1991, flows from the Colorado River could reach Matagorda Bay directly. A comparison of the relative contributions of inflow from the Colorado River, Lavaca River, and coastal areas was made for the eleven year post-diversion project periods and the latest eleven year pre-diversion period.

Annual average estimated inflow to the bay from the Colorado River, Lavaca River and coastal area for the period prior to (1979-1989) and after (1993-2003) the Corps of Engineers diversion project on the Colorado River is shown in Figure 2.5. The 1992 flood year, during which the maximum inflow on record of 14.9 million acre-feet occurred, is not included. The annual average total estimated freshwater inflow to the bay from 1979 to 1989 was to 3,208,000 acre-feet per year and was 4,405,000 acre-feet per year for the 1993 to 2003 time period. The estimated annual average total surface inflow to the bay was higher during the post-diversion period, and the relative distribution of these flows among the three major sources demonstrate an

increase in the portion from the Colorado River basin after the diversion project was completed as shown in Figure 2.6.



*The 1992 Flood Year is not included.

Figure 2.5 Annual Average Inflows to Matagorda Bay: Pre- and Post-Diversion.

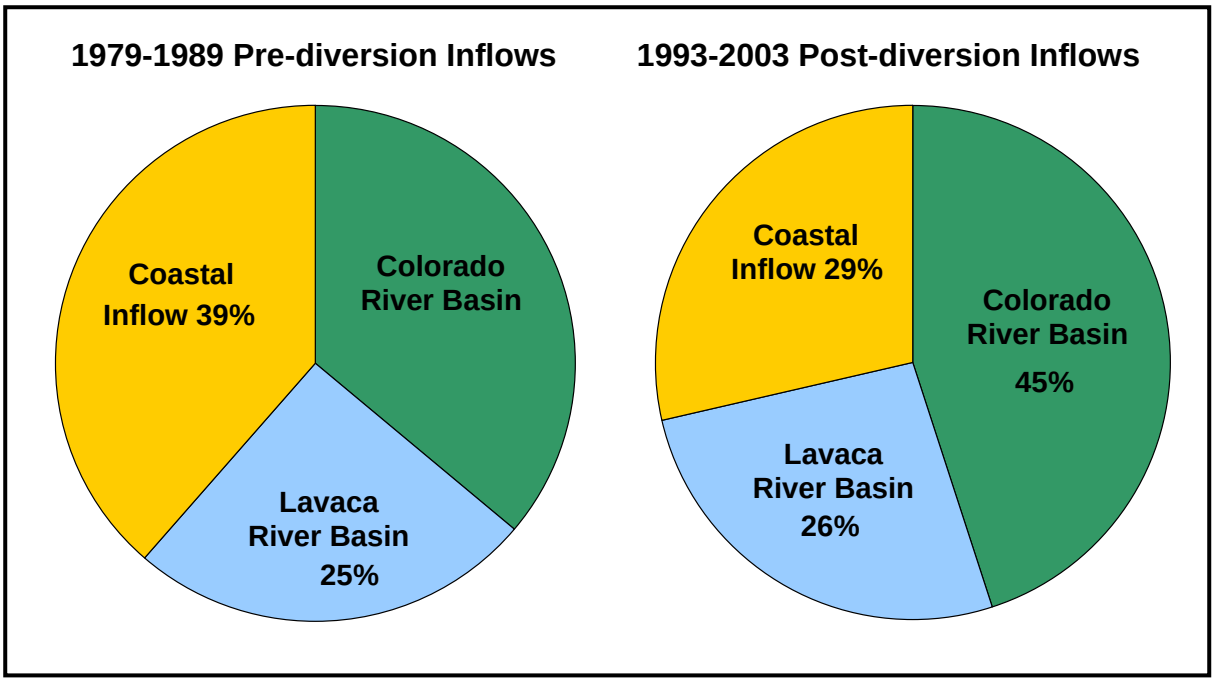


Figure 2.6 Distribution of Annual Average Inflows to Matagorda Bay: Pre-Diversion and Post-Diversion.

CHAPTER 3
Biology

3.1 Introduction

The relationship between freshwater inflows and biological productivity in Matagorda Bay is an essential component in developing Target freshwater inflow need recommendations. Fisheries equations relating freshwater inflows and species productivity were developed for nine target species in the 1997 Freshwater Inflow Needs study. The 1997 analysis used both TPWD Coastal Fisheries data and commercial harvest data to calculate annual productivity. Equations for seven species were developed using the bag seine subset of the Coastal Fisheries data, while equations for oysters and southern flounder were developed using commercial harvest data because bag seines are an ineffective sampling method for those species. Both data sets included data through 1992, the first full year of the diversion of the Colorado River into Matagorda Bay. The lack of post-diversion data is a potential limitation of the 1997 fisheries equations.

The primary purpose of this re-evaluation was to assess the relationship of inflows and fisheries productivity since the diversion of the Colorado River. This chapter also evaluates the spatial distribution, pre- and post-diversion abundance and salinity preferences of select species. Twelve candidate target species, considered economically and/or ecologically important to Matagorda Bay, were evaluated in this study, although viable statistical relationships were found for only seven of those species (Table 3.1). Statistically significant equations were not developed for five of the candidate species.

The biological productivity regression equations use estimates of river basin inflow from the two primary sources - the Colorado River basin and the Lavaca River basin. These regression equations do not include other sources of inflow including the unmeasured portions of the river basins and the remaining coastal basins (as discussed in Chapter2). This differs from the 1997 study in which these coastal inflows were included in the development of the biological productivity regression equations. Omission of these coastal inflows adds some degree of uncertainty to the equations.

Table 3.1 Species and Data Used to Evaluate Fisheries Equations in the 1997 and 2005 Freshwater Inflow Needs Studies.

Species	Data Used in 2005	Equation Developed	1997 Target Species
Blue Crab	Coastal Fisheries	Yes	Yes
Brown Shrimp	Coastal Fisheries	Yes	Yes
White Shrimp	Coastal Fisheries	Yes	Yes
Eastern Oyster	Coastal Fisheries	Yes	Yes
Gulf Menhaden	Coastal Fisheries	Yes	Yes
Striped Mullet	Coastal Fisheries	Yes	Yes
Red Drum	Coastal Fisheries	Yes	Yes
Black Drum	Coastal Fisheries	No	Yes
Southern Flounder	Coastal Fisheries	No	Yes
Grass Shrimp	Coastal Fisheries	No	n/a
Croaker	Coastal Fisheries	No	n/a
Spot	Coastal Fisheries	No	n/a
Spotted Sea Trout	Coastal Fisheries	No	n/a

3.2 Data Description

The two primary sources of data used to develop statistical relationships between freshwater inflows and fisheries productivity are commercial harvest data and TPWD Coastal Fisheries data. Commercial harvest data reports commercial fishing landings of finfish and shellfish by bay system. These data are influenced by factors including fishing effort, efficiency, harvest regulations and economic factors such as fuel prices. In addition, commercial data often reflect an advanced life stage for which many factors other than freshwater inflow can affect productivity.

The TPWD Coastal Fisheries program systematically samples Matagorda Bay using four gear types: bag seines, otter trawls, gill nets and oyster dredges. Bag seine samples are randomly collected monthly and otter trawls samples are collected monthly in a stratified random manner. Bag seine samples are collected only near the shoreline; otter trawls are collected in areas where water is at least one meter deep and free of obstructions. Gill nets, used in the spring and fall seasons, are placed so that they are perpendicular to the shore and left overnight. The oyster dredge program, which has changed over time, involves taking samples monthly at known reefs.

The TPWD Coastal Fisheries data was used in these analyses for all species. Except for oysters, the bag seine subset was determined to be the appropriate gear type for all species since the gear type selects for the juvenile life stage. Juveniles should provide less bias and better relationships to inflows because of their dependence on inflow for creating appropriate environmental conditions needed for proper growth and development. The adult life stage of many organisms can be significantly influenced by a variety of factors unrelated to freshwater inflow (e.g., commercial fishing pressure). The variation in annual productivity measured from the advanced life stages is more difficult to directly link to freshwater inflows, because adults are mobile and more tolerant to environmental conditions such as higher salinity. Thus, it is appropriate to measure the juvenile life stage, which is more sensitive to freshwater inflows.

The number of monthly bag seine samples collected by TPWD has increased over time (Table 3.2). The systematic change in collection effort has implications for fishery equation development. First, average annual density derived from six samples per month can be influenced by a single large catch. In addition, the variance of the average annual density derived from six samples per month will tend to be larger than the corresponding variance based on 20 samples per month. Second, there is a clear difference in the amount of coverage between six and 20 samples per month. Some portions of the bay were not represented when only six samples were collected, which is problematic to the calculation of annual productivity. For example, six samples located in prime habitat could lead to an inflated annual catch. Conversely, six samples during key months in suboptimal habitat could underestimate annual productivity. Ultimately, the difference in sampling efficiency could contribute to considerable variation in annual catch. Therefore, caution should be used when comparing annual averages derived from various collection efforts. Fortunately, there has been consistent sampling since 1992.

Table 3.2 Number of Bag Seine Samples per Month, since 1976.

	Month											
Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1976				4	4							
1977										6	10	6
1978	6	6	6	6	6		6	6	6	6	6	6
1979	6	6	6	6	6	6	6	6	6	6	6	6
1980	6	6	6	6	6	6	6	6	6	6	6	6
1981	6	6	6	6	6	6	6	6	6	10	10	10
1982-1987	10	10	10	10	10	10	10	10	10	10	10	10
1988	10	10	10	12	12	12	12	12	12	12	12	12
1989	12	12	12	12	12	12	12	12	12	12	12	12
1990	16	16	16	16	16	16	16	16	16	16	16	16
1991	16	16	16	16	16	16	16	16	16	16	16	16
1992	20	20	20	20	20	20	20	19	20	20	20	20
1993-2002	20	20	20	20	20	20	20	20	20	20	20	20

The annual density calculated from bag seine data for selected species are shown in Table 3.3. Most species show a large amount of inter-annual variation. For example, the annual density of Gulf menhaden ranges from 1838 individuals/acre to 28 individuals/acre. Several species show particularly low productivity during extended periods of low inflows. The annual density of white shrimp, Atlantic croaker, Gulf menhaden, striped mullet and spot were low during the drought in 2000.

Table 3.3 Annual Density of Various Species in Matagorda Bay (individuals/acre), 1978 – 2002.

Year	Blue Crab	Brown Shrimp	White Shrimp	Gulf Menhaden	Striped Mullet	Red Drum	Oysters (number /dredge)
1978	8.28	133.74	442.02	**3170.71**	31.72	3.23	
1979	21.85	155.56	434.26	693.52	78.52	6.67	
1980	18.89	114.26	417.96	92.22	17.04	7.22	
1981	34.76	125.24	642.38	278.10	43.65	8.73	
1982	25.00	165.33	**1399.67**	656.33	**450.56**	9.67	
1983	28.11	198.56	315.33	647.22	29.44	5.22	
1984	**39.11**	131.67	958.56	840.11	28.33	2.11	
1985	22.56	145.44	233.78	1527.44	27.00	4.33	
1986	20.67	**203.00**	270.11	1837.89	14.44	1.33	
1987	14.33	178.00	231.78	1434.11	16.56	7.00	
1988	11.50	83.09	136.43	145.12	21.35	2.22	
1989	18.06	147.78	153.43	74.63	11.67	2.78	
1990	29.44	168.68	180.49	206.04	11.88	6.11	
1991	23.13	180.28	248.26	1211.11	34.17	**15.00**	
1992	17.85	107.89	257.02	767.64	25.22	7.42	6.36
1993	20.50	93.00	234.00	196.89	17.94	4.83	4.89
1994	38.33	161.00	204.83	165.28	24.89	3.33	8.95
1995	25.44	137.78	242.83	287.11	11.00	3.22	13.51
1996	15.39	110.83	181.94	593.56	13.06	7.94	19.66
1997	25.11	96.17	192.50	918.83	28.39	7.72	16.70
1998	19.28	150.44	188.56	379.89	13.56	3.17	15.08
1999	13.94	192.44	594.11	159.72	7.44	5.11	19.14
2000	17.72	179.28	77.33	28.67	9.33	1.67	**19.92**
2001	14.39	141.89	137.72	1676.17	42.17	4.28	9.99
2002	15.56	99.78	309.22	97.56	14.11	4.44	10.10
Annual Average	21.57	144.04	347.38	723.43	40.94	5.39	13.12

Note: All organisms except oysters were collected in bag seine. The oysters were collected by dredging. **Bold indicates the maximum annual abundance,** Underlined indicates the minimum annual abundance.

3.3 Target Species

The life cycles of many marine organisms are complex because development from egg to adult often occurs through many stages, which are dependent upon appropriate temperature, salinity and other environmental factors (TWDB, 1994). Many marine organisms use marsh habitat located in the smaller bays and river deltas in estuaries for the development of their juveniles. Such organisms have co-evolved with the natural pattern of freshwater inflows. For example, the arrival of larval/juveniles in the spring or fall often corresponds to historic peak spring and fall inflows. These inflows create lower salinity conditions and provide nutrients that nourish developing juveniles in the marshes.

3.3.1 Brown Shrimp

Brown shrimp is one of the most commercially and economically important species in Matagorda Bay (Figure 3.1). Adult shrimp spawn in the deeper waters of the Gulf from September through May; February and March are considered peak months (Lassuy, Brown Shrimp, 1983). Development of eggs to the larval stage is similar to white shrimp, with several molts and life stages occurring in the offshore water (Lassuy, Brown Shrimp, 1983). Brown shrimp larvae use tides to emigrate into the estuary and seek shallow, soft bottom marsh habitat for development. Smaller shrimp appear to prefer salinity in the 20 parts per thousand (ppt) range and avoid areas of low salinity (LCRA, 1997). Brown shrimp migrate out of the bays during the summer months June and July on favorable tides.

Brown shrimp are caught throughout Matagorda Bay, with the largest densities occurring in the tertiary bays, such as Caracahua Bay and Powderhorn Lake (Appendix C, Figure 1). Brown shrimp have clear seasonal patterns in Matagorda Bay. Catch density for bag seines peaks in May and June, as shown in Figure 3.2.

Figure 3.1 Brown Shrimp (TPWD).

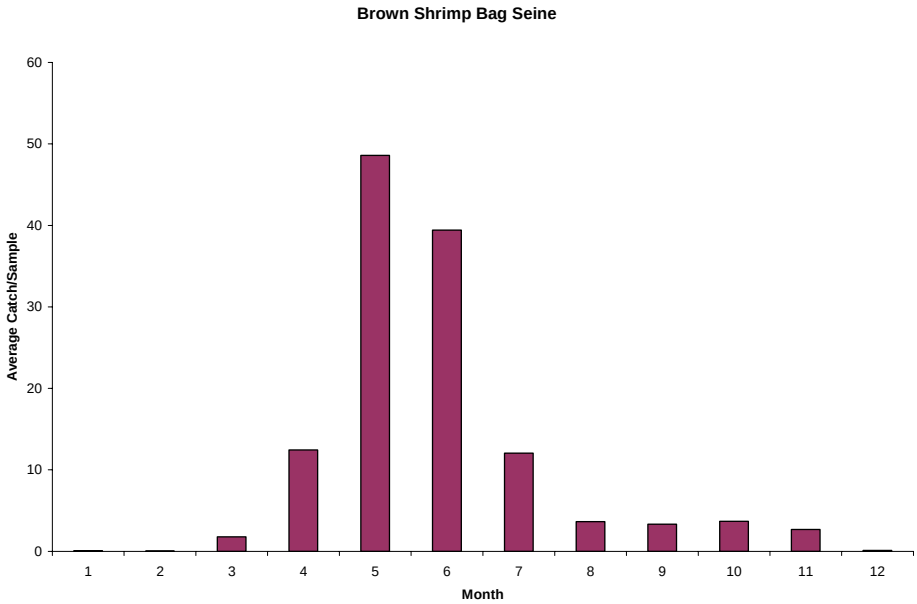


Figure 3.2 Average Catch of Brown Shrimp per Bag Seine by Month.

3.3.2 White Shrimp

Ecologically important white shrimp are also one of the most commercially important species in Matagorda Bay (Figure 3.3). White shrimp spawn in the Gulf of Mexico from April to August (Muncy, 1984). Eggs hatch about 12 hours after spawning and undergo a series of molts and life stages offshore before reaching the larval stage (Muncy, 1984).

Larval shrimp enter the estuary on flood tides and locate in the far reaches of the estuary (Muncy, 1984). White shrimp prefer shallow, low saline marsh while developing (TWBD, 1994). The shrimp develop rapidly in the nursery ground in the summer, stage in the open bay during fall and migrate to the Gulf late fall, typically when water temperatures drop (Muncy, 1984).

Figure 3.3 White Shrimp (TPWD).

The peak density of white shrimp collected with bag seines in Matagorda Bay occurs from July to November (Figure 3.4). White shrimp densities are highest in the secondary bays (Caracahua, Powderhorn) and far into the Tres Palacios and Lavaca bays (Appendix C, Figure 2).

The annual density of white shrimp strongly correlates to inflows during July-August. Decreased annual productivity is demonstrated when flows during this bimonthly period are extremely high or low. This response led to the selection of July-August flows for the white shrimp equation. As with brown shrimp, larger flows were eliminated to limit the data to a region where a linear response is justified.

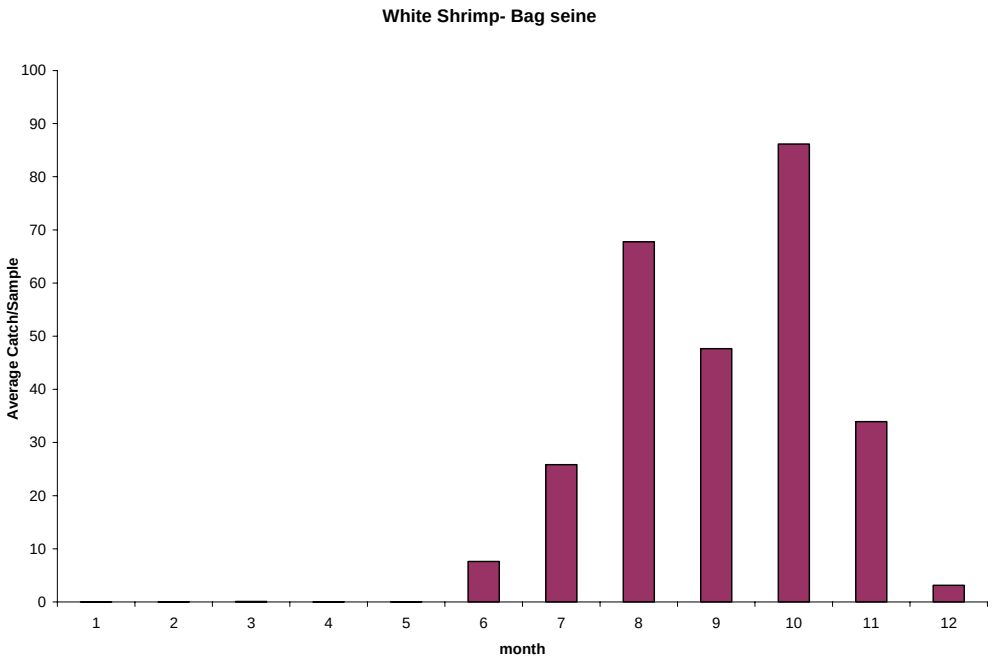


Figure 3.4 Average Catch of White Shrimp per Bag Seine by Month.

3.3.3 Blue Crab

Blue crab (Figure 3.5), an ecologically and economically important species in Matagorda Bay, occupies the estuary year round, although abundance in bag seines peaks in spring, as shown in Figure 3.6. Mating occurs in low salinity waters in the upper reaches of the estuary (Van Avyle, 1984). Females migrate to the Gulf to spawn during the fall (TWDB, 1994). Larvae return to the estuary on incoming tides and are distributed equally around the estuary during winter. Juvenile crabs tend to concentrate in the upper reaches of the estuary during the spring (Appendix C, Figure 3) (LCRA, 1997). Crabs can tolerate a wide range of salinities, although peak abundance appears to occur in intermediate salinities in the Matagorda Bay system (LCRA, 1997). Upon maturation, male and female crabs inhabit different portions of the estuary with males preferring lower salinity waters and females in higher salinity waters (Van Avyle, 1984).

Figure 3.5 Blue Crab.

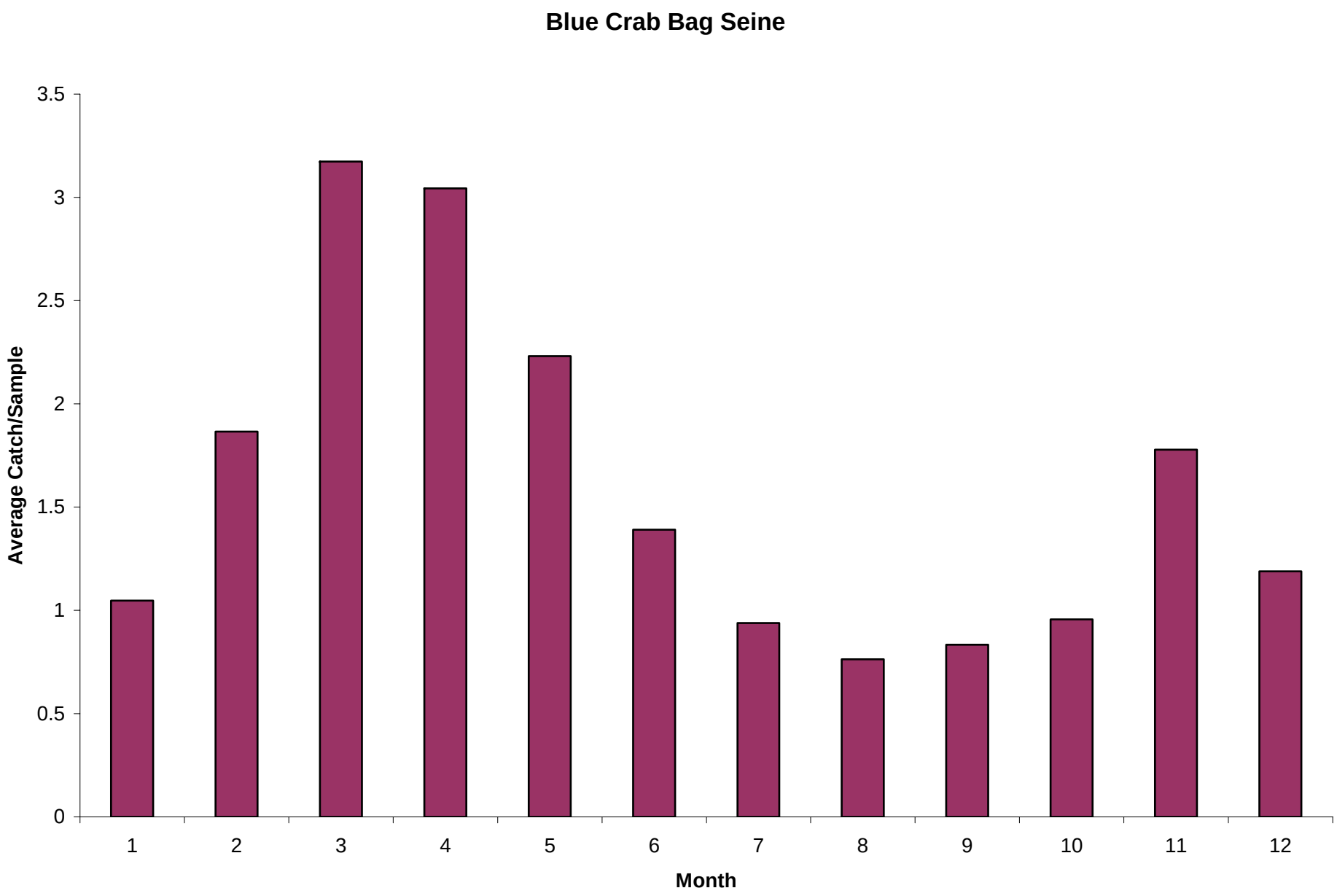


Figure 3.6 Blue Crab Bag Seine

3.3.4 Oysters

Oysters are ecologically and commercially important sessile mollusks that inhabit the estuary full time (Figure 3.7). Oysters live in groups known as beds or reefs and continue to re-establish in favorable areas. Spawning is a function of temperature and salinity. Temperatures above 20 degrees C and salinity above 10 ppt are favorable (Stanley and Sellers, 1986). Oysters spawn throughout the year, but peak in late spring and early summer in Matagorda Bay. Mass spawning occurs at a temperature above 25 degrees C (Stanley and Sellers, 1986). Larvae remain in the water column up to three weeks, when they attach to a hard substrate (preferably existing shell) and become spat (Stanley and Sellers, 1986). Growth depends on environmental conditions, such as salinity (LCRA, 1997). Oysters are subject to parasites and diseases, particularly at elevated salinity and temperatures. Increased salinities favor the oyster drill predator (LCRA, 1997). High salinities also increase the rate of infection and mortality by the parasitic oyster disease Dermo, especially at salinities over 25 ppt (Balboa, 2004). Fluctuations in salinity levels keep infection rates low.

The oyster equation was developed using market-sized oysters from the Coastal Fisheries oyster dredge data. Oyster density was low following large inflow events associated with the floods of 1992, when Matagorda Bay received nearly 10 million acre feet of inflow. The population steadily grew until 2000, when a drought and high salinities resulted in heavy oyster mortality associated with disease. The data from 2001 and 2002 were not used because the density of market sized oysters had not recovered from the high mortality in 2000. While the flows during 2001 and 2002 were favorable for oysters, the low population density resulted in poor correlations to inflows. Thus, excluding the years impacted by drought allowed for the period of growth (1992 to 2000) to be statistically modeled.

Figure 3.7 Oysters (TPWD).

3.3.5 Striped Mullet

Adult finfish are usually tolerant to a range of salinities from freshwater to seawater. However, juveniles of these species often depend upon estuarine environments for development. Striped mullet (Figure 3.8) are a common finfish in Matagorda Bay, present in the estuary throughout the year (Figure 3.9 and Appendix C, Figure 4). Striped mullet spawn offshore primarily during November and December, coinciding with the period of lowest density in the bay (Collins, 1985). Juvenile mullet distribute throughout the estuary during the spring, with the largest concentrations occurring in the upper reaches of the Tres Palacios, Caracanhua, Turtle and Lavaca bays. Adults migrate offshore to spawn during the fall and may return to the estuary, stay offshore or migrate up freshwater rivers (Collins, 1985).

Figure 3.8 Striped Mullet (TPWD).

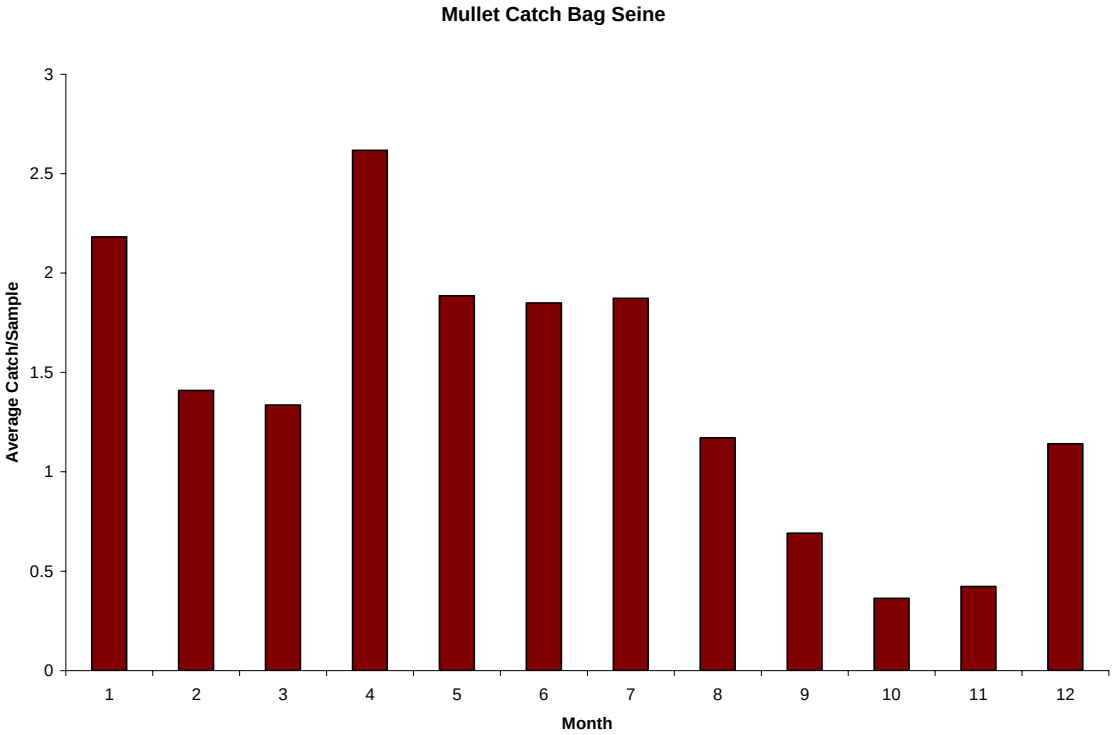


Figure 3.9 Average Catch of Striped Mullet per Bag Seine by Month.

3.3.6 Gulf Menhaden

Gulf menhaden is an abundant estuarine-dependant finfish species (Figure 3.10). Menhaden are commercially important in the upper Texas coast and Louisiana (Lussuy, Gulf Menhaden, 1983). Adult menhaden spawn in the Gulf of Mexico during the fall and winter, which coincides with the lowest density collected in bag seines (Figure 3.11). Spawning may occur up to five times in a single season (Lussuy, Gulf Menhaden, 1983). Larvae develop offshore for three to five weeks before entering the estuary on favorable currents (Lussuy, Gulf Menhaden, 1983). Larvae seek shallow, low salinity areas. Juveniles form large schools and remain in the low salinity areas until fall. Similar to mullet, the largest concentrations occurred in the upper reaches of the Tres Palacios, Caracanhua and Lavaca bays as shown in Appendix C, Figure 5. Young fish migrate to the Gulf with adults, but it is unclear whether they participate in spawning (Lassuy, Gulf Menhaden, 1983).

Figure 3.10 Gulf Menhaden (TPWD).

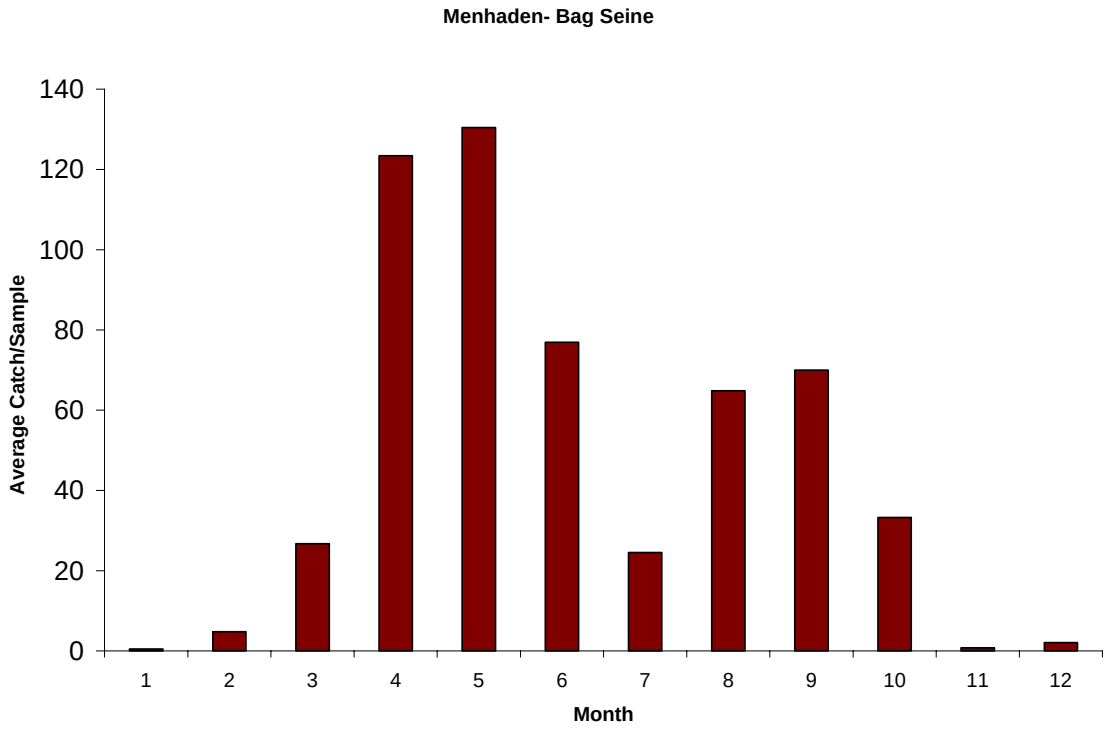


Figure 3.11 Average Catch of Gulf Menhaden per Bag Seine by Month.

3.3.7 Red Drum

Red drum are one of the most important sport fish on the Texas coast and historically an important commercial finfish as well (Figure 3.12). Juvenile red drum use the estuary for development, with peak density occurring during winter (Figure 3.13). Red drum spawn offshore during late summer and fall (Reagan, 1985). Eggs are carried into the bays on tidal currents where they develop in sea grass beds and wetland marshes (Reagan, 1985). Red drum were collected throughout the bay (Appendix C, Figure 6), and were apparently more abundant in the upper reaches of the estuary (LCRA, 1997). Red drum migrate to the Gulf after remaining in the estuary for four or five years (Reagan, 1985).

Figure 3.12 Red Drum (TPWD).

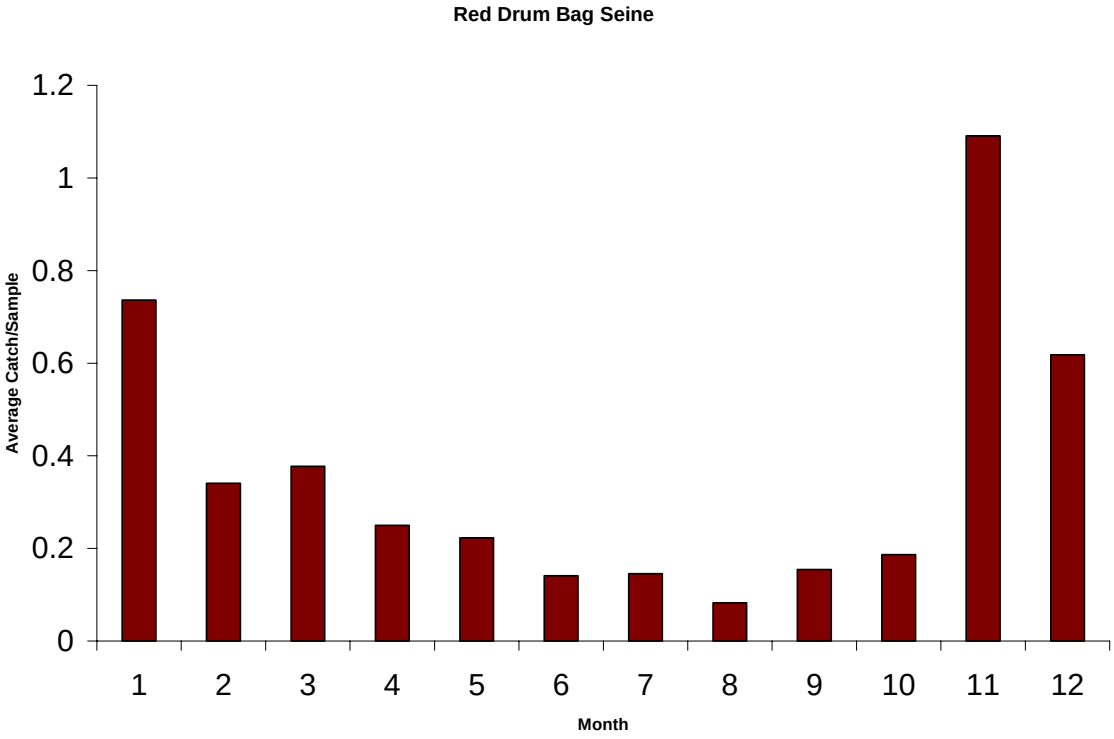


Figure 3.13 Average Catch of Red Drum per Bag Seine by Month.

3.4 Salinity and Species Abundance

Estuarine organisms are adapted to a wide range of salinity conditions. However, abundance of many estuarine organisms appears highest at intermediate salinities. Metabolic stress occurs when salinity is too high or low. Table 3.4 shows average annual salinity to average annual density for target species. Annual productivity is generally highest when annual average salinities are between 15 and 23 ppt.

Table 3.4 Salinity and Density of Selected Estuarine Organisms.

Species	Individuals/Acre			
	<15 ppt	15 – 18 ppt	18 – 23 ppt	> 23 ppt
Blue Crab	19.8	21.4	26.1	17.7
Brown Shrimp	134.4	145.9	144.9	147.0
White Shrimp	278.9	384.4	452.8	220.6
Gulf Menhaden	953.5	644.0	1130.2	201.3
Striped Mullet	37.2	76.6	26.7	12.5
Red Drum	9.2	6.2	4.3	4.3

Source: Calculated from Texas Parks and Wildlife Department, "Coastal Fisheries Data for Matagorda Bay Bag Seine1977 – 2002" database. (Austin, Tex. 2004).

3.4.1 Species Abundance Before and After the Diversion

A comparison of annual abundance of selected species in Matagorda Bay was conducted for the pre- and post-diversion period. The null hypothesis is that there are no differences in annual density of blue crab, brown shrimp, white shrimp, Gulf menhaden, mullet, and red drum in the pre- and post-diversion periods, based on a Student's *t* test. Although there are large differences in mean density between the periods, the null hypothesis was not rejected for any species (Table 3.5).

This is an unexpected result since there was more water and lower salinity concentrations on average since the diversion. Additional intertidal marsh habitat was created in the new Colorado River delta, thus, productivity was expected to increase. However, it should be noted that within the spring flows May-June period 1992, 1993 and 1997, the Colorado River discharged greater than 1.5 million acre-feet into Matagorda Bay. That

volume is equivalent to the estimated target need for the entire year and such a large volume in a short time could have disrupted productivity.

Table 3.5 Average Annual Species Abundance (individuals/acre) Before and After the Diversion.

Species	Pre Diversion 1978 – 1990	Post Diversion 1992 – 2002	p value
Brown Shrimp	150	134	0.25
White Shrimp	447	238	0.07
Blue Crab	22.5	20.31	0.51
Striped Mullet	60	19	0.23
Gulf Menhaden	892	479	0.17
Red Drum	5.7	4.8	0.46

Source: Calculated from Texas Parks and Wildlife Department, "Coastal Fisheries Data for Matagorda Bay, 1977 – 2002" database. (Austin, Tex. 2004).

3.4.2 Importance of Location within Matagorda Bay

The Matagorda Bay system has several smaller secondary bays. The smaller bays can be the most productive areas in a bay system because they have optimal habitat (marsh) and salinity conditions. Table 3.6 compares species density at four sites. White shrimp, brown shrimp and menhaden were more abundant in Carancahua Bay than the eastern arm of Matagorda Bay or Tres Palacios Bay. Mullet, red drum and speckled trout showed little preferences between the systems. While Carancahua Bay and Tres Palacios Bay receive significantly less inflow than Lavaca Bay and the eastern arm of Matagorda Bay, it appears that the right combination of inflows and habitat is present to promote productivity. For example, the eastern arm of Matagorda Bay receives the most freshwater inflow but had the lowest abundance of most species. It should be noted, however, that sampling does not occur in the Colorado River delta proper, an area of newly created marsh habitat and potentially the highest abundance of organisms.

Table 3.6 Species Abundance at Different Locations in the Matagorda Bay System (individuals/acre).

Site	Eastern Arm Matagorda	Tres Palacios	Carancahua	Lavaca
Brown Shrimp	113.07	151.06	220.57	123.80
White Shrimp	157.76	208.33	529.27	202.01
Blue Crab	19.09	32.13	19.98	16.07
Striped Mullet	32.94	31.01	27.71	15.34
Gulf Menhaden	623.99	1381.99	1316.14	551.90
Red Drum	7.23	3.95	5.12	4.87

Note: Abundance is the average number of individual organisms per acre
Source: Calculated from Texas Parks and Wildlife Department, "Coastal Fisheries Data for Matagorda Bay, 1977 – 2002" database. (Austin, Tex. 2004).

3.4.3 Conceptual Model for Developing Flow-Productivity Relationships

The relationship between freshwater inflows and estuarine productivity is complex. A description of the full range of influences of freshwater inflows on productivity fell beyond the scope of this FINS analysis. The FINS analysis was limited to relating freshwater inflows to productivity using only available data on productivity, most notably the TPWD Coastal Fisheries data. Developing relationships, for example, between freshwater inflows (via nutrient loading) on algal (primary) productivity was not possible because of the minimal data available on nutrient loading and algal productivity for Matagorda Bay. While these and many other relationships are well recognized, their treatment was beyond the scope of the FINS study due to limited data. Further data collection is recommended and additional work to help support development of additional relationships is the focus of other studies (e.g. LCRA-SAWS Water Project). These and other studies will likely continue long into the future to help develop more reliable and new relationships.

In general, freshwater inflows moderate salinity, provide nutrients necessary for primary productivity, and build and maintain habitat. Depending on their timing, volume and location, freshwater inflows can either benefit or harm productivity. Under certain conditions, the impacts are immediately felt and short–lived; in other cases, the impacts are not evident for months but might last for years. The same level of freshwater inflows

are not uniformly beneficial to all species because flow volumes that benefit one species can harm productivity of another. Flow volumes can also have a more direct impact on juveniles than adults of some species.

In general, the relationship between inflows and productivity becomes more complex and less certain the further in time, the farther up the food chain and the more mature the species one considers. The ultimate purpose of this analysis was to distill these complex interactions to a level that could be represented in the form of simplified mathematical equations relating flow to productivity. The form of these equations had to be compatible with use in TXEMP, the optimization model used to determine target inflows for Matagorda Bay. This requirement placed restrictions on the form of equations that could be used, and led to the need for simplifying assumptions. Because the relationships developed here are of a simple form, they are not meant to capture the full range of influences of inflows on productivity nor all the factors that contribute to productivity. This section discusses some of the assumptions inherent to the relationships and the conditions they are meant to represent.

Statistical Approach

Prior efforts (LCRA, 1997) to develop flow-productivity equations made use of the all-possible-subsets statistical approach, in which all combinations of the independent variables (bi-monthly flows) were regressed against the dependent variable (annual species productivity) in a broad search for statistically significant regressions. Only monotonic functional forms (linear, log, square root) were applied. (Monotonic functions continually either increase or decrease.) Similar attempts in the current study to develop flow-productivity equations with updated data sets were not uniformly successful.

Use of both the all-possible subsets approach and of monotonic functional forms applied over limited flow ranges allowed the development of the best available equations that related freshwater inflows to productivity. This recognizes that equations that describe species response to freshwater inflows need not be of the same type for all species, nor should they necessarily be expected to. Some species inhabit the bay throughout the year, thus using the all possible subsets approach selected the best statistical fits from all

flow possibilities. Brown and white shrimp, however, are in the bay for very specific periods of time and also were shown to respond negatively to extremely large inflows. Thus, modeling their response over limited inflow ranges with monotonic (uniformly increasing) functions provided very strong correlations that correspond to the species life history requirements. However, there were not enough data points to capture the negative relationship of productivity with inflows, if any exists. Overall, the use of two approaches sought to utilize the best equations for all species.

Indeed, no statistically significant relationships were found for several species using these approaches. In some instances, relationships were weak, and the most statistically significant independent variables were not consistent with historical observations and what is believed to be the mechanisms of the bay. Rather than adhere to the use of the all-possible-subsets approach, alternate approaches were used in this study to develop the needed equations, particularly for shrimp.

Use of juvenile organisms to represent productivity

Except for oysters, productivity in this study is defined as the biomass of juvenile organisms of the size captured in bag seine sampling gear used in TPWD's Coastal Fisheries sampling program. Productivity for oysters is based on biomass of live oysters collected with oyster dredges in the Coastal Fisheries program. Use of juveniles reduces the influence of confounding factors that are magnified when considering adult organisms, such as fishing pressure, predation and disease. The assumption made in selecting juvenile species is that the inflow-productivity relationship is most direct and simple at the earliest stages of the life cycle, but is complicated by the pressures mentioned earlier as the animals mature. The response of juveniles to salinity is also more critical than that of adults. TPWD bag seine data from Matagorda Bay indicates juveniles prefer a narrow range of salinities until they mature, and extremely high or low salinities can lead to mortality.

In a sense, this approach treats potential productivity associated with juveniles, rather than productivity associated with fully realized adult biomass. While the use of adults as

indicators of bay productivity would also be suitable, the use of juveniles would be expected to be less problematic.

Seasonal occurrence of species – selection of independent variables

Occurrence in the bay of some species, e.g., brown and white shrimp, is highly seasonal. Juvenile brown shrimp, for example, are found in the bay primarily from April through July, while few are found in the bay outside of these months. For brown shrimp to flourish, satisfactory salinity, nutrient and habitat requirements must be maintained between April and July. Assuming that neither nutrients nor habitat constrains productivity, salinity in the bay during these months has the most direct influence on productivity (e.g. energetics), while outside of those times, salinity and other factors are less important (Longley, ed., 1994). These assumptions support the selection of certain flow months, during or immediately prior to the time the species are present in the bay, as independent variables to be used in the flow-productivity equations.

Extreme inflows – need to filter data

Very low flows are assumed to have short-term (months to 1 to 2 years) negative impacts on productivity (see Figures 3.3 and 3.6 for brown shrimp and white shrimp productivity relative to a wide range of flows). Droughts are known to have an impact on productivity by both reducing nutrient input to the system and by elevating salinities to extreme levels. Extremely large flows provide beneficial nutrients and sediment but can also disrupt or reduce productivity in the short term. Floods reduce salinities to the other extreme, increase turbidity levels, and physically transport species away from desired habitat. Finally, moderate flows tend to support greater productivity than extreme flows. These assumptions about the effects of extreme flows (i.e. low productivity for small and large flows, and higher productivity for moderate flows) on productivity imply that quadratic or other higher order functions, rather than monotonic functions, are needed to represent this response. Alternatively, if monotonic functions must be used, , as required in the application of the TXEMP optimization model (Chapter 7) in this study, the range of flows used should be limited to that in which productivity is monotonic.

This alternate approach was taken in the development of equations for some species. Extremely high flows were eliminated with the reasoning that the monotonic functions used in the regression equations, as required in TXEMP, simply cannot represent the response of productivity to flow over the entire range of flows. Data were eliminated for years in which "large" floods occurred during the months (or immediately prior months) when the species are in the bay. The elimination of these data points was not based on the assumption that they were aberrant or anomalous due to measurement inaccuracies or other reasons, but rather that they did not fall within a range in which a monotonic response would be expected. While identifying "high" flows is subjective, it was felt to be necessary due to the above restrictions.

Conceptual model

The above assumptions are summarized below in a conceptual model for the flow-productivity equations:

1) Juvenile species are representative of potential productivity and good candidate measures since they are less influenced by other external pressures than more adult species. Simple models to relate inflows to productivity are more likely to succeed with juvenile species than with more mature species.

2) Freshwater inflows influence salinity, nutrient supply and habitat. The bay is not nutrient limited nor habitat impaired under the normal range of flows considered in TXEMP. The response of juveniles to salinity is a primary response relative to responses to nutrients and habitat.

3) Some juvenile species in Matagorda Bay have strong seasonal preferences (i.e., they are found in the bay during specific seasons). Simple equations that relate the response of these species to inflows should include flows during or immediately prior to the seasons during which the species are found in the bay. The beneficial effect of inflow in moderating salinity and in providing nutrients is assumed to be most influential during the months in which the species are observed to be in Matagorda Bay and decreases in significance away from that period.

4) The immediate effects on productivity of droughts and large floods are both assumed to be negative relative to "normal" flow conditions, since droughts and floods strongly influence salinity. Monotonic functions relating flow to productivity cannot adequately represent both the increasing and decreasing response of productivity to extreme inflow conditions. Since monotonically increasing functions are used to represent flow and productivity due to restrictions imposed by the application of TXEMP in this study, the range of data must be limited to a region in which a monotonic response is justified.

Application

Different species require different approaches to development of equations relating inflow to productivity. Although the all-possible-subsets approach succeeded with some species, it was not adequate for others. For these species, the above description provides a simple conceptual model for the equations that were developed. It attempts to limit the analysis to data meeting the monotonic-function model assumptions. It reduces the likelihood that data outside this range will generate spurious results simply because they do not meet the model assumptions. It simplifies the analysis and allows for immediate use in the existing TXEMP formulation. Finally, it can be accomplished in relatively short time.

The equations developed here are highly restricted in their applicability. It would be ideal if an equation relating inflow to all life stages of a species (based on data from the different gear types in the TPWD Coastal Fisheries database) and overall flow ranges could be developed. However, this is impractical given the available data and complexity of estuarine ecosystems. Instead, equations relating flow to a particular life stage (one gear type), and in some cases over limited flow ranges, were developed. Constraints in TXEMP limit use of the equations over specific flow ranges, so this was chosen as a more appropriate approach for this analysis. Further studies should investigate the development of quadratic or higher-order equations relating flow to productivity, and use of these forms of equations in TXEMP. Further basic studies on the effects of floods in providing nutrients to recharge the system are needed. Time series or other types of models should be pursued to allow for more complex descriptions of bay productivity.

3.5 Species Abundance Relationships

Statistically significant regression equations for mullet, menhaden, red drum, blue crab and oyster were developed using the all possible subsets approach for the post diversion period (Table 3.7). The equations estimate abundances based on bi-monthly seasonal inflow into the estuary. For example, the blue crab equation explains the annual catch based on freshwater inflows occurring in March-April, May-June, and September-October. Flows during March-April negatively influence annual catch, while flows in May-June and September-October bolster productivity. Statistically significant equations were investigated, but none could be identified, for black drum, spot, Atlantic croaker, grass shrimp or spotted sea trout with this approach. Flounder were not evaluated because they are not effectively captured with any gear type.

Equations for white shrimp and brown shrimp were developed using a simple linear technique relating bimonthly flows that were concurrent with peak abundance as seen in Table 3.7. Both species demonstrated strong seasonal occurrence in bag seines. Since the relationships were linear, a plot of the relationship between annual abundance and productivity is provided for brown and white shrimp. The relationship between freshwater inflow and species abundance for other species were described with multiple regression equations, making it difficult to demonstrate graphically.

The annual density of brown shrimp strongly correlates to inflows during May-June. Decreased annual productivity is demonstrated when flows during this bimonthly period are either extremely high or low (Figure 3.14). This behavior led to the selection of May-June flows for the brown shrimp equation (Figure 3.15). However, larger flows were eliminated from the analysis to limit the data to a region in which a linear response is justified. These flood flows are outside of the range of what would be considered optimal.

The annual density of white shrimp strongly correlates to inflows during July-August. Decreased annual productivity is demonstrated when flows during this bimonthly period are extremely high or low (Figure 3.16). This response led to the selection of July-

August flows for the white shrimp equation (Figure 3.17). As with brown shrimp, larger flows were eliminated to limit the data to a region where a linear response is justified.

Table 3.7 Catch as a Function of Inflow* for the Seven Target Species.

Target Species	**Discharges (Q)**						
	Constant	Jan-Feb	Mar-Apr	May-Jun	Jul-Aug	Sep-Oct	Nov-Dec
Brown Shrimp	85.63			.003			
White Shrimp	56.36				.001		
Blue Crab	-19.98		-3.38**	6.77**		3.86**	
Eastern Oyster	17.01			- .0000079	.000016		
Striped Mullet	7.00	10.20**				-7.51**	
Gulf Menhaden	-468.71	538.68**				-335.89**	
Red Drum	3.626				1.06**	.796**	-1.58**

* Post-diversion period data were used.
** Indicates the natural log of inflow. The September-October term was lagged 1 year for Menhaden and Striped Mullet.

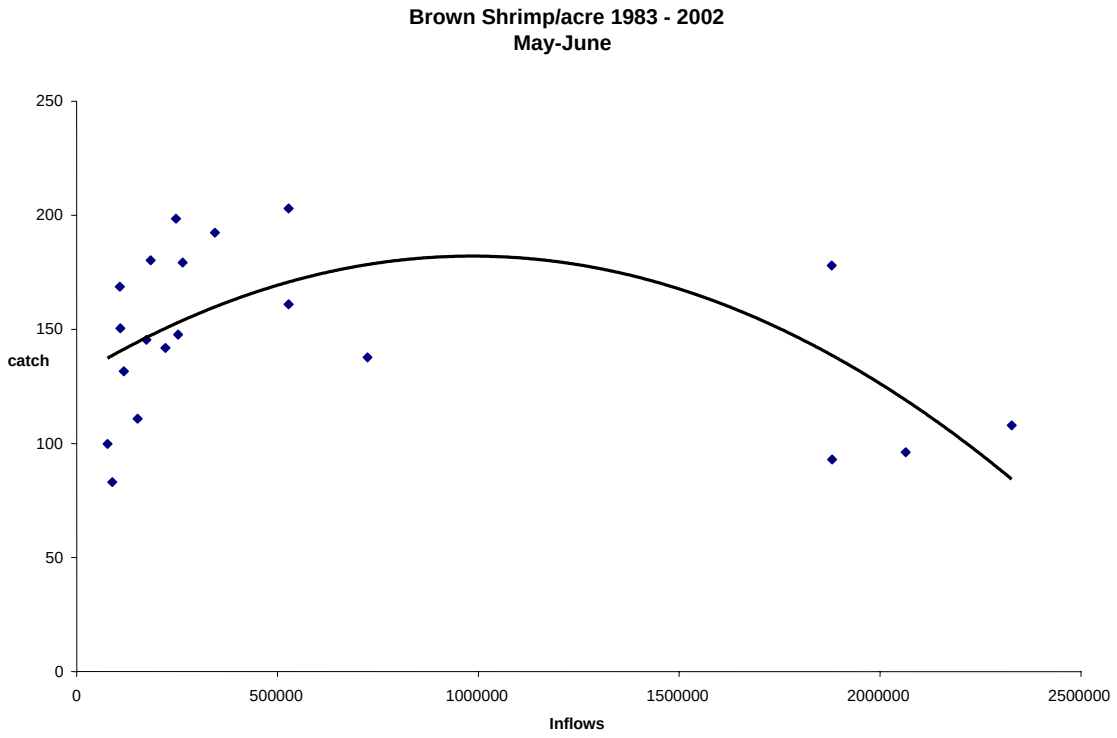


Figure 3.14 Annual Brown Shrimp Density (individuals/acre) to May-June Inflows.

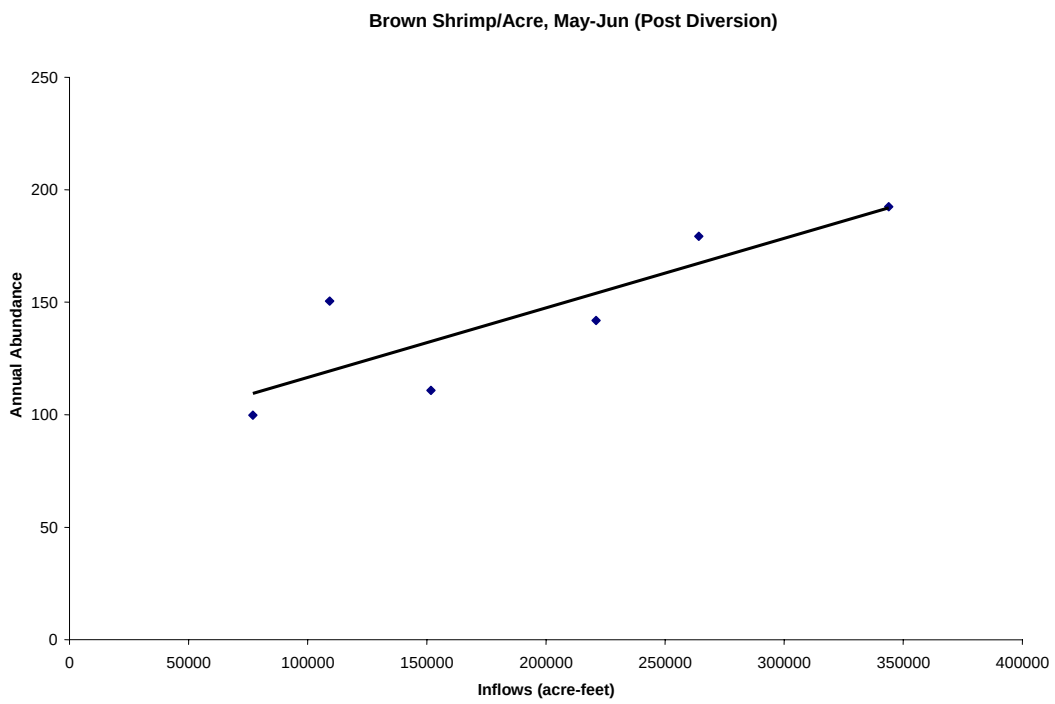


Figure 3.15 Relationship between Annual Brown Shrimp Abundance and May-June Inflows.

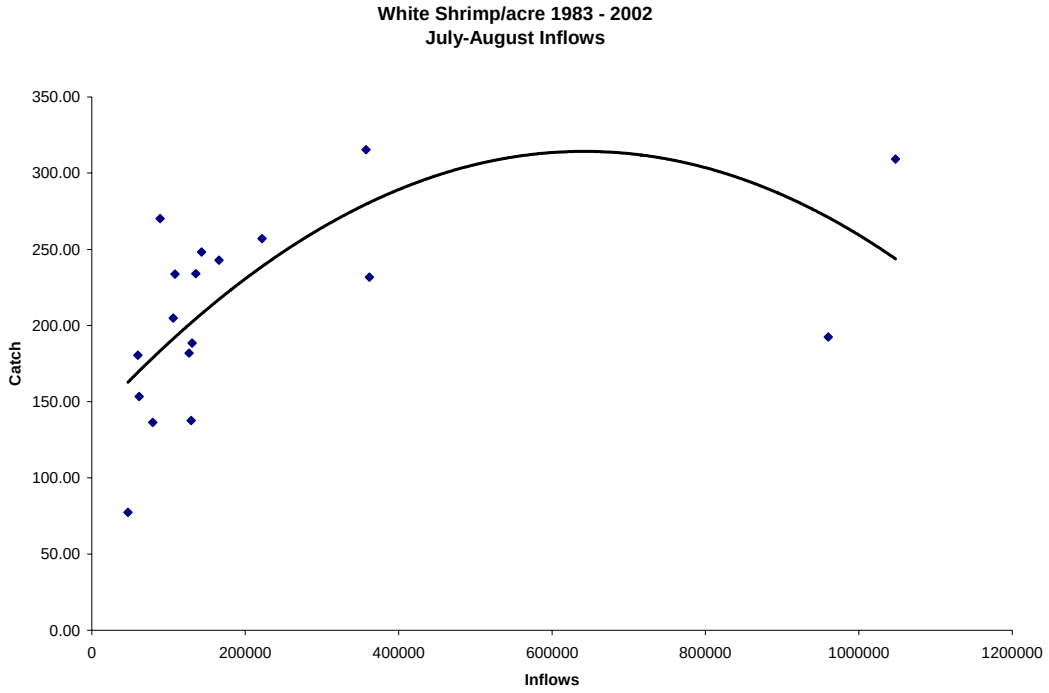


Figure 3.16 Annual White Shrimp Density (individual/acre) to July-August Inflows.

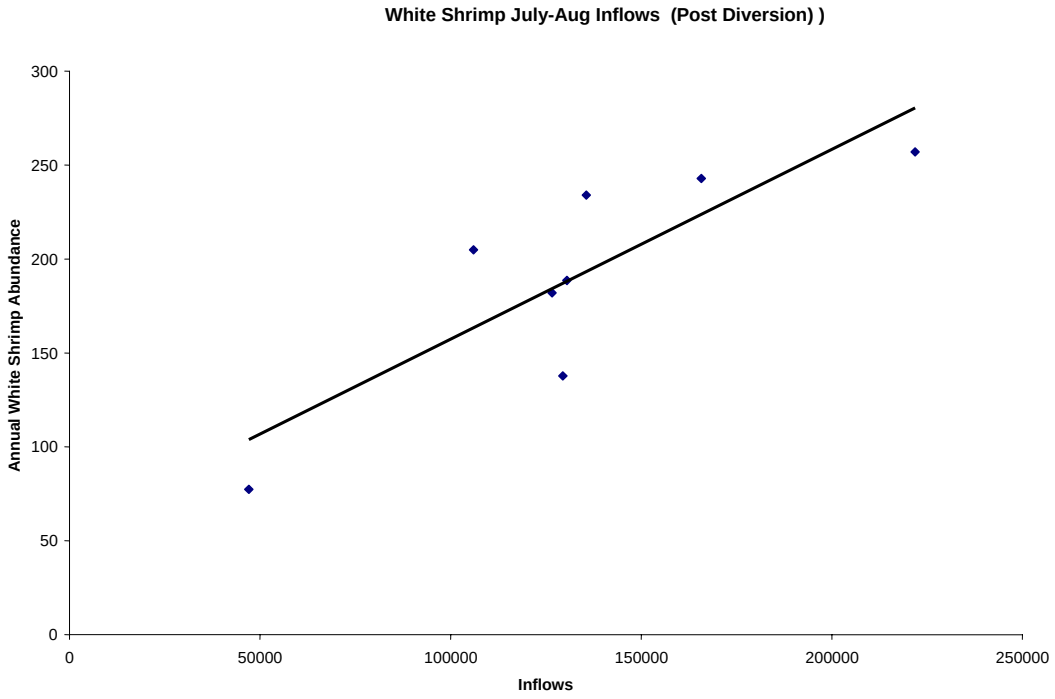


Figure 3.17 Relationship between Annual White Shrimp Abundance and July-August Inflows.

The statistical equations indicate a relationship between freshwater inflow and juvenile abundance. Freshwater inflows are important in establishing chemical and physical conditions in the estuary needed by many estuarine organisms. Thus, the simple multiple regression models attempt to capture this fundamental relationship between freshwater inflows and productivity of key species. Since freshwater inflows are the only independent variable, other potentially important factors to productivity are excluded from the models. The health and abundance of specific organisms rely on a healthy source population, ability to enter the system, and the availability of appropriate combinations of physical and chemical conditions and food resources (Ward, 1999). Thus, many factors unrelated to freshwater inflow affect abundance.

CHAPTER 4

Matagorda Bay Salinity

4.1 Introduction

The biological productivity of Matagorda Bay depends in part on maintenance of a salinity gradient between fresh and marine waters. This gradient is preserved by maintaining appropriate quantities of freshwater inflows (Longley, ed., 1994). Fortunately, a significant amount of salinity monitoring and historical data over much of Matagorda Bay is available. This data was used to derive relationships between salinity to changes in freshwater inflows from the Colorado and Lavaca rivers. These relationships are to be used for several aspects of this study, including the support and calibration of the TXEMP model and computation of the minimum flows needed to maintain critical salinity levels at select locations within the bay. Relationships for use in TXEMP are described in Chapter 5 and relationships for evaluating critical salinities are described in Chapter 6. This chapter describes the data sources and general characterization of salinity within Matagorda Bay.

4.2 Need to Update Salinity-Inflow Relationships

Salinity data used in the prior FINS study (LCRA, 1997) was limited to only five years following the Corps of Engineers diversion project. That leaves insufficient data to predict a relationship between salinity and bay health. Discrepancies were observed between the levels of salinity that had been predicted and what was observed at the West Bay Tripod in the eastern arm of Matagorda Bay during the drought in the summer of 2000. This led to a review of the relationships developed in the prior study. Data collection also has improved in recent years and now provides significantly more data with fewer gaps. The purpose of updating these equations is to develop relationships with fewer predictive errors.

4.3 Salinity Data

Salinity data in Matagorda Bay is collected by LCRA, TWDB and Texas Parks and Wildlife Department (TPWD) Coastal Fisheries Program. The analysis for this study primarily used the intensive site-specific data collected using automated measuring devices (datasondes) operated by TWDB in Lavaca Bay and data collected by LCRA in the eastern arm of Matagorda Bay. The datasondes operate continuously and sample hourly. Data collected by TPWD for the fisheries program began around 1976 with an increase in sampling around 1982. The data is collected from grab samples using a refractometer and is recorded to the nearest part per thousand (ppt).

4.3.1 Site-Specific Salinity Data

Site-specific salinity data is collected at three sites in Matagorda Bay. In late 1992, LCRA installed two datasondes to provide hourly measurements of salinity, dissolved oxygen, pH and other field parameters. The devices are located in Matagorda Bay (Figure 4.1), with one near the mouth of the Colorado River Diversion Channel, called West Bay Tripod (Site A), and the other on the GIWW called Channel Marker #4 (Site B). The data collected by this method is considered to be accurate to within +/- 2 ppt.

Prior to 1998, instrument malfunction and the need to temporarily relocate datasondes for other studies led to notable data gaps. However, improved maintenance and reliability of the LCRA datasondes resulted in significantly improved records after 1998. Salinity at the West Bay Tripod was recorded hourly during most of the period from 1993 through present.

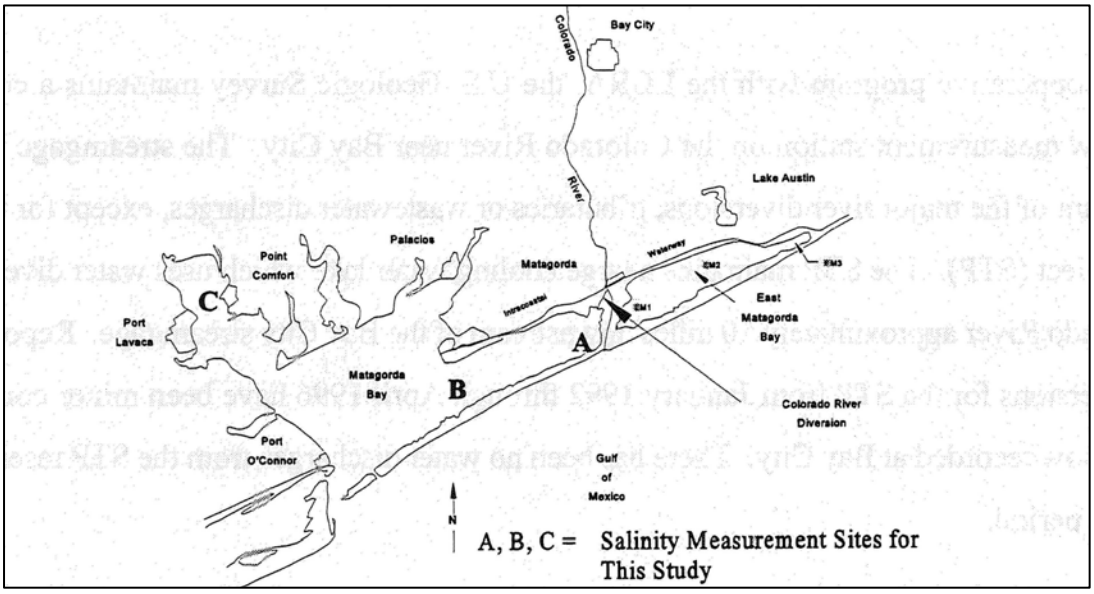


Figure 4.1 Locations of Site Specific Salinity Measurement Stations.

Beginning in 1986, TWDB installed a similar continuous monitoring station in upper Lavaca Bay (site C in Figure 4.1). This station has collected hourly measurements of field parameters, including salinity. Data from this source was used in developing relationships for Lavaca Bay.

The site specific data provides a consistent location and sampling methodology that is preferred for the development of statistical relationships to support TXEMP and critical flow conditions analysis.

Particular attention was given to the salinities in the eastern arm of Matagorda Bay as this is the area of greatest anticipated influence of the recent Corps of Engineers diversion project. Typical day to day variation in salinity at the West Bay Tripod is from 1 to 5 ppt. Salinity changes are influenced by tides, inflows, evaporation and mixing, among other factors. Figure 4.2 illustrates the frequency of positive and negative changes in salinity at the West Bay Tripod. As seen in the figure, the likelihood of salinity increase is about equal to the likelihood of a decrease. Salinity decreases more than 2.8 ppt in a day or 5.6 ppt in a week only 10 percent of the time. Conversely, about 10 percent of the time salinity increases more than 2.4 ppt in a day and 5.5 ppt in a week.

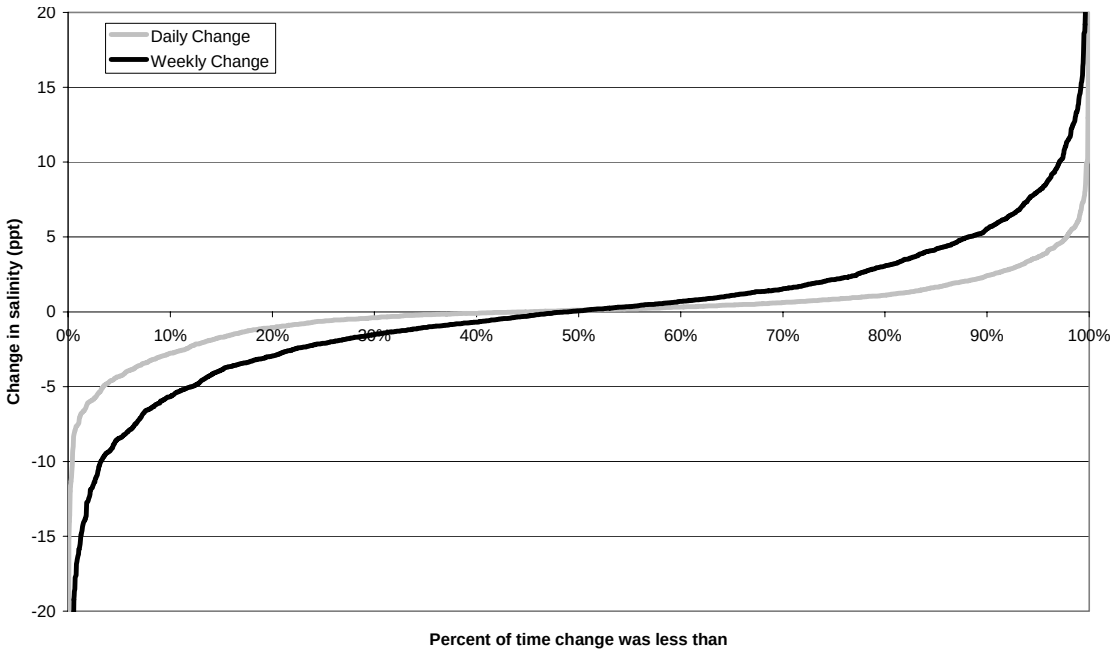


Figure 4.2 Frequency of Salinity Change at the Western Tripod 1993 to 2002.

4.3.2 Bay Wide Salinity Data

TPWD Coastal Fisheries data is useful in characterizing salinity in Matagorda Bay because of its spatial variability, good coverage and long period of record.

Spatial variation of monthly salinity averages were developed using GIS by interpolating between data observations using an inverse distance weighting (IDW) method to identify typical salinity neighborhoods and gradients.

Monthly bay-wide salinity observations are presented in Figures 4.3 through 4.14. Lower salinity is depicted in green and higher salinity is depicted in red. The clustering of low salinity readings near the mouths of major and minor tributaries is demonstrated, and the clustering of higher salinity near points of major tidal inflows is similarly identified. The variation in salinity patterns can be compared month to month. Salinity gradients for individual months may appear overly severe on a localized basis due to influence of isolated observations. Additional research into this area, such as upper and lower quartile spatial salinity gradients as well as other return periods and larger averaging areas, could also be informative.

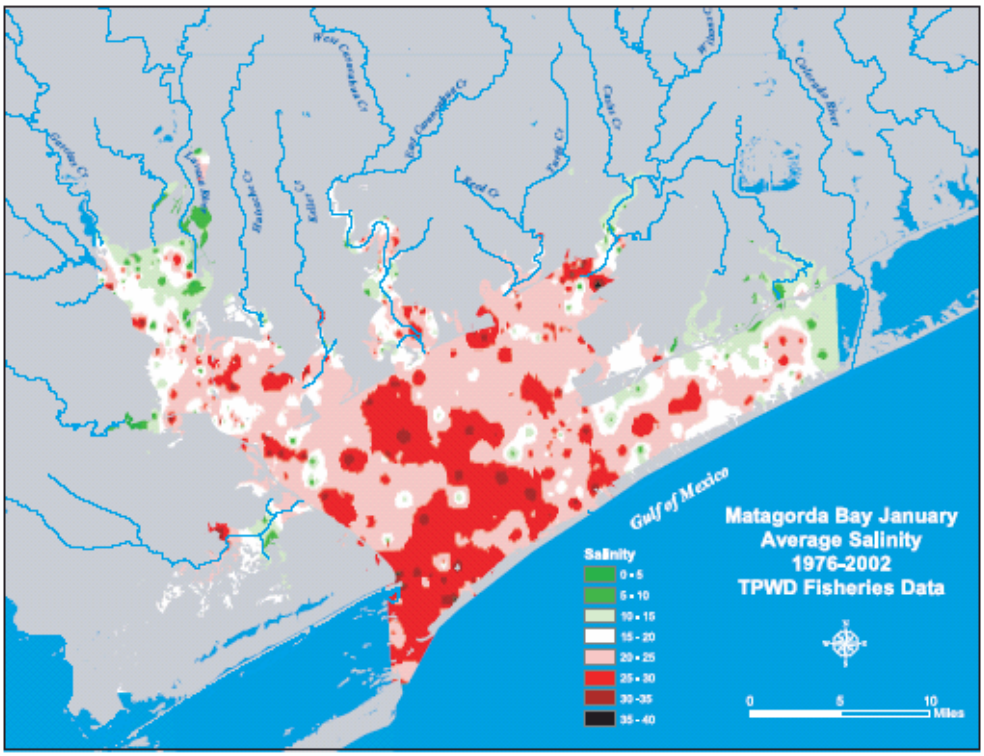


Figure 4.3 Average Salinity Zones for January.

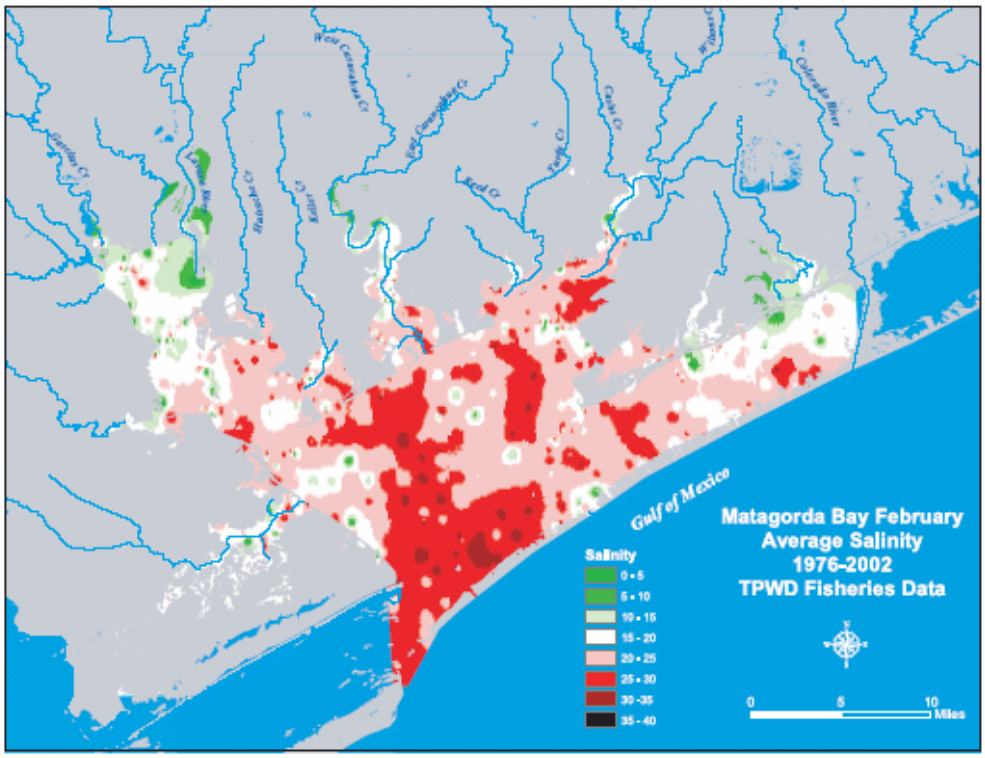


Figure 4.4 Average Salinity Zones for February.

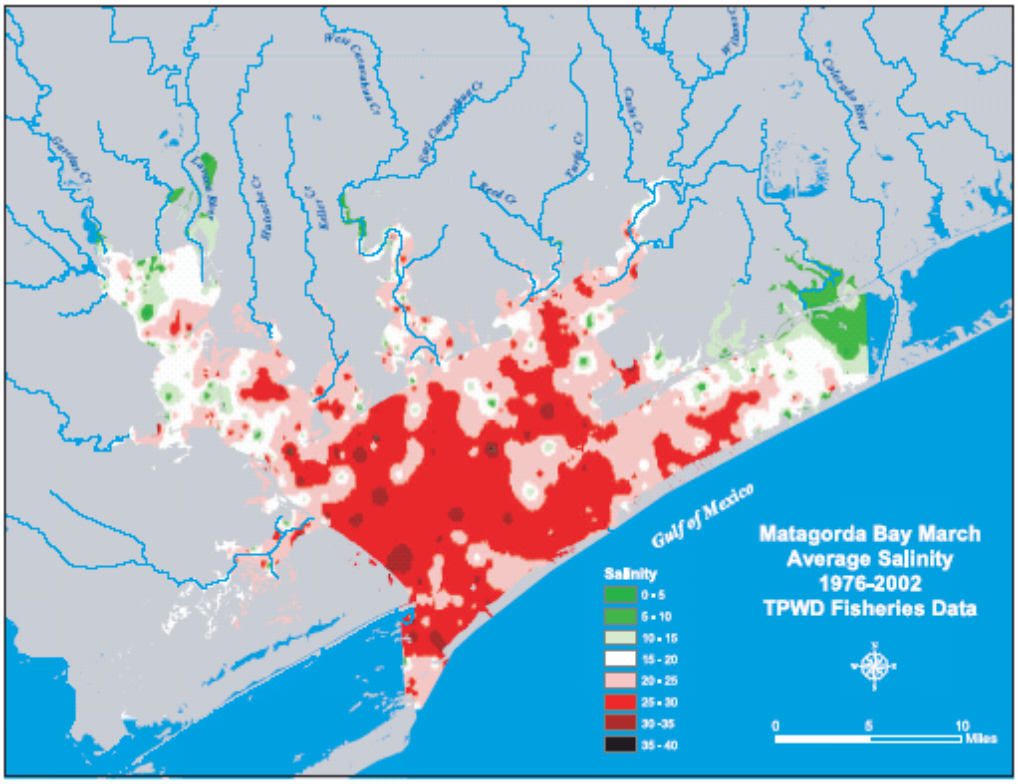


Figure 4.5 Average Salinity Zones for March.

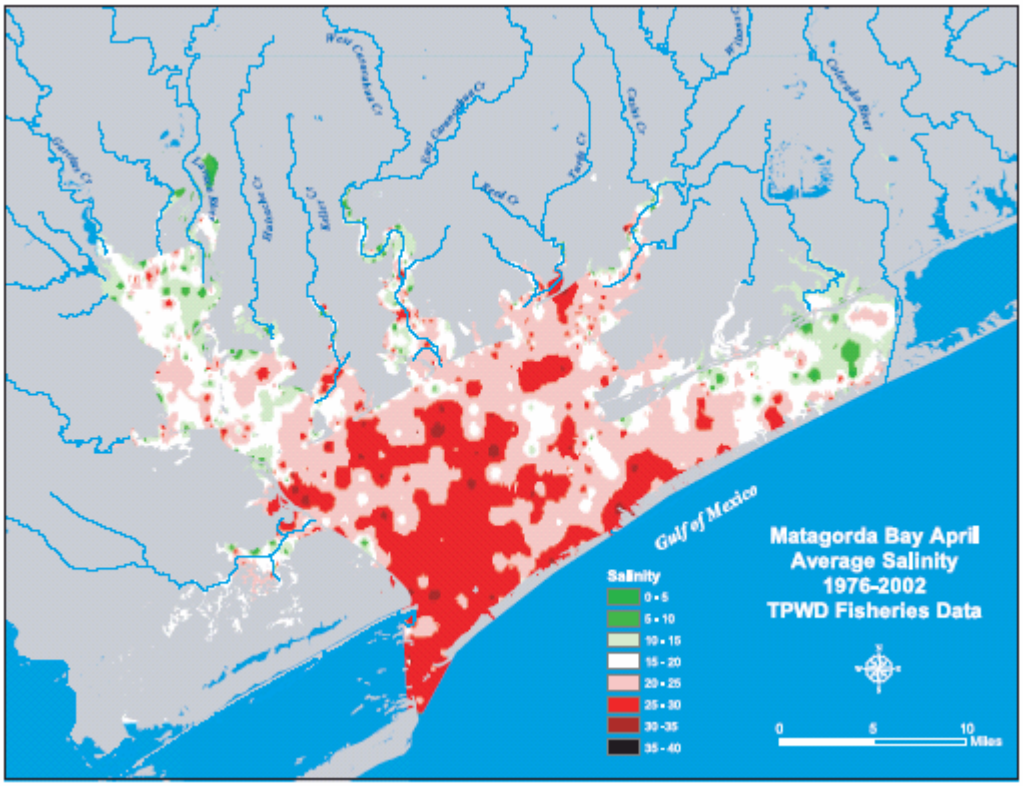


Figure 4.6 Average Salinity Zones for April.

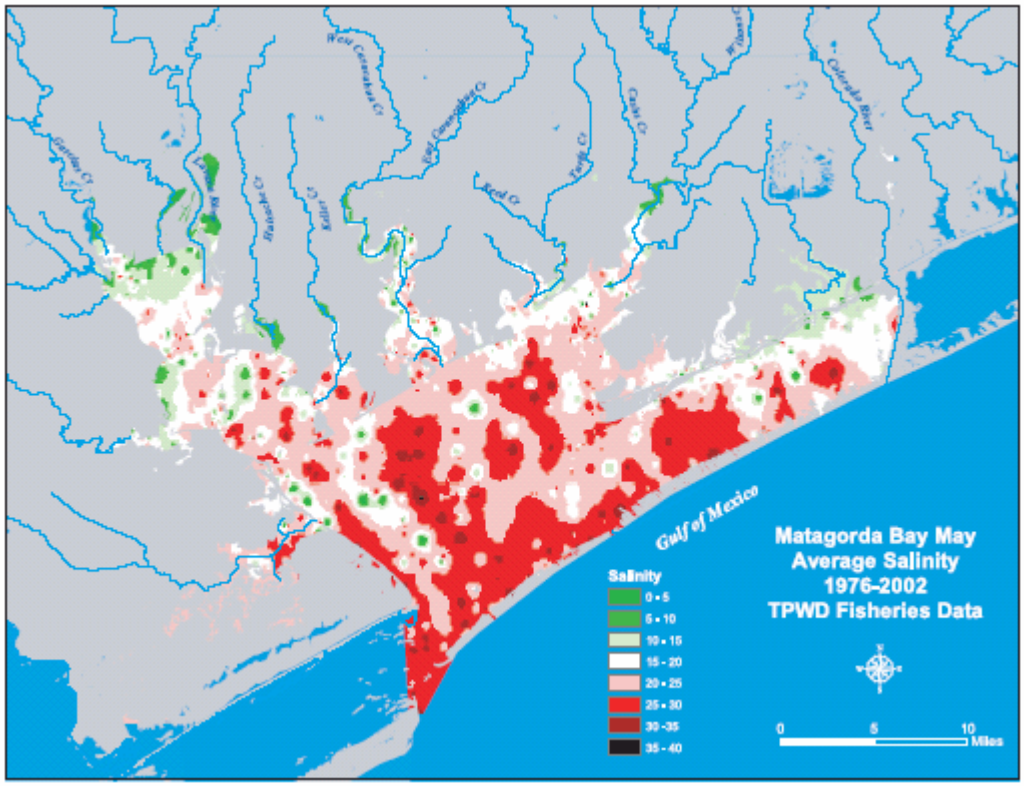


Figure 4.7 Average Salinity Zones for May.

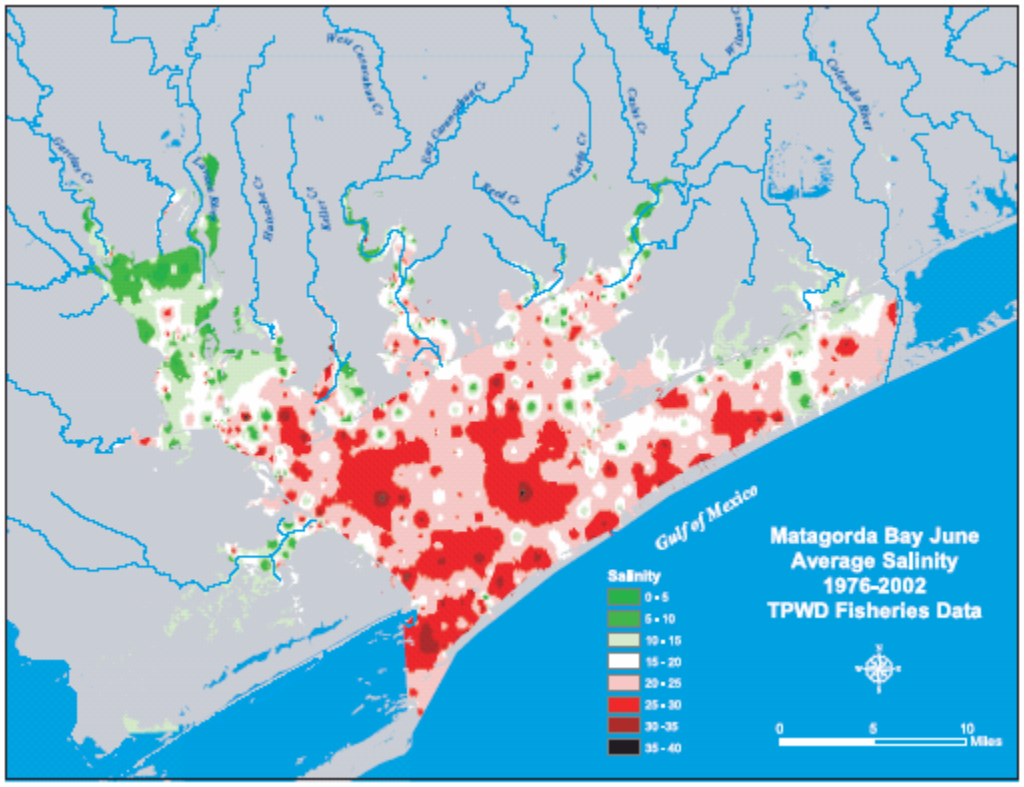


Figure 4.8 Average Salinity Zones for June.

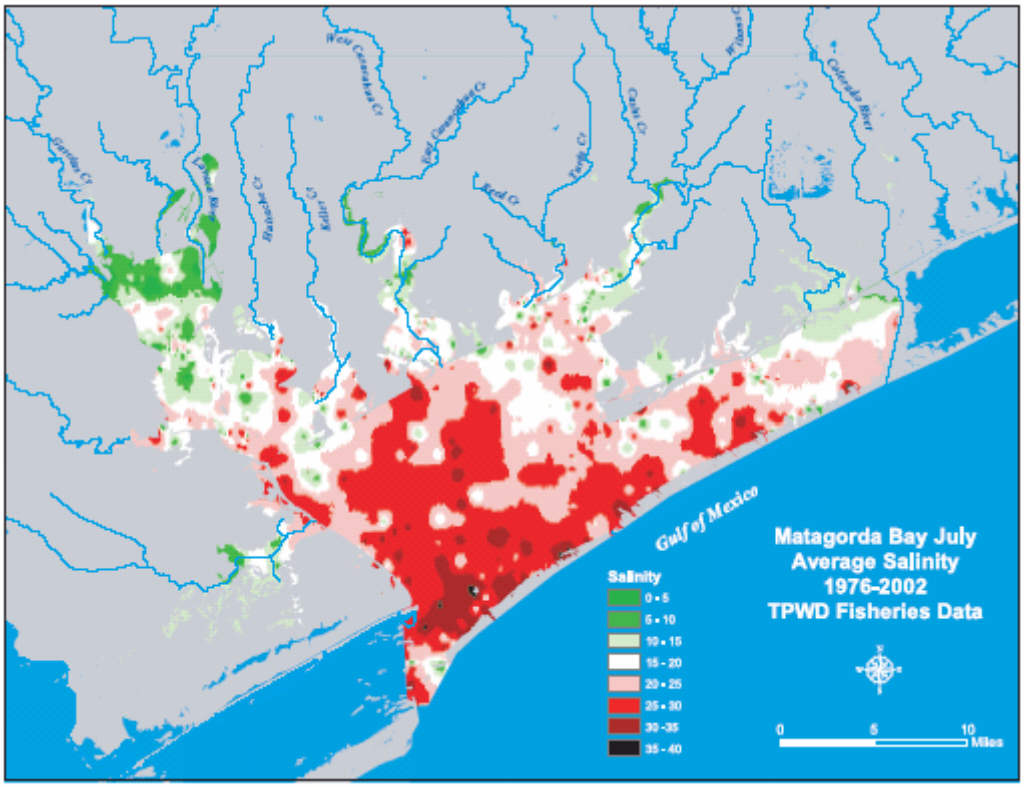


Figure 4.9 Average Salinity Zones for July.

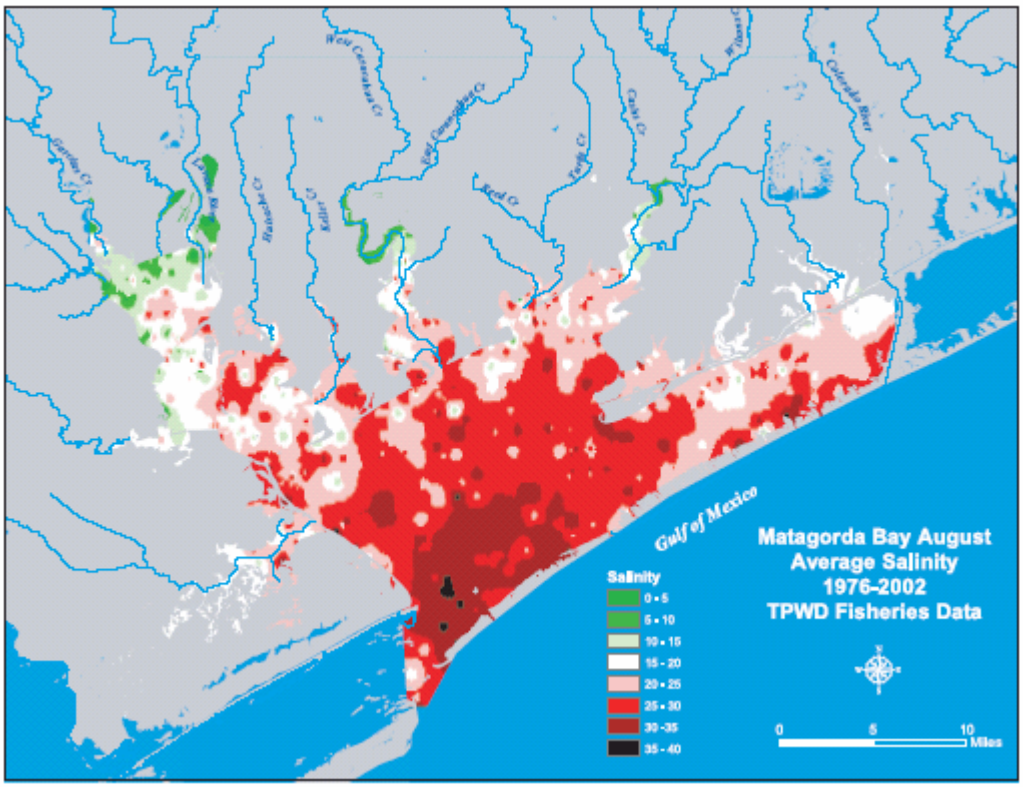


Figure 4.10 Average Salinity Zones for August.

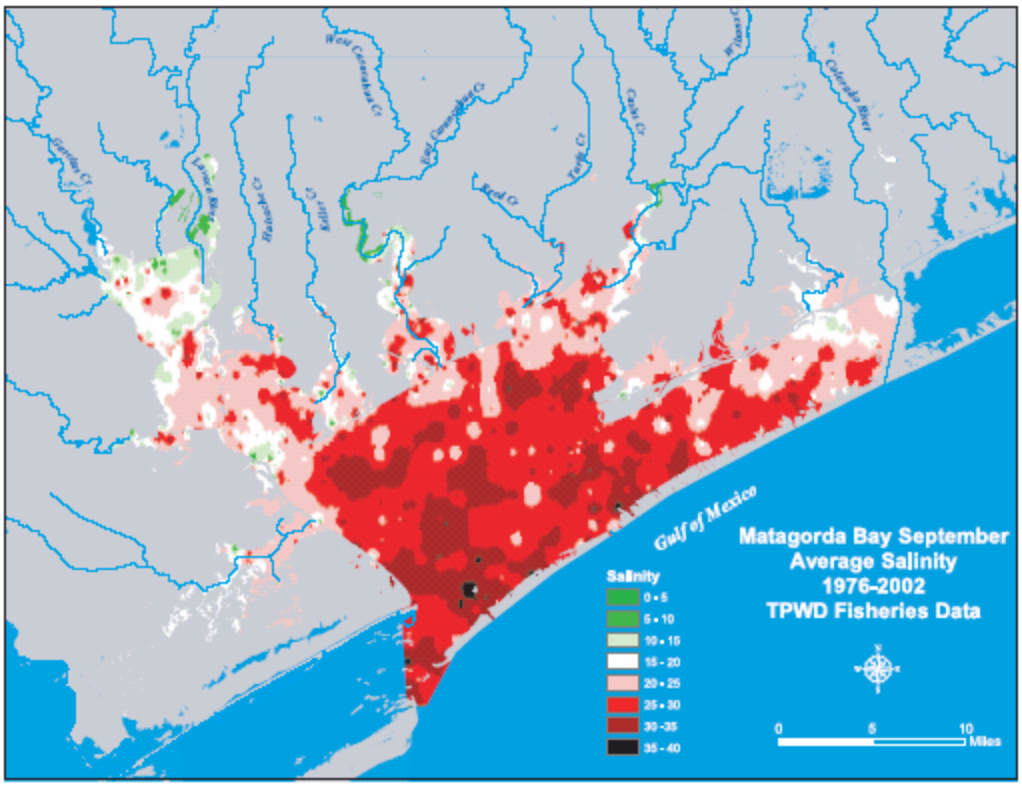


Figure 4.11 Average Salinity Zones for September.

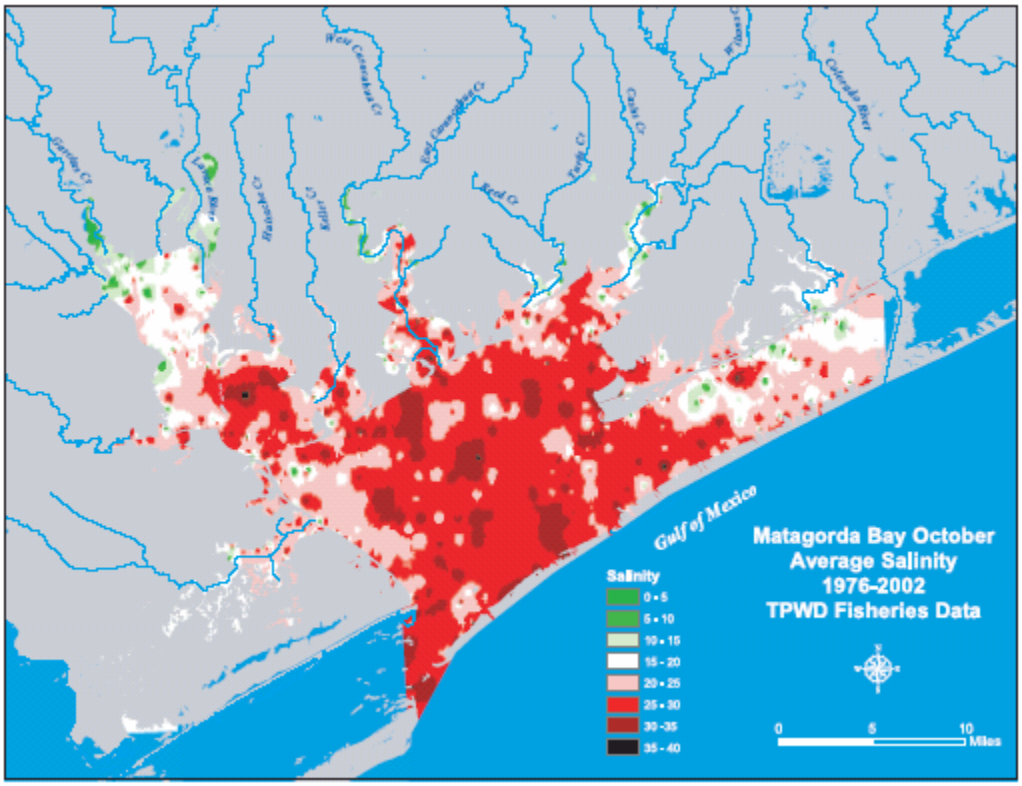


Figure 4.12 Average Salinity Zones for October.

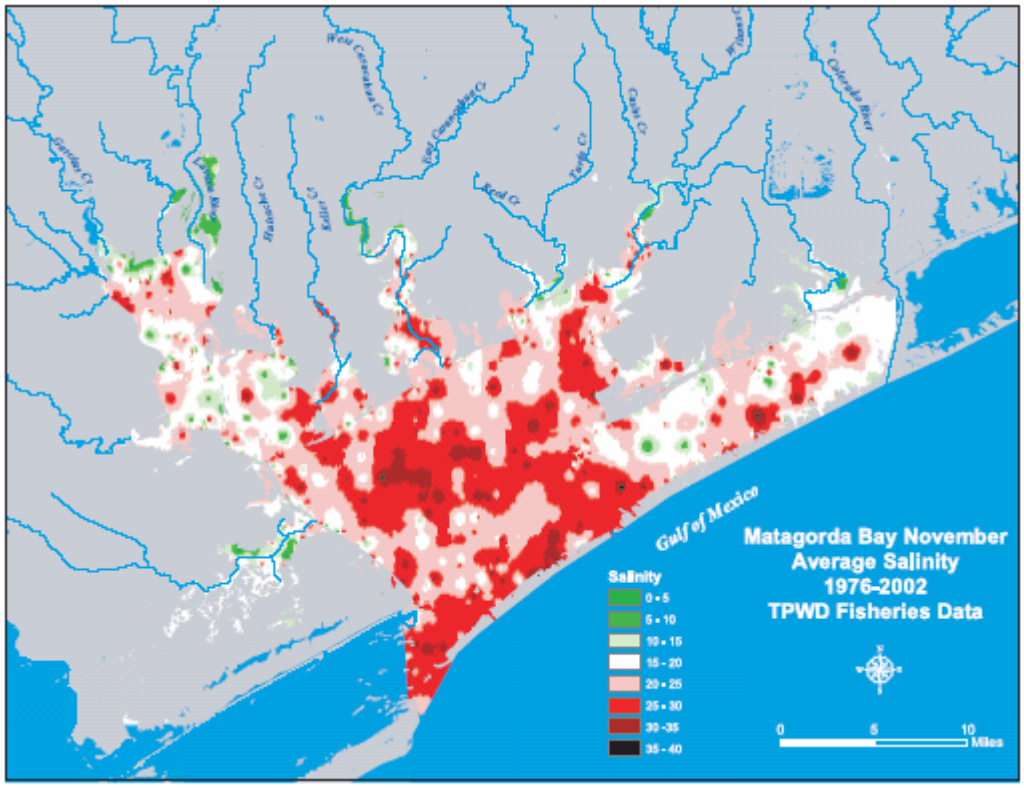


Figure 4.13 Average Salinity Zones for November.

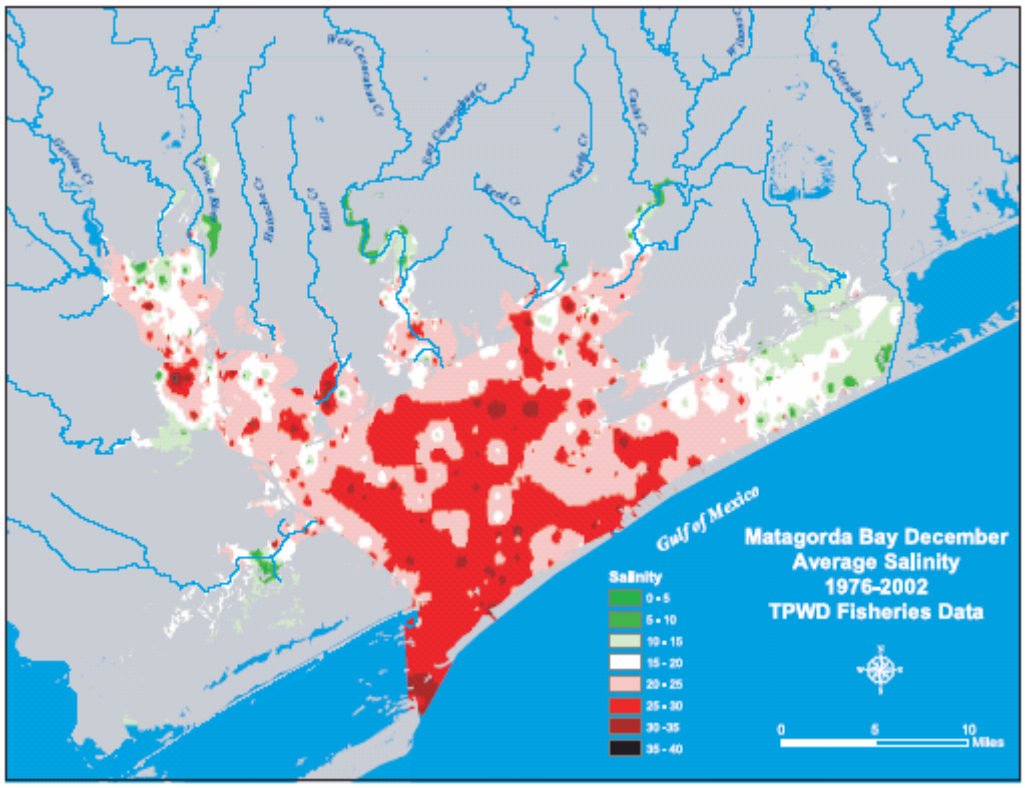


Figure 4.14 Average Salinity Zones for December.

Salinity frequencies for the secondary and tertiary bays of Matagorda Bay are depicted in Figure 4.15. Lavaca Bay is shown to be the freshest secondary bay, with the open bay and the western half of the eastern arm being the most saline.

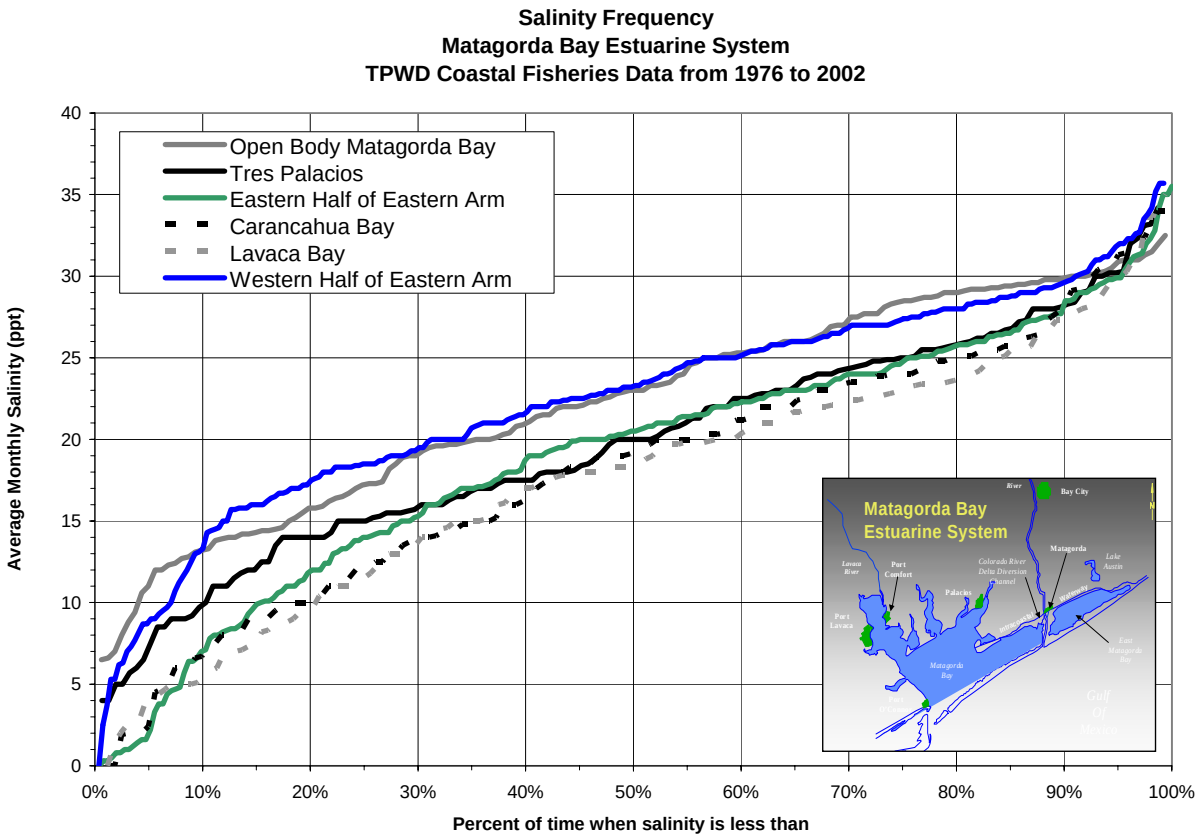


Figure 4.15 Salinity Frequencies in Matagorda Bay.

4.3.3 Matagorda Bay Eastern Arm Characterization

TPWD data was applied to evaluate salinity in the eastern arm of Matagorda Bay before and after the Mouth of the Colorado River Diversion Project. The average salinity for these periods is summarized in Table 4.1. The salinity is spatially described in four quadrants of the arm which are illustrated in Figure 4.16. Freshening of the bay after the diversion is likely due not only to the diversion but also to above normal inflows during this period, as illustrated in Figure 2.4 of the Hydrology Chapter.

Table 4.1 Average Salinity Pre- and Post-diversion in the Eastern Arm of Matagorda Bay-TPWD Coastal Fisheries Data.

Quadrant	1976 to 1990 (ppt)	1991-1998 (ppt)	Change (ppt)
Northwest	23.4	18.2	-5.3
Northeast	20.0	15.3	-4.7
Southwest	25.2	22.1	-3.1
Southeast	23.5	16.8	-6.7

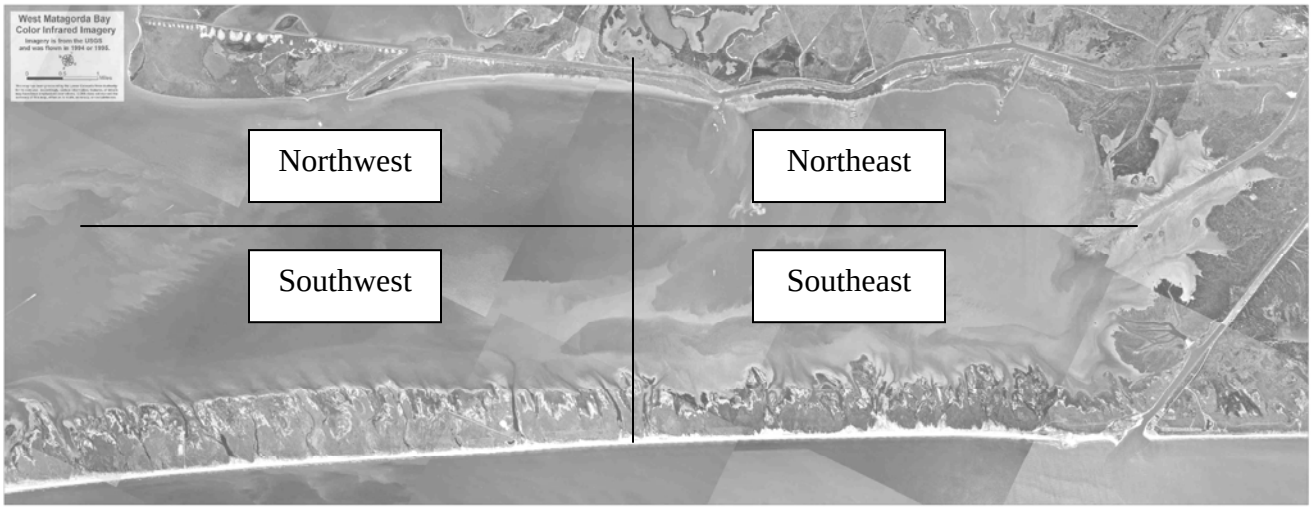
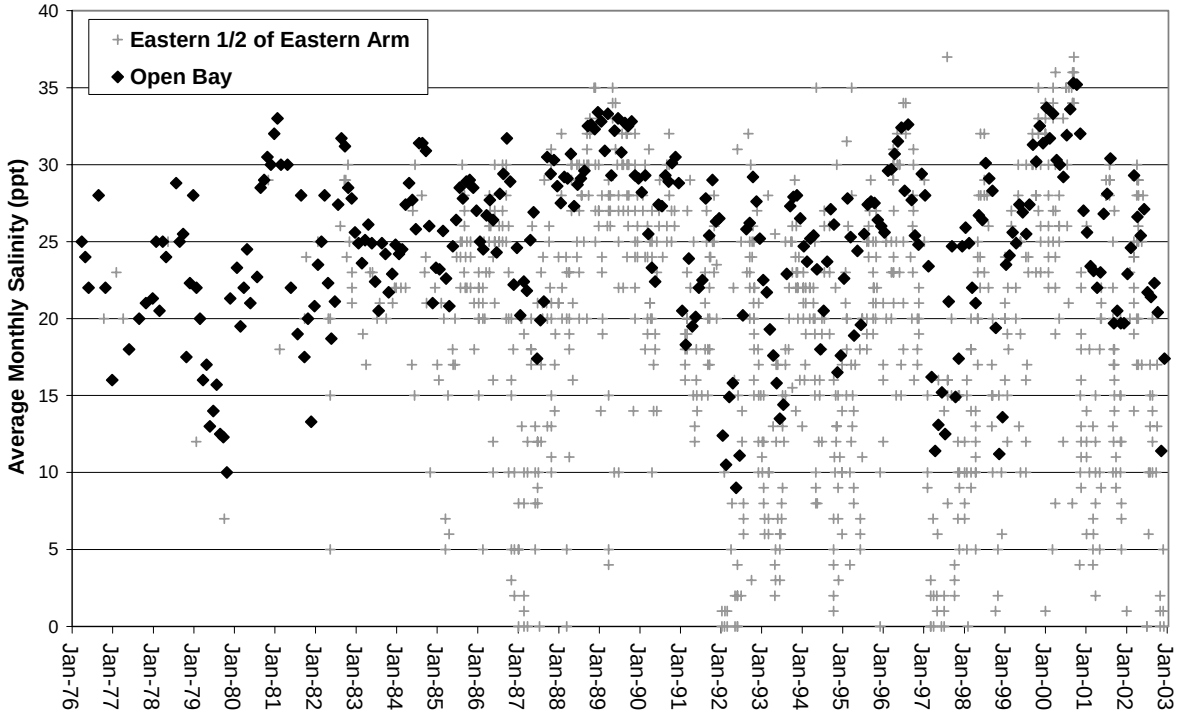


Figure 4.16 Quadrants of the Eastern Arm of Matagorda Bay.

Similarly data from the northeast and southeast quadrants were combined to examine salinities in the eastern half of the eastern arm. This area roughly approximates the region identified as a nursery and refuge during drought conditions. Salinity in this region has ranged from 0 ppt to 37 ppt over the period of March 1976 to December 2002 as shown in Figure 4.17. Summary statistics are also presented in Table 4.2.



*Diversion channel inflow to the Bay started in 1992.

Figure 4.17 Monthly Salinity in the Eastern Half of the Eastern Arm and Open Bay of Matagorda Bay - TWPD Coastal Fisheries Data.

Table 4.2 Comparison of Eastern Half of the Eastern Arm of Matagorda Bay to the Open Bay from 1976-2002.

Statistic	Open Bay Monthly Value (ppt)	Eastern ½ East Arm Monthly Value (ppt)
Mean	24.74	19.05
Standard Deviation	5.37	8.62
Median	25.40	20.00
Minimum	9.00	0.00
Maximum	35.30	37.00

CHAPTER 5

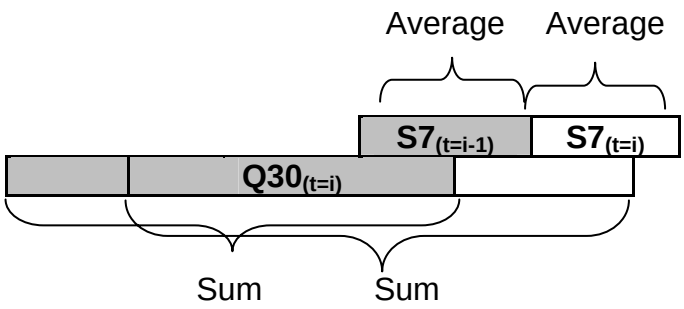
Development of Salinity Inflow Relationships for Use within TXEMP

5.1 Introduction

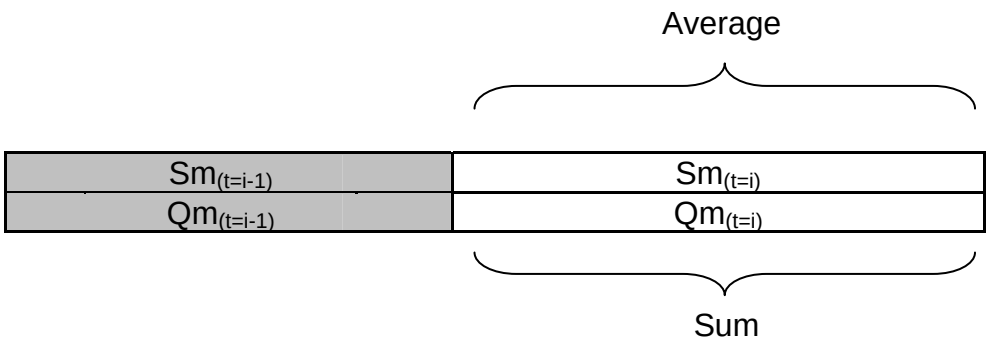
The purpose of this analysis is to determine the relationship between salinity at several locations in Matagorda Bay and changes in the freshwater inflows. Two equations are recommended, one for the West Bay Tripod related to the Colorado River inflow and one for Lavaca Bay related to the Lavaca River. These relationships are to be used within the TXEMP model for simulation of salinities at constraint locations. This analysis used salinity data presented in Chapter 4. The differences between prior study and current study results are also presented.

5.2 Methodological Differences from Prior Study

The prior study made use of a relationship between a straddled and lagged seven-day average salinity to a 30-day river flow. This strategy made effective use of limited salinity data but led to a high level of autocorrelation. It also served as a reasonable proxy for the monthly salinity and flow input requirements of TXEMP. However, with the benefit of increased monitoring intensity following the Mouth of the Colorado River Diversion Project, this proxy is no longer needed for Matagorda Bay. For purposes of this study, matched pairs of monthly average salinity and total monthly flows were used in all regression relationships. Both the 1997 and the current strategies are illustrated in Figure 5.1.



1997 Study straddled relationship



2005 Study matched pairs relationships

Figure 5.1 Development of Time Series Data Sets and Regression Equations.

5.3 Colorado River Influence at West Bay Tripod

5.3.1 Ordinary Least Squares (OLS) Regression: Monthly Salinity-Inflow Relationship

A variety of multivariate relationships were tested to discover patterns between monthly Colorado River flows passing the South Texas Project and observed mean monthly salinity at the West Bay Tripod. Seasonal, flow-range specific and salinity-range specific relationships were tested but did not perform better than a generic monthly model. This finding confirms the results of prior studies (LCRA, 1997).

A minimum threshold of 25 observations was applied for a given month before that monthly average salinity entered the model because the high quality salinity dataset was available at this location. The sample for the regression analysis consisted of 62 monthly average observations. Although the salinity data collected at West Tripod Bay started in 1992, instrument malfunction led to notable data gaps up to 1998. In all instances, a natural logarithmic transformation of the flow variables significantly improved the predictive equations results. The best fit equation is a multivariate equation of the form given by Equation 5.1 and includes the freshwater inflows for the current month and the two prior months.

Equation 5.1 Monthly Salinity-Inflow OLS Relationship for West Bay Tripod

$$SM_i = 106.62 - 4.13 \times LN(QM_i) - 2.05 \times LN(QM_{i-1)}) - 1.53 \times LN(QM_{i-2)})$$

where: i = month
Qm_i = Total Monthly Flow past STP for month i (acre-feet)
Sm_i = Average Monthly Salinity at West Bay Tripod for month i (ppt)

Solving Equation 5.1 for flow in 1,000 acre-feet for use in TXEMP gives:

$$Sm_i = 53.37 - 4.13 \times LN(Qm_i / 1000) - 2.05 \times LN(Qm_{i-1} / 1000) - 1.53 \times LN(Qm_{i-2} / 1000)$$

The relationship suggests an adjusted R-square value of 78 percent and a standard error of 3.53 parts per thousand of salinity (ppt). Each of the independent variables is significant at the 95 percent confidence level. However, the relationship has a Durbin-Watson statistic of 1.45, which indicates some serial autocorrelation but is within the 1.3 to 2.7 range of acceptability (Hilton, 2004). Full regression results are provided in Appendix D. The presence of autocorrelation reduces the statistical inference and confidence in these traditional measures of fit.

5.3.2 Advanced Regression Techniques: Monthly Salinity-Inflow Relationship

The presence of autocorrelation in the residuals has been largely ignored in fields other than econometrics (Thejll, 2003). However, there was interest for the purpose of this study to investigate how the salinity relationship could be improved by better understanding the nature of the autocorrelation and possibly removing its influence.

The Durbin-Watson statistic of 1.45 revealed the presence of some autocorrelation, which was anticipated for time series data. Multi-lagged autocorrelation analyses revealed that the nature of the serial autocorrelation was greater than first order but diminished significantly with sequential lags. Nielsen (2004) identifies the following implications of an ordinary least squares (OLS) relationship with autocorrelation:

> *Because of auto-correlation:*
> *1. The OLS and true regression lines may differ sharply from sample to sample depending on the initial disturbance*
> *2. MSE {mean square error} may underestimate true variance of error term, thus standard errors of estimate of the regression coefficients may also be underestimated*
>
> *In general, auto-correlation of the disturbances may have the following effects with OLS estimation:*
> *1. Estimated regression coefficients are still unbiased but no longer minimum variance*
> *2. MSE (the OLS estimate of variance) may underestimate the true variance of errors may underestimate true standard error of estimate. Thus, statistical inference using t and F tests is no longer justified*

Nielsen identifies five methods of remediation for first-order serial autocorrelation. The first is to include missing independent variables. However, this was not practical for application with TXEMP. The four remaining methods are the Cochrane-Orcutt (C-O), the Hildreth-Lu (H-L), the first differences and regression model with autocorrelated errors. The C-O, H-L and the first differences approaches involve transformation of the current observation with the help of previous observation. These methods are reasonably tolerant to missing data. Finally, the regression with an explicit model for the error term is good for a dataset with minimal missing values so that the error term can be sufficiently characterized.

The first approach was not feasible for use in TXEMP but is employed for Critical Flow analyses of Chapter 9. The C-O and H-L transforming methods were also attempted. They showed that a first order autocorrelation correction was sufficient to remove undesirable effects of autocorrelation and that the autocorrelation was most problematic due to the salinity term and not

the flow terms. Unfortunately, because application of these other methods requires use of prior period terms or errors, they were not useful for developing TXEMP compatible equations.

The final method investigated was regression with an explicit error model developed using the maximum likelihood estimate method. This method also requires the use of prior period terms and is similarly not useful for developing TXEMP equations but it was pursued to identify the potential error of not accounting for serial correlation.

A select portion of the dataset was chosen for the analysis to minimize missing values. This period was found from September 1999 to March 2004 for the West Bay Tripod salinity dataset.

Equation 5.2 Monthly Salinity-Inflow Regression with Error Model for West Bay Tripod

$$Sm_i = 108.93 - 3.84 \times LN(Qm_i) - 2.66 \times LN(Qm_{i-1}) - 1.34 \times LN(Qm_{i-2}) + 0.44 \times \varepsilon_{i-1}$$

where: i = month
Qm_i = Total Monthly Flow past STP for month i (acre-feet)
Sm_i = Average Monthly Salinity at West Bay Tripod for month i (ppt)
$\acute{\varepsilon}_{i-1}$ = error in salinity prediction for month i-1 (ppt)

Solving equation 5.2 for flow in 1,000 acre-feet for use in TXEMP gives:

$$Sm_i = 54.76 - 3.84 \times LN(Qm_i / 1000) - 2.66 \times LN(Qm_{i-1} / 1000) - 1.34 \times LN(Qm_{i-2} / 1000) + 0.44 \times \varepsilon_{i-1}$$

This model provided an adjusted R-square of 84.5 percent and a standard error of 3.05 ppt (Equation 5.2). The Durbin-Watson for the relationship with error correction improved to nearly 2.14, which is nearly free of autocorrelation. Each of the constant and the independent variables were significant at the 95 percent confidence level.

From this effort it has been learned that:

- First order error correction methods are likely sufficient remediation for autocorrelation at the West Bay Tripod,
- Three independent flow terms are statistically significant for the West Bay Tripod,
- The standard error may be reduced by as much as 0.50 ppt with the use of error corrections, and

- Modification of TXEMP so that it could utilize a prior period salinity could enable the C-O method, which should effectively eliminate any impact of serial autocorrelation and slightly improve predictive ability.

The OLS relationship and the OLS with error correction relationships are compared for the period of 1993 to 2003 against the 1997 relationship in Figure 5.2. Computation of salinity using the regression with error term is limited by lack of continuous data and therefore the line appears broken. The figure shows that both equations perform better than the 1997 relationship. When it can be applied (data is sufficient to compute prior month prediction error), Equation 5.2 appears to outperform the 5.1, particularly during the 2000 drought. However, the mean difference is less than 1.3 ppt. The estimated instrument error of salinity measurement is 2 ppt so there is not a significant loss in proceeding with the OLS model.

Figure 5.2 also shows that the predictive accuracy is not uniform. The error tends to be larger at high and low salinities. This suggests that the relationship may not be linear in the lower range or that important independent variables have not been captured in this analysis. However, for the purposes of this study the accuracy at extreme salinities is of less importance. Future studies may be able to develop nonlinear relationships with an improved error profile over a larger range of salinity that can still support TXEMP.

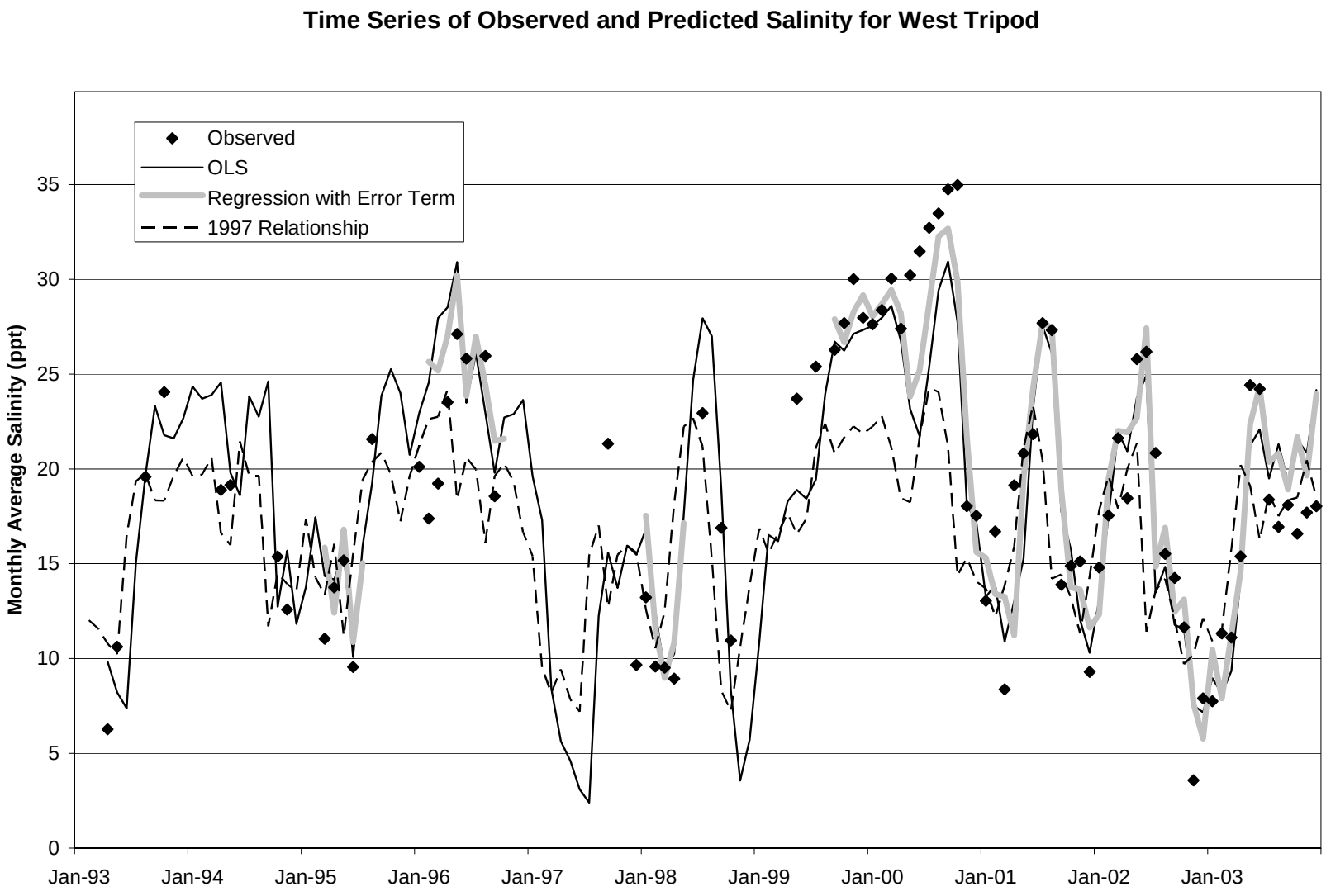


Figure 5.2 Observed and Predicted Salinity for Eastern Matagorda Bay near Mouth of Colorado River (West Bay Tripod) Using Three Models.

5.4 Lavaca River Influence on Estuarine Salinity at Lavaca Bay

5.4.1 Ordinary Least Squares (OLS) Regression: Monthly Salinity-Inflow Relationship

A variety of nonlinear relationships were tested to discover patterns between cumulative monthly inflows (Qm) and observed mean monthly salinity (Sm). Factors other than flow were not investigated for use in TXEMP due to requirements of the model. Both Ordinary Least Squares (OLS) regression and more advanced statistical techniques were employed. A variety of multivariate relationships were tested to discover patterns between monthly Lavaca flows and observed mean monthly salinity (ppt) in Lavaca Bay. A minimum of 25 daily observations was applied before a monthly average salinity entered the model. The sample for the regression analysis consisted of 125 average monthly observations that met this criterion. In all instances, a natural logarithmic transformation of the flow variables significantly improved the predictive equation's results.

The best fit equation is a multivariate equation of the form given by Equation 5.3 and includes a term for freshwater inflows for the current month and the three prior months.

Equation 5.3 Monthly Salinity-Inflow OLS Relationship for Lavaca Bay

$$Sm_i = 64.77 - 1.74 \times LN(Qm_i) - 1.77 \times LN(Qm_{i-1}) - 0.64 \times LN(Qm_{i-2}) - 0.77 \times LN(Qm_{i-3})$$

where: i = month
Qm_i = Total Monthly Flow Discharging from Lake Texana for month i (acre-feet)
Sm_i = Average Monthly Salinity at Lavaca Bay for month i (ppt)

Solving Equation 5.3 for flow in 1,000 acre-feet for use in TXEMP gives:

$$Sm_i = 30.78 - 1.74 \times LN(Qm_i / 1000) - 1.77 \times LN(Qm_{i-1} / 1000) - 0.64 \times LN(Qm_{i-2} / 1000) - 0.77 \times LN(Qm_{i-3})$$

The relationship suggests an adjusted R-square of 72 percent and a standard error of 4.02 ppt of salinity. Each of the constant and independent variables is significant at the 95 percent confidence level. However, the relationship has a Durbin-Watson statistic of 1.33, which indicates some autocorrelation but is within the acceptable range of 1.3 to 2.7 (Hilton, 2004).

Full regression results are provided in Appendix D. The presence of autocorrelation reduced confidence in these traditional measures of fit, but the performance of the relationship as seen in Figure 5.3 suggests it is acceptable for use in TXEMP.

5.4.2 Advanced Regression Techniques: Monthly Salinity-Inflow Relationship

The Durbin-Watson statistic of 1.33 revealed the presence of some autocorrelation, which was anticipated for time series data. Multi-lagged autocorrelation analyses revealed that the nature of the serial autocorrelation was greater than first order but diminished significantly with sequential lags. Refer to Section 5.2.2 for discussion of the implications of serial autocorrelation and its potential treatment.

Cochrane-Orcutt (C-O), the Hildreth-Lu (H-L) and regression with explicit error term models were all developed for this site and each was sufficient remediation for first order autocorrelation. Only the regression with error and explicit error models using the maximum likelihood method is presented. This was performed for a select portion of the dataset to minimize missing values. More gaps are found in salinity data for Lavaca Bay than for the West Bay Tripod, therefore, determination of an error correction term was more difficult. Even after relaxing the data quality to only 15 daily observations per month, only 22 continuous monthly observations could be obtained. Instead, a reasonably continuous period with only short periods of missing data from January 1992 to October 2000 was chosen and missing observations were ignored. Since autocorrelation of the errors exceeds the first order, this technique may have some merit. The regression model with error correction is shown in Equation 5.4.

Equation 5.4 Monthly Salinity-Inflow by Regression with Error model for Lavaca Bay

$$Sm_i = 67.11 - 1.69 \times LN(Qm_i) - 2.02 \times LN(Qm_{i-1}) - 0.83 \times LN(Qm_{i-2}) - 0.59 \times LN(Qm_{i-3}) + 0.49\varepsilon_{i-1}$$

where: i = month
Qm_i = Total Monthly Flow past Lavaca Reservoir in month i (acre-feet)
Sm_i = Average Monthly Salinity for month i at Lavaca Bay (ppt)
$\acute{\varepsilon}_{i-1}$ = error salinity prediction for month i-1 (ppt)

Solving Equation 5.4 for flow in 1,000 acre feet for use in TXEMP gives:

$$Sm_i = 31.66 - 1.69 \times LN(Qm_i / 1000) - 2.02 \times LN(Qm_{i-1} / 1000) - 0.83 \times LN(Qm_{i-2} / 1000)$$
$$- 0.59 \times LN(Qm_{i-3} / 1000) + 0.44 \times \varepsilon_{i-1}$$

This model provided an adjusted R-square value of 85 percent and a standard error of 3.19 ppt. The Durbin-Watson for the relationship with error correction improved to nearly 2.04, which indicates that the residuals are free of auto-correlation. The constant and each of the independent variables were significant at the 95 percent confidence level. Detailed statistical analysis is included in the appendix.

From this effort it has been learned that:

- Error correction methods are likely sufficient remediation for first order autocorrelation at the Lavaca Bay site;
- Four independent flow terms are statistically significant for the Lavaca Bay site; and
- The standard error may be reduced with the use of error corrections

Equation 5.3 and 5.4 are compared for the period of 1987 to 2003 against the 1997 equation in Figure 5.3. It shows very little difference in performance between the 1997 relationship and either of the newer equations. For consistency Equation 5.3 will be used in further efforts of this investigation.

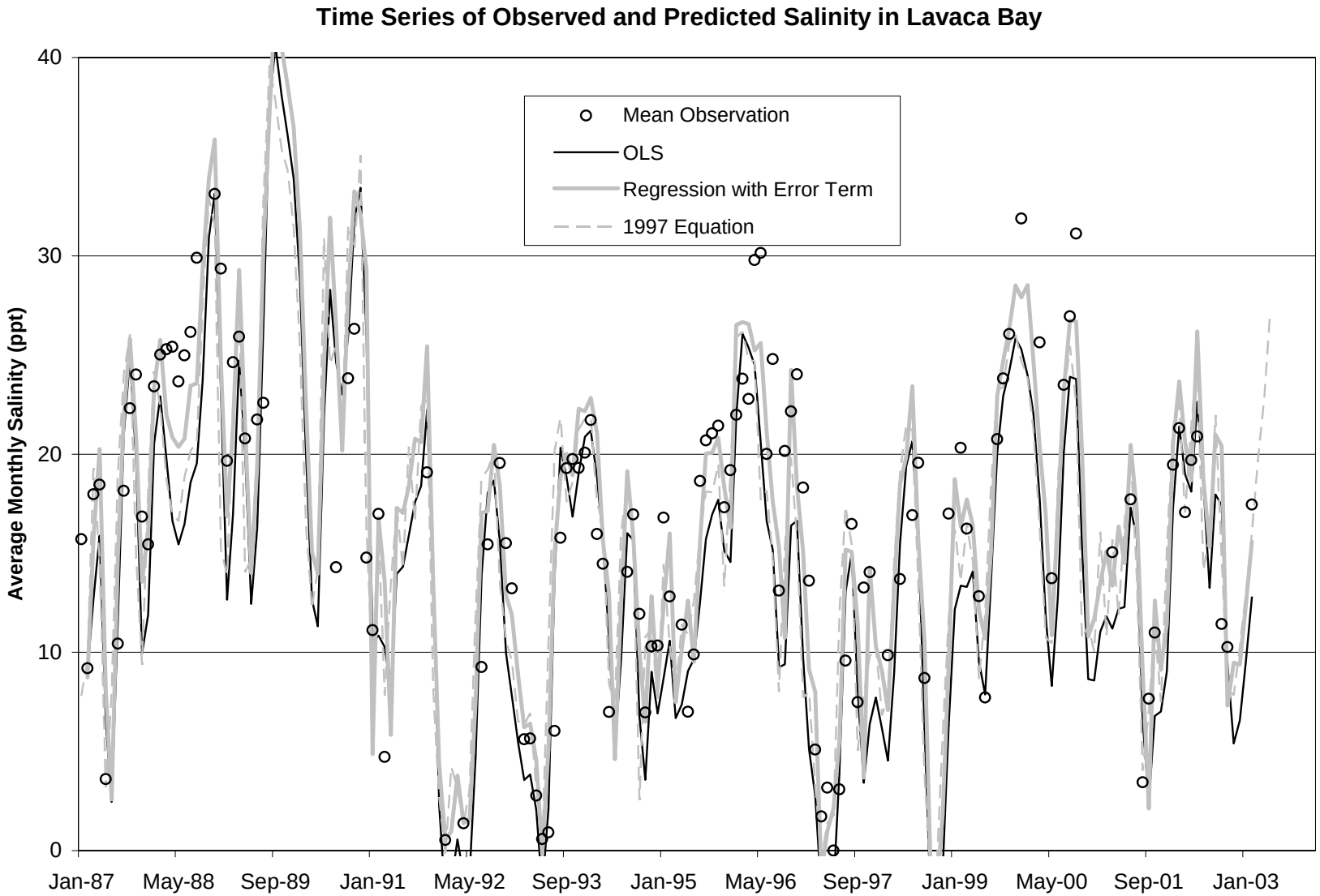


Figure 5.3 Observed and Predicted Salinity for Lavaca Bay Using Three Models.

The OLS relationship and the OLS with error correction relationships are compared for the period of 1993 to 2003 in Figure 5.3. Computation of salinity using the regression with error term is limited by lack of continuous data and therefore the line appears broken. When sufficient data exists to employ the regression with error term, it appears to be a slightly better predictor than the OLS. However, the mean difference is less than 2 ppt, which is the limit of the data collection methods so there is not significant loss in proceeding with the OLS model.

5.5 Conclusions

5.5.1 Mathematical Relationships for Use in TXEMP

For the West Bay Tripod site, the autocorrelation of the first order residuals was found to be present but not extreme. Time series prediction plots reveal notable improvement for the eastern arm to slight improvement in Lavaca Bay of the ordinary least squares models developed in this investigation over those developed in the prior study. However, in spite of the minor improvement offered by the error term models and that tests demonstrate some autocorrelation, it is recommended that the ordinary least squares models (Equations 5.1 and 5.3) be applied in TXEMP to determining salinity from inflows. This recommendation is due primarily to the fact that TXEMP does not currently have the capability to handle the prior period terms. Additionally, correction for autocorrelation appears to lead to only marginal improvement in the model's performance which did not justify major modifications to the TXEMP code at this time.

The number of months for which flow was a statistically significant independent variable differed among the regression relationships. The Lavaca Bay regression included four periods and the West Bay Tripod included three. The number of months or periods may also be influenced by the bay residence time and by physical access of ocean water to the site. Residence time of fresh water in the bay zones is related to the bay volume/inflow ratio. Lavaca Bay, with its shallow depths and small volume, has a smaller residence time than the West Bay Tripod. It is also less physically accessible to ocean inflows than the other site. Large freshening events would tend to linger for longer periods of time in Lavaca Bay due to these two factors. This would in turn lead to more significant periods in the regression equation.

This investigation showed serial autocorrelation in the residuals of flow and salinity predictive relationships to be a common problem. Future development of the TXEMP method to support use of the prior month salinity prediction could enable use of first order correction methods such as the Cochrane-Orcutt or similar, which would effectively eliminate influences of autocorrelation. However, for practical purposes, the first order autocorrelation does not seem to be problematic for the locations investigated in this study. Sensitivity analysis of the model to the less than 2 ppt improvement in relationships could indicate if this improvement is worthwhile.

CHAPTER 6

Nutrient Requirements of Matagorda Bay

6.1 Introduction

The nutrient income to Texas estuaries has become an important part of the freshwater inflow needs debate. Nutrients include nitrogen, phosphorous and organic matter and are a basic food source for many organisms that are critical to overall bay health and productivity. These nutrients are fed into the bay and estuary with the freshwater inflows. A review of existing bay monitoring data confirms the expected spatial relationships and responses to changes in inflows. To ensure Texas estuaries receive nutrient loads sufficient to maintain their health and productivity, a nitrogen budget is an important yet poorly understood component of the freshwater inflow studies. Bay data collected by the University of Texas Marine Science Institute suggests that nitrogen is the nutrient that appears to be limiting in most situations. This finding is consistent with that of the 1997 FINS.

This chapter reviews the nutrient status of Matagorda Bay, the relationship of nutrients to biological productivity and nutrient delivery from freshwater inflows that may result in reasonable biological productivity. The 1997 report included an analysis of nitrogen loadings and losses combined into a nitrogen budget. However, because nutrient water quality data is extremely limited for Matagorda Bay, the contributing rivers and coastal watersheds as well as the adjacent marshes, a new nitrogen budget was not compiled as part of the current study. Instead, insights from previous efforts make up the evaluation of nitrogen dynamics observed in Matagorda Bay for this update. Currently, the Bay Health Study of the LCRA-SAWS Water Project is underway to conduct an evaluation of the impact of nutrients on the health and productivity of the Matagorda Bay System.

6.2 Productivity and Nutrients

Almost all life is supported by plants because they have the unique ability to turn energy from the sun into organic matter, which serves as food for other living organisms. In doing so, plants also produce oxygen. These plants are producing energy the rest of the ecosystem can use and therefore are called the primary producers. The energy they produce is called primary production and the rate at which they produce energy is called productivity. In an estuary, most of the primary producers are microscopic single-celled algae or phytoplankton. Phytoplankton need light and nutrients to drive primary productivity. Because phytoplankton are designed to float, they stay near the surface and receive ample sunlight. However, a lack of nutrients can be a limiting factor in their growth. Nitrogen and phosphorus are usually in the greatest demand by phytoplankton but are typically scarce in the marine environment. Dissolved inorganic nitrogen (DIN) represents the form of nitrogen most available to promote phytoplankton production. The composition of the phytoplankton community in the bay varies seasonally and, to some extent, as the salinity gradient changes. Turbidity, seasonal temperature variation and flushing rate are physical parameters that are also important in determining primary production in estuaries (Boynton et al. 1982).

6.3 Nutrient Status of Matagorda Bay

Nitrogen is often considered the controlling nutrient in estuaries (Nixon, 1983; Nixon and Pilson, 1983). Ryther and Dunstan (1971) demonstrated that additions of nitrogen stimulated growth of marine algae. Dortsch and Whitledge (1992) found that algae growth is limited when inorganic nitrogen concentrations are lower than 0.014 mg/l. Scott Nixon (1983) took results from several estuary studies and compared the inorganic nitrogen load with the amount of productivity for each system. He concluded that a pattern of increasing productivity with increasing inorganic nitrogen load exists.

Table 6.1 presents the loading of major nutrients to the Matagorda Bay system as reported in Longley (1994). Similar data are presented from Ward and Armstrong (1980) and from Gorham-Test (1997).

Table 6.1 Inputs of Major Nutrients to Matagorda Bay System (millions grams per year).

Element	Gaged	Ungaged	Wastewater	Subtotal	Precipitation	Total
Longley, 1994						
TN	3,950	2,130	369	6,450	370	6,820
TP	520	300	200	1,020	-	1,020
TOC	27,600	13,600	700	41,900	-	41,900
Ward and Armstrong, 1980						
N	17,890	3,870	140	21,900		
P	890	200	40	1130		
C	10880	4780	730	16390		
Gorham-Test, 1997						
TN 1984	1,300	1,290	110	2,700	1,280*	3,980
TN 1987	7,820	1,580	110	9,510	1,470*	10,980

* Precipitation for 1984, 1987 includes dry deposition.

Given the standards used to judge estuaries on the national scale, Matagorda Bay has been classified as moderately eutrophic. That is, it exhibits concentrations of nutrients and chlorophyll that are on the high end of normal. Those are conclusions drawn from the National Oceanic and Atmosphere Administration's (NOAA) National Estuarine Eutrophication Assessment (Bricker, et. al, 1999). It is enlightening to consider the nutrient data from Matagorda Bay in the context of NOAA's criteria.

The following observations are based on 1993 through 2004 TCEQ regular monitoring data, with instances of less-than-detection-limit values reported as one-tenth the threshold. TCEQ collects quarterly samples at 12 locations within the Matagorda Bay System. Nutrients collected are Nitrite + Nitrate-N, Ammonia-N, Orthophosphorus (as P), Total Phosphorus (as P), Total Kjeldahl Nitrogen (as N), Chlorophyll-a, and Pheophytin.

In most years, the maximum dissolved inorganic nitrogen (DIN) concentration is above 1.0 mg/l, placing Matagorda Bay in NOAA's high nitrogen category. In all years, maximum concentration of total phosphorus (TP) is above 0.1 mg/l, placing Matagorda Bay in the high phosphorus category. It should be noted that NOAA's standard is based on total dissolved phosphorus, not total phosphorus as measured in recent years. However, prediversion dissolved phosphorus maxima were above 0.1 mg/l in most years. In most years, maximum chlorophyll-a concentration are between 20 and 60 micrograms/l, again within NOAA's high category.

Evaluating the concentration data using volume-weighted average concentrations may be more suitable, considering that many sampling stations represent small secondary bays not within the main freshwater flow paths. Matagorda Bay was subdivided into areas with one TCEQ monitoring station each and a bay volume assigned to that station. Bay-wide average concentrations were computed giving more weight to stations representing larger volumes (areas). Considering the nutrient status of Matagorda Bay using this TCEQ data and NOAA standards, the following is observed:

- Most years have maximum chlorophyll-a concentrations between 5 and 20 micrograms/l, NOAA's medium category.
- Most years have maximum total phosphorus above 0.1 mg/l, NOAA's high category.
- Most all years the DIN are above 0.1 mg/l, but below 1.0 mg/l, placing Matagorda Bay in NOAA's medium nitrogen category.

The above exercise indicates that the nutrient status of Matagorda Bay, at least for nitrogen and phosphorus, is typically within the range NOAA would consider sufficient to promote biological production. Therefore, current nutrient loading rates appear to be sufficient to support medium to high biological productivity.

6.4 Statistical Relationship between Inflows and Nutrients

With respect to freshwater inflows, a concern would be whether there are inflows below which nutrient loading rates are not sufficient to fuel typical productivity. In other words, the bay's productivity becomes limited due to a lack of nutrients. Previous evaluations of nutrient limitation for estuaries have been made on the basis of the concentrations of nutrients in freshwater inflow on the basis of the ratio of major nutrients dissolved in estuarine waters and on the basis of enrichment experiments, which are tests to determine which nutrients produce significant algal response (for further discussion, see Hecky and Kilham 1988).

To investigate the relationship between inflows and bay concentrations, tests were performed on volume-weighted bay concentrations, for which non-detect data were assigned a value one-tenth

the threshold or 0.01 mg/l. Concentration-inflow relationships were based on cumulative three- and six-month inflows preceding the sample date. A nonparametric ANOVA (Kruskal-Wallis) test was used to test whether concentrations differed between inflow categories, defined by inflow quartile breaks. Tables 6.2 and 6.3 present the results.

Table 6.2 Average Nutrient Bay Concentrations (mg/l) at 90 - day Inflow Quartiles.

90 day Inflow Quartile	DIN mg/l	TN mg/l	TP mg/l
First	.109	.937	.119
Second	.266	1.075	.118
Third	.139	.771	.126
Fourth	.100	1.225	.214
Significance	ns	ns	ns

ns – not significant

Table 6.3 Average Nutrient Bay Concentrations (mg/l) at 180 - day Inflow Quartiles.

180 day Inflow Quartile	DIN mg/l	TN mg/l	TP mg/l
First	.087	1.209	.133
Second	.419	.844	.121
Third	.137	.946	.148
Fourth	.195	1.124	.173
Significance	.049	ns	ns

ns – not significant

These tests suggest that low bay DIN may be associated with low inflows. However, the general pattern in the tests does not give an indication that variation in medium time-scale inflows is associated with low bay nutrient concentrations.

The Kruskal-Wallis test was performed on nutrient concentrations grouped by one-year inflow quartiles (Table 6.4). At this level there are fewer low-quartile periods, which may reduce the validity of the results. However, nutrient concentrations were not found to be associated with inflow level.

Table 6.4 Average Nutrient Bay Concentrations (mg/l) at 360 - day Inflow Quartiles.

360 day Inflow Quartile	DIN Mg/l	TN mg/l	TP mg/l
First	.024	.807	.141
Second	.230	.831	.126
Third	.226	1.209	.162
Fourth	.108	1.041	.142
Significance	ns	ns	ns

ns – not significant

Even though the above tests do not show a strong relationship between inflows and nitrogen concentrations in the water column, this may not preclude nutrient limitation at low inflow volumes. The limited amount of water quality data may mean that significant times and areas of production are not covered.

6.5 Nitrogen as the Indicator Nutrient

Nitrogen is usually considered to be the nutrient most often limiting to estuarine production. However, other nutrients such as phosphorus and silica have been found to limit primary productivity in other estuaries. Previous studies have utilized enrichment experiments to indicate which element may limit production. In his assessment of the primary ecological interactions in four Texas estuarine systems, Davis (1973) reports studies that show that nitrogen was usually limiting to chlorophyll production in Matagorda Bay, although phosphorous was also limiting.

Dortch and Whitledge (1992) found silica often to be the limiting nutrient in the Mississippi River plume. Unfortunately, there is no recent data for the Matagorda system to test the adequacy of silica concentrations. However, limited data from the early 1970s shows silica concentrations typically higher than the 0.0056 mg/l threshold suggested by Dortch and Whitledge.

Jones et al. (1986) from a study of Lavaca Bay and the associated area of Matagorda Bay concluded that nitrogen was often limiting. However, they considered phosphorus to be ultimately limiting to biological productivity because nitrogen fixation in the system seemed to be able to compensate for some nitrogen losses, whereas phosphorus concentrations would be directly linked to the actual phosphorus loading.

Data on dissolved inorganic phosphorus (DIP) is very limited in the 1990s through 2003. Analysis of data collected for the TWDB monitoring program, 1983-1989, showed 7% of all measurements reported at the detection threshold (0.01 mg/l), and an additional 2% reported below threshold. According to the Redfield ratio (Redfield, 1958), DIP would have to be at a level of 0.0062 mg/l for limitation of phytoplankton growth. Thus, the data suggest potential phosphorus limitation occurs less than 10% of the time.

Given that silica and phosphorus appear adequate to maintain biological productivity, nitrogen remains a suitable focus for investigation of potential impacts of an altered inflow regime. However, phosphorus monitoring should continue, as phosphorus limitation might become important depending on changes in upstream nutrient processes and wastewater treatment.

6.6 Nitrogen Budget

A budget approach is a means to comparatively assess changes to nutrient loadings in the context of all nutrient sources and sinks. A detailed nitrogen budget was presented in the 1997 report for conditions of high and low inflows. The objective was to look for a potential link between major budget components and inflows that would allow the estimation of a nitrogen requirement to sustain production.

Table 6.5 is the nitrogen budget from the 1997 report, including adjustments for post-diversion loadings. The negative balance for the budget in both years and lack of certainty regarding major terms limited its interpretation for the use in assessing the Matagorda Bay system nitrogen requirements.

Table 6.5 Total Nitrogen Budget (millions of grams) for the Lavaca-Colorado Estuary.

Direct Inputs	**1984 Low inflow**		**1987 High inflow**	
Colorado River	716	*592	8339	*5992
Navidad River	420		1021	
Lavaca River	68		465	
Tres Palacios River	190		207	
Garcitas/Placedo Creeks	28		137	
Wastewater Return	111		111	
Ungaged Flow	1290		1585	
Precipitation	951		875	
Atmos. Dry Deposition	330		596	
Nitrogen Fixation	487		487	
Subtotal	4591	4467	13822	11476
Water Exchanges In				
Ship Entrance Channel	1322		4239	
Ship Entrance Channel, Entrained	3880		7137	
Pass Cavallo	1017		2825	
Pass Cavallo, Entrained	2840		5263	
Subtotal	9059		19464	
Loses				
Water Column Storage	625		1897	
Water Exchanges Out				
Ship Entrance Channel	2674		14762	
Ship Entrance Channel, Entrained	6010		7187	
Pass Cavallo	2007		7227	
Pass Cavallo, Entrained	4398		5299	
Subtotal	15713		36372	
Bio-geochemical Losses				
Denitrification	2438		2438	
Burial in Sediments	60		410	
Fisheries Harvests	82		97	
Escapement	104		208	
Subtotal	2685		3153	
Total In	13649	13526	33286	30940
Total Out	18398		39525	
IN/OUT	0.74	0.74	0.84	0.78
* Adjusted to Colorado River nitrogen input prior to the construction of the Diversion Channel				
REMAINING	-4748	-4872	-6239	-8585
Water Balance Error	-44		5833	
Total In. Adjusted for Water Balance Error	13605	13482	39119	36773
In/Out with WB Correction	0.74	0.73	0.99	0.93

In concept, using the budget approach to predict the nitrogen needs of the system requires information about biological and geochemical mechanisms that may affect budget terms. A major consideration in this regard is a budget component that now has to be largely inferred: system storage. During times of high nutrient loading, the various living and non-living components of the system probably store significant nutrients. There is data to estimate water column storage, but that may not be the major storage. Benthic organic and inorganic storage should be considerable, for example, but is practically unknown. So during times of high nutrient loading, one would expect significant storage in the system; whereas during months or years of low input, the storage should be depleted. With a more complete or accurate budget for other components of gains and losses the size of system storage can be inferred and used as a means of recommending an inflow that sustains the systems productivity.

Some new information suggests that some of the terms of the nitrogen budget may need revising. Gardner et al (2005) summarizes data from a number of more recent studies of Texas estuary nitrogen processes and shows that nitrogen fixation and denitrification are often balanced. Further, these studies offer evidence that at increasing salinities, nitrogen processes shift from denitrification (loss) to pathways that recycle nitrogen back into biological availability. Getting more information about those processes would be important to our understanding of how changes in nitrogen loading would affect productivity. A nitrogen budget may still offer a means to estimate or validate a nitrogen requirement for the system. However, for now other avenues may have to be investigated.

6.7 Approaches Used for Determining Nitrogen Loading Requirements

Several approaches to determining nitrogen loading requirements were investigated in the 1997 report. These are revisited or augmented in view of new data or new perspectives from recent literature.

6.7.1 Maintaining Current Levels of Productivity

The nitrogen loading to the system should be adequate to maintain the trophic state near the present status quo. That is, the nutrients should be sufficient to fuel the present level of productivity. Concerns about eutrophication in many estuaries on U.S. and European coasts have spawned most of the work on relationships between loading and productivity. Nixon (1995) proposed a definition of eutrophication related to the amount of increase in organic carbon in the system and proposed thresholds for oligotrophic, mesotrophic and eutrophic estuaries based on rates of organic carbon increase. Based on the information present at the time that the 1997 report was written, it appeared that Matagorda Bay would be classified as mesotrophic and that nitrogen loading sufficient to maintain phytoplankton organic carbon production at that level should be an appropriate objective. Applying this concept, Gorham-Test (1997) determined that 13,360 x 10^3 grams nitrogen per year from all sources would maintain appropriate productivity. This translates to approximately 1.71 million acre-feet freshwater inflow per year as determined in the 1997 FINS. However, there is confusion over whether Nixon's definition of eutrophication really considered all sources of organic carbon that drive estuarine production and what measure of productivity should be used for Matagorda Bay. Matagorda Bay, like most other Texas bays, receives significant organic carbon from riverine and wastewater sources and from fringing wetland production as well as from phytoplankton production. The summation of carbon loading from phytoplankton, return flow and riverine sources would place Matagorda Bay at a much higher trophic level than seems correct. Therefore, more consideration may be required in applying Nixon's definition of trophic status to Matagorda Bay and using that as a basis for quantifying nitrogen needs.

6.7.2 Nutrient Limitation

An approach that seems to offer promise is to quantify a loading that would maintain concentrations of nitrogen at levels above which phytoplankton production would be limited. This is complicated by the findings above that show no or little relationship between freshwater inflow (and associated nitrogen loading) and bay nitrogen concentrations (Section 6.4). The problem appears to be that internal mechanisms of storage and recycling are sufficient to maintain nitrogen concentrations at times of low loading between pulses of higher loading. So it

is hard to determine from present data how the bay would respond to loadings significantly less than at present. To remedy this problem, it is proposed that we take advantage of information from sister bays along the coast, which comprise a gradient of inflows and loadings. Of course, each system has characteristics that may complicate comparisons. In particular, a portion of Sabine Lake inflows skirt the main bay and so system loadings and system concentrations may not be as tied as in other systems; the isolation of the main part of the Guadalupe Estuary from direct Gulf exchange also may give it special characteristics.

In general, the concentration of a non-conservative substance, such as a nutrient, in the bay is related to the loading, the flow-through and the rate of removal by biological or geochemical processes (eg. Dortch, 1997). Rates of removal of nutrients are generally assumed to be influenced by the hydraulic residence time of the system. For the major bays of the Texas Coast, except Laguna Madre, relationships were examined between loading per unit volume, residence time and average DIN concentration.

Residence time within an estuary is a function of freshwater inflow and tidal exchange; however, for this analysis residence time was based just on freshwater replacement from data given by Armstrong (1982) to simplify interpretation. Average bay concentrations were compiled from routine monitoring data from TCEQ, 1990-2001. Nutrient loading data were taken from Longley (1994) or from datasets used to create those tables and from more recent updates (in appendices to Pulich, et al., 1998; Lee, et al., 2001; Pulich, et al. 2002; Kuhn and Chen, 2005). Sabine Lake was dropped from the analysis because its residence time is so much different than the other systems. The data suggest there is a general relationship between residence time and DIN concentrations in the bays. Linear regression produced the following:

$$DIN = 0.264 - 0.103 * Res \qquad R2 = 0.667,\ p = 0.062$$

In this relationship, residence time (Res) is the bay volume divided by average net freshwater inflow per year.

This relationship can then be used to predict a bay-wide average DIN that would limit phytoplankton growth. The prediction has a great degree of uncertainty, not least because it would be extrapolating past the bounds of data in the relationship. Therefore, the following is offered only as a guide. From this relationship, the bay-wide average DIN should approach the productivity-limiting threshold of 0.014 mg/l (Dortch and Whitledge, 1992) when inflows are 714,000 acre-feet per year.

6.7.3 Historic Loading

Prior to growth of the urban areas, farmland, and irrigated agricultural development in the basin, inflows to the bay would have had lower nitrogen concentrations than what is found today. Those concentrations should be similar to concentrations now found in streams not impacted by human activities. Twidwell and Davis (1989) documented nutrient concentrations in stream segments identified as relatively unaffected. These data are similar to those compiled by Omernik (1976) for land use categories comparable to what was characteristic of the basin. From these data, a reasonable estimate of natural stream concentrations would be on the order of 0.7 mg/l N. Actually, the recent flow-weighted average TN concentration for all sources to Matagorda Bay is near 1.50 mg/l N.

An unimpacted inflow TN concentration was combined with median inflow volume to produce an estimate of historic nitrogen loading to Matagorda Bay. Using an unimpacted stream concentration of 0.7 mg/l N and 3,076,000 ac-ft median inflow, a historic annual TN load would be $2{,}655 \times 10^6$ g N /y from the drainage basin. This rate is proposed as a minimum target nitrogen load, capable of supporting Matagorda Bay's productivity at historically characteristic levels for the system. At today's typical input concentrations from all sources, 1.50 mg/l N, an equivalent TN load would be supplied by 1,440,000 ac-feet.

6.8 Preliminary Findings

The amount of inflow necessary to continue to maintain a healthy estuarine system is difficult to determine due to the limited understanding of many of the interacting processes. Nitrogen appears to be sufficient as a nutrient indicator for determining the nutrient requirements to

sustain biological productivity for Matagorda Bay. If this is the case, as much as approximately 1.71 million acre-feet freshwater inflow per year may be sufficient to provide the nutrient loading necessary to maintain optimum productivity of the bay. In addition, minimum inflows of approximately 714,000 acre-feet per year may be necessary to avoid nutrient (nitrogen) limitation. However, determination of a nutrient requirement to sustain productivity in Matagorda Bay is compromised by lack of data on non-riverine sources of nutrients to the system.

Recent studies [e.g., Gardner et al. (2005)] suggest nitrogen fixation may be more important than anticipated. Sources of nutrients from atmospheric dry-deposition are also poorly known. Allochthonous carbon inputs may make important contributions to productivity of many Texas bays, but isotope studies show that the picture is complicated (Kaldy, Cifuentes and Brock, 2005). There are measurements of riverine TOC, but fewer measurements of contributions from delta and fringing wetlands.

To explore the degree to which estuary freshwater inflow recommendations can be made on the basis of comparisons among sister estuaries, more information would be needed to ensure such comparisons could be done correctly. In addition, parameters and processes that could contribute to cross-system analyses should be given particular study, such as nutrient dependence patterns among similar bays. For Matagorda Bay, additional information is needed on which major nutrient is limiting productivity seasonally and at very low inflow conditions. It has been suggested that imbalances in nutrient ratios can lead to growth of noxious or undesirable algal species. The nitrogen budget exercise illustrated the need for more study of many processes and components. Further modeling or study of Gulf-bay exchange, for example, would help. Studies to determine whether or not nutrients are stored in an exchangeable way in sediments, wetlands and biota would be needed to help enable deductions concerning changed conditions based on a budget-type approach.

CHAPTER 7

Estimation of Freshwater Inflow Needs

7.1 Introduction

This chapter describes an application of the State Methodology for determination of freshwater inflow needs (Longley ed., 1994) to determine Target inflow needs for Matagorda Bay. The discussion related to Critical Flows, is presented later in Chapter 9.

The primary management objective of the State Methodology is to maintain existing ecologically and economically important species in Matagorda Bay at near historical levels[1]. A secondary objective, and the purpose in applying an optimization model, is to make the most efficient use of the water. TXEMP computes the maximum productivity that can be obtained for a given annual amount of inflow.

Model results from multiple runs of TXEMP meeting all of the imposed constraints[2] are used to develop a response curve of viable solutions. Target Flows are described in the 1997 study (LCRA) as attempting to achieve the maximum productivity found on this curve subject to prudent consideration of "marginal benefits to biomass with additional freshwater inflows". The same approach is taken in this study to determine Target flows.

In searching for flows that meet the above objectives, TXEMP assumes that flows can be distributed throughout the year as required by the solution. TXEMP does not recognize restrictions due to other competing demands for water, nor does it take into account limitations in the ability to control flows, during floods or droughts for example. These additional restrictions and limitations make the Target flow solution difficult to achieve in practice. Nonetheless, TXEMP does provide the best solution possible for getting the greatest productivity for a given amount of water. How best to utilize the information provided by TXEMP solutions is left for later management and regulatory decisions.

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[1] See Section 7.4.6, Limits on Individual Species Productivity. Lower limits at 80% of mean species productivity were applied to each species to achieve this objective.
[2] See Section 7.4, Key Model Constraints, for further description of the imposed constraints.

In addition, although specific recommendations for Intermediate flows are not provided in this study, information related to the potential use of TXEMP as a tool to assist in the development of Intermediate flows is provided in this chapter.

7.2 Optimization Model

7.2.1 Purpose of TXEMP Model

TXEMP is a mathematical optimization model used to estimate freshwater inflows required to optimize productivity in Matagorda Bay. The objective in applying TXEMP is to determine the monthly flow distribution required to maximize productivity of key species in Matagorda Bay subject to hydrological and biological constraints. Productivity for each of the key species is related to monthly inflows through equations developed and described in Chapter 3 and presented in Table 3.7. Hydrological constraints are based on historical (1941-2003) flows in the Colorado River basin, the Lavaca-Navidad River basin and the remaining coastal basins that contribute inflow to Matagorda Bay. Biological constraints are based on physiological requirements for each of the species modeled and on the observed abundance of each species.

7.2.2 Differences from the 1997 Study

Several key aspects of the current study differ from the 1997 study. First, physical alterations to the Matagorda Bay system, primary of which are the diversion of the Colorado River into Matagorda Bay in 1991 and the closing of Parker's Cut in 1992, have created a physical, chemical and biological system that differs significantly from the system as it existed prior to these changes. The current study estimates inflow requirements for the current configuration of the system, i.e. the system following the completion of the diversion channel and the closing of Parker's Cut.

In the application of TXEMP, the current study uses productivity and salinity regression equations that are related to flows from the Colorado and Lavaca-Navidad river systems, but does not include drainage from the coastal watersheds. This differs from the 1997

analysis in which coastal watersheds were included in the development of the regression equations.

In the current study, seven key species identified in Chapter 3 are modeled in TXEMP. The seven target species include brown shrimp, white shrimp, menhaden, red drum, striped mullet, blue crab and oyster. This differs from the 1997 study that included nine species, including the above seven species, as well as black drum and southern flounder. The use of seven instead of nine species led to a reduction in optimal biomass computed in the current study in comparison to the biomass compiled in the 1997 study. The approach taken in developing the productivity equations in the current study is somewhat different as well. Rather than applying a statistical "all possible subsets" approach for all species as in the 1997 study, different approaches were adopted for the shrimp equations than for the finfish or oysters.

The salinity-inflow regression equations were based on data extending through March 2004 and included periods of both extreme flood and drought conditions. The equation for the eastern arm of Matagorda Bay (West Tripod) contains three flow terms, while the equation for Lavaca Bay contains four flow terms. In the 1997 study, both equations were developed with just two terms, representing flows for the current and antecedent months. The use of highly variable data sets and the use of additional terms in the equations have led to equations that are considerably more robust than those used in the 1997 study.

In the current study, an attempt was made to use the same model parameters in TXEMP that were applied in the 1997 study. For example, both the salinity and harvest probabilities used in the current study were the same as those used in the 1997 study. However, for parameters and constraints based on the statistics of hydrological or biological data (upper monthly flow constraints, e.g.), the parameters and constraints were changed to reflect the updated data sets. A significant difference in the development of Target flow estimates in the current study is the use of 70th percentile monthly flows for upper monthly flow constraints and the use of slightly higher salinity constraints. In the 1997 study, the upper monthly flow constraints were set to the mean

monthly flows, and the upper salinity constraints were set 1 ppt lower than in the current study. Input files used to develop Target flows in this study are provided in Appendix E.

The rationale for use of higher flow and salinity constraints in this study are discussed in Appendix F.

7.3 Model Variables

The key decision variables that TXEMP solves for are the twelve monthly inflows each from Colorado River basin and from the Lavaca River basin. Annual coastal basin inflow is estimated as a fixed fraction, 0.361, of the combined Lavaca and Colorado river basin annual flows. Total flows are computed by combining the Lavaca and Colorado river basin flows with the coastal basin inflow.

7.4 Key Model Constraints

7.4.1 Upper and Lower Limits on Monthly Inflows for Colorado River Basin.

The lower limits on monthly flows for the Colorado River basin are defined as 10th percentile monthly flows based on historical data for the USGS streamflow gage on the Colorado River at Bay City (#08162500) from January 1941 to December 2003 less the diversion at the South Texas Project (Table 7.1). The upper limits are defined as 70th percentile monthly flows based on the same data.

Table 7.1 Flow Constraints on the Colorado River Basin Inflows (1000 acre-feet/month).

Month	Lower Constraint	Upper Constraint
January	30.6	208.9
February	26.8	197.6
March	22.3	231.7
April	22.9	221.7
May	28.4	255.4
June	22.0	210.5
July	20.0	120.1
August	17.3	68.7
September	25.3	133.8
October	33.1	154.2
November	26.2	162.5
December	23.8	166.2

7.4.2 Upper and Lower Limits on Monthly Flows for Lavaca River Basin.

Lower and upper limits for the Lavaca River basin monthly inflows are based on flow records for USGS gage on the Lavaca River near Edna (#8164000) and the Navidad River near Ganado (#8164500) from January 1941 through December 2003, and on releases from Lake Texana (Table 7.2). As with the Colorado basin, the lower limit is the 10th percentile monthly flow and the upper limit is the 70th percentile monthly flow.

Table 7.2 Flow Constraints on the Lavaca River Basin Inflows (1000 acre-feet/month).

Month	Lower Constraint	Upper Constraint
January	2.2	77.0
February	3.5	68.9
March	3.3	43.7
April	3.7	85.0
May	5.9	139.4
June	4.8	86.0
July	4.6	29.2
August	2.0	18.3
September	4.9	50.6
October	1.7	58.1
November	1.5	53.4
December	1.9	57.9

7.4.3 Upper and Lower Limits on Monthly Lavaca Basin Inflows Used to Develop Lavaca Salinity Equation.

Lower and upper limits for the Lavaca River basin inflows are based on flow records for the USGS gage the Lavaca River near Edna (#8164000) and the Navidad River near Ganado (#8164500), and on releases from Lake Texana. The minimum constraint was set to 1.0 thousand acre-feet/month, and the upper constraint was set to 1043.0 thousand acre-feet/month. These constraints are less restrictive than those in Table 2 and therefore do not come into play in the optimization, but are included for the sake of completeness.

7.4.4 Ratio of the Lavaca Basin to Colorado Basin Flows.

Means and standard deviations for "seasonal" flows, defined as bimonthly flows for January and February, March and April, May and June and so on, were computed for the Lavaca and Colorado basins. Upper and lower constraints were applied for each season on the ratio of the average seasonal flow for the Lavaca basin to the average seasonal flow for the Colorado basin. The constraint about the mean for each season is in proportion to the standard deviation of the seasonal flows. The intent of this constraint is

to ensure inflow contributions from the Lavaca and Colorado basins are in proportion to historically observed inflows.

7.4.5 Upper and Lower Limits for Seasonal Flows

Upper and lower constraints were set for the combined Lavaca and Colorado basin "seasonal" flows. The upper and lower constraints are based on the minimum and maximum values used in developing the productivity equations. The purpose of this constraint is to prevent use of the equations to extrapolate beyond flows used in the development of the equations.

7.4.6 Limits on Individual Species Productivity

Lower limits on individual species productivities were set to 80% of the mean productivities. The mean productivity for each species was based only on data used in developing the productivity equations (Appendix B, Table B.2) applied in TXEMP. This includes data from 1992 through 2002, although data for some species and some years in this period were eliminated during development of the equations. Upper limits on all species were high enough to prevent these constraints from influencing the solution.

7.4.7 Upper and Lower Limits for Nutrients

A lower limit on total annual inflow was set at 1.710 million acre-feet. This limit is based on the nutrient budget described in Chapter 6 and is intended to limit conditions to which the system is not nutrient limited.

7.4.8 Salinity

Upper constraints on salinity were set to 16 ppt for May, June and July and to 21 ppt for all other months. Lower constraints on salinity were set to 1 ppt for May through August and to 5 ppt for the remaining months. The same constraints are applied to the Lavaca Causeway (Lavaca basin flows) and West Tripod (Colorado basin flows) sites.

Salinity constraints in the State Methodology are based on multiple studies that have been conducted to determine species viability limits (see, e.g., TDWR 1980a, Table 9-1 and Longley 1994, Table 6.7.3). However, this information is site specific and is variable and there remains the need to apply subjective judgment in using it for a particular bay, as pointed out in TWDR (1980a): "Since universal consensus is not evident for precise salinity viability limits, the seasonal bounds were established subjectively based upon the results available from scientific literature." Judgment is also needed in applying information from past studies because salinity reference locations have varied. For example, the salinity reference locations for the eastern arm of Matagorda Bay used in the 1980 study (TDWR, 1980a) were "… line 330 site 2, line 333 sites 1,2,3, line 340 sites 2, 3, and line 350 site2 …," referring to multiple locations in that region of the bay. The equivalent reference location in the present study is the West Bay Tripod.

The salinity constraints in the current study were based on constraints developed in the 1997 study, which in turn were based on "limits selected by the TWDB and TPWD in their study of estuarine inflow needs of the Guadalupe estuary." This refers to constraints developed in the example application of the State Methodology in Longley (1994). The Longley (1994) report presents salinity constraints based on earlier studies by TDWR (1980b) and Espey Huston and Associates (1986), but ultimately used constraints recommended by TPWD. Judgment and consensus between the state resource agencies and LCRA was applied in using this information to develop constraints particular to Matagorda Bay for the 1997 study.

7.5 Target Flow

Multiple runs of TXEMP over a range of total annual flows were used to create the response curve shown in Figure 7.1. The curve represents Matagorda Bay productivity as a function of total inflow, where productivity is defined as the sum of the computed biomasses for each of the seven species modeled. Total annual inflow is the sum of the

annual inflows from the Colorado River basin, the Lavaca-Navidad River basin and the coastal basin.

Each point on the curve in Figure 7.1 represents the optimal productivity attainable for a particular total annual flow subject to the hydrological and biological constraints described above. TXEMP provides the monthly distribution of flows for both the Colorado and Lavaca basins needs to attain those levels of productivity. As described in the Appendix 6, overall system productivity could be made to increase by relaxing the constraints applied to this problem. However, the more restrictive hydrological and biological constraints applied here in estimating a Target flow are a means of obtaining solutions that are considered more reasonable and feasible from the perspectives of water management and biology.

Peak productivity (subject to the flow and salinity constraints applied for the target solution) of 236 thousand pounds occurs for a range of flows between 2.75 and 3.50 million acre-feet/year. Productivity drops to 72% of peak productivity (169.4 thousand pounds) at flows of 2.05 million acre-feet/year. Following the approach taken in the 1997 study, since no appreciable increase in productivity is provided for flows greater than 2.75 million acre-feet/year, the prudent choice for the Target flow is 2.75 million acre-feet/year. This flow is estimated to result in peak productivity for the least amount of water. This Target flow is less than the average annual inflow to Matagorda Bay from 1941 to 2003 (3.44 million acre-feet/year), and is also less than the median inflow for the same period (3.095 million acre-feet/year) (Table 2.2).

The total annual inflow is distributed between the Lavaca River basin (593 thousand acre-feet), the Colorado River basin (1.428 million acre-feet) and the coastal basins (729 thousand acre-feet). Table 7.3 provides monthly distributions for each of these annual inflows.

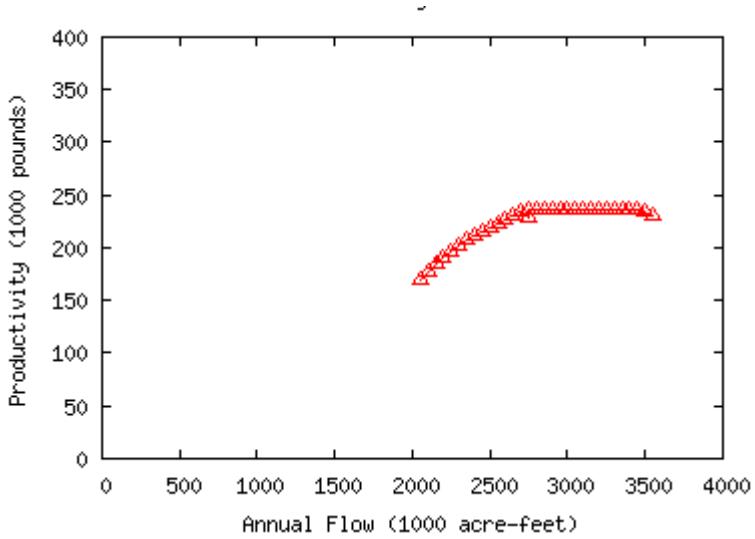
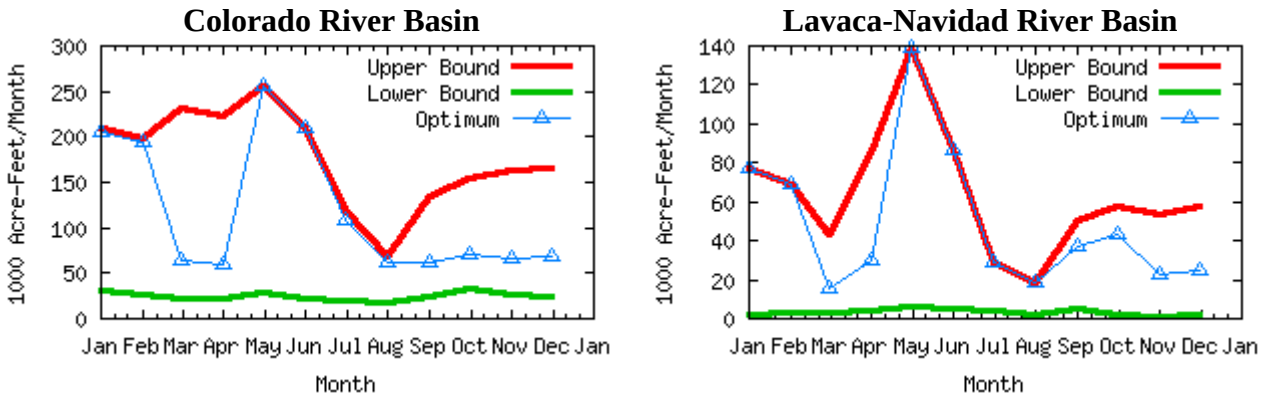


Figure 7.1 Total System Productivity versus Total Annual Inflow for Target Flow Runs.

The monthly solutions are shown in Figure 7.2 relative to upper and lower flow constraints for both the Colorado and Lavaca basins. Corresponding salinities relative to the upper and lower salinity constraints are presented in Figure 7.3. For both the Colorado and Lavaca basins, the solutions are confined by the upper flow constraints in January, February and May through August. Upper salinity constraints for Colorado basin flows (West Bay Tripod) affect the solution primarily during September through December.

Table 7.3 Monthly Inflows Corresponding to Target Solution (1000 acre-feet/month).

Month	Colorado	Lavaca	Coastal Basins	Total Monthly Inflows
January	205.6	77.0	37.2	319.8
February	194.5	68.9	44.5	307.9
March	63.2	15.6	42.3	121.1
April	60.4	30.3	51.1	141.8
May	255.4	139.4	85.3	480.1
June	210.5	86.0	80.2	376.7
July	108.4	29.2	66.4	204.0
August	62.0	18.3	31.4	111.7
September	61.9	37.3	107.2	206.5
October	71.3	42.9	100.7	214.9
November	66.5	23.0	47.4	136.9
December	68.0	24.9	35.7	128.7
Total	1427.8	592.8	729.4	2750.0
Percent%	51.9	21.6	26.5	100.0

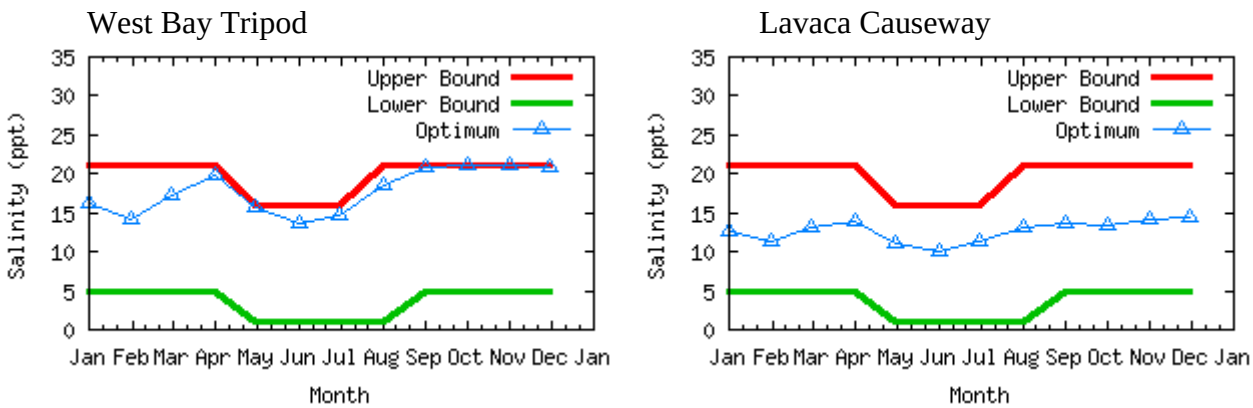


Upper bound – red line. Lower bound – green line. Optimum solution – blue line.

Figure 7.2 Distribution of Monthly Flows for Colorado River Basin and Lavaca-Navidad River Basin.

Mean productivities, based on the 1992-2002 TPWD data used to develop the regression equations, and productivities corresponding to the Target flow solution are presented in Table 7.4. The mean total productivity is 126.5 thousand pounds. Mean productivity resulting from Target flows is significantly higher at 236.2 thousand pounds, but significantly less than the maximum total productivity (again, based on the 1992-2002 TPWD data) of 258.9 thousand pounds. The distribution of total biomass among species is maintained with slight percentage increases in brown shrimp and menhaden and small percentage decreases in the remaining species. The ratio of target to mean productivity is

influenced by the use of a limited (1992-2002) data set. Relatively low productivity for many species during this period was possibly influenced by high flows in 1992 and 1997, and low flows in 1996, 1999, and 2000. Observed productivities for the selected species prior to the diversion in 1992 were higher than for 1992-2002, so it is expected that higher productivities will occur in the future, thereby reducing the target to mean productivity ratio.



Upper bound – red line. Lower bound – green line. Optimum solution – blue line.

Figure 7.3 Monthly Salinity Distributions Corresponding to Target Flow Solutions for Colorado River Basin and Lavaca-Navidad River Basin.

Table 7.4 Mean Productivity (1,000 pounds), Percent of Total Mean Productivity, Target Productivity (1,000 pounds), and Percent of Total Target Productivity. Mean productivity is based on the 1992-2002 TPWD productivity data.

Species	Mean	% of Total	Target	% of Total
Brown Shrimp	37.6	27.9	77.4	32.8
White Shrimp	29.0	22.9	42.1	17.8
Menhaden	40.4	31.9	94.9	40.2
Red Drum	0.5	0.4	0.6	0.3
Striped Mullet	1.2	0.9	2.0	0.8
Blue Crab	2.0	1.6	2.5	1.1
Oyster	15.9	12.6	16.8	7.1
Total	126.5	100	236.2	100

7.6 Intermediate Flow Ranges

This report identifies the total Target inflow need at 2.75 million acre-feet per year and the annual Critical inflow need (Chapter 9) at 483,600 acre-feet (432,000 ac-ft from the Colorado River and 51,600 ac-ft from the Lavaca River basin). However, further work is needed to develop appropriate Intermediate freshwater inflow needs to bridge the gap between wet and dry hydrological conditions. No guidelines currently exist in the State Methodology to assist in developing criteria for Intermediate flows. This section provides TXEMP results for runs in which salinity and hydrological constraints were relaxed from those used to develop Target flows. While this study does not develop a specific Intermediate flow recommendation, it does provide TXEMP model results to help any possible future development of Intermediate flow recommendations.

7.6.1 Intermediate Flows Management Objective

While the broad management objective for Target flow is to optimize productivity within historical ranges and the objective for Critical flow is to provide refuge for important species until more normal conditions return, as indicated above, there are no guidelines currently in the State Methodology for developing criteria for either Intermediate or Critical flows. One approach to developing Intermediate flows may be to provide flows to achieve a particular level of productivity. Another may be to determine the best distribution of flows so as to maximize productivity for a particular annual flow. Another may be to vary between Target and Critical objectives. During wetter than normal conditions, for example, this could be achieved by trying to maintain productivity in an optimal fashion and, during drier than normal conditions, gradually moving towards maintenance of refuge conditions. The variation in objectives could be tied to reservoir storage and inflow conditions and may also include the use of water use and supply forecasts. TXEMP can be used to help determine appropriate management objectives and to evaluate the flows and flow distributions required to meet them.

A crucial question in setting management goals for Intermediate flows is whether or not excess and available water for bay needs can indeed be stored for use at other times of the year. If so, then this water might be managed to optimize productivity for a given amount of available water. Another question is whether or not a single or small number of discrete Intermediate flow targets should be identified or if solutions should be provided for a continuous range of flows. Answers to these questions will determine if and how the information provided here can be used to help develop guidelines or criteria for Intermediate flows.

7.6.2 TXEMP Runs with Widened Constraints

Several additional TXEMP model runs were completed to develop information useful for determining a range of possible Intermediate flows. These are similar to runs described in Appendix F in which sensitivity analyses were performed on TXEMP by varying flow and salinity constraints. One possible solution taken from these runs is described here. This suggestion does not imply a recommendation and is offered for demonstration purposes only. In this run, inflow and salinity constraints were widened relative to the constraints used in the Target flow runs. The minimum inflow constraint was lowered from 1.71 million acre-feet/year to 0.50 million acre-feet per year. The upper salinity constraint for both the Colorado and Lavaca basins was set to 23 ppt for all months. By lowering the minimum annual inflow constraint and increasing the upper salinity constraint, conditions less than ideal relative to target conditions but better than conditions represented by critical, are simulated. This appears to be a reasonable approach to setting constraints for intermediate conditions.

The TXEMP solution with these altered constraints is presented in Figure 7.4. This curve is similar to that for Target flows in Figure 7.1. Total system productivity is plotted versus total annual inflow. As in simulations for Target flow conditions, each point on the curve represents the maximum productivity possible for a particular annual inflow. Solutions in this case are found down to 1.3 million acre-feet/year, well below the minimum inflow of 2.05 million acre-feet in Figure 7.1 for Target flow conditions. This is significant because it provides inflow recommendations well below target (2.75 million

acre-feet/year) and closer to critical (0.667 million acre-feet/year). Solutions for even lower total annual inflows are possible by increasing the upper salinity constraint, although at the lowest inflows the solutions become questionable because of the limits on the data used to develop the productivity equations.

Monthly inflows for the Colorado basin corresponding to the total annual inflows in Figure 7.4 are presented in Figure 7.5. The Colorado basin monthly median inflows are also shown in red as a basis for comparison (the sum of the Colorado basin median monthly flows is 1.07 million acre-feet). Figure 7.5 shows that when water is available, it is preferentially distributed by TXEMP to months where productivity is enhanced (January, February, May, June and July), and is removed when possible from months where productivity is harmed (March, April). As water availability decreases, model inflows are gradually adjusted as needed to achieve the greatest possible productivity. At the lowest inflow volumes, the monthly inflows become more uniformly distributed throughout the year, and the information provided by TXEMP regarding optimal inflow distribution loses its importance.

During some months, inflows remain well below the median monthly inflow (March, April, and September through December). In other months, inflows can exceed the median monthly. Providing these flows in an operationally ideal manner might be possible if excess inflows could be stored for later delivery during other months. For example, excess inflows stored late in the year might be delivered to provide most benefit during January, February or May through July. The volume of water available would determine the amount and distribution to be provided at that later time.

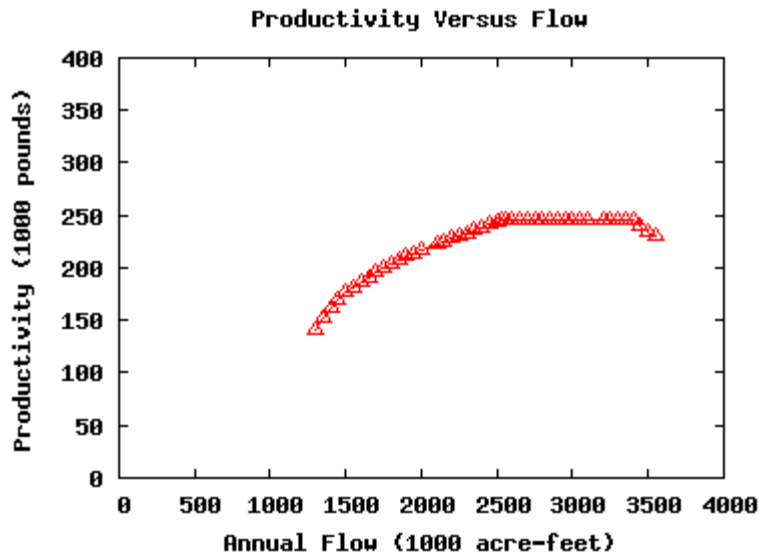
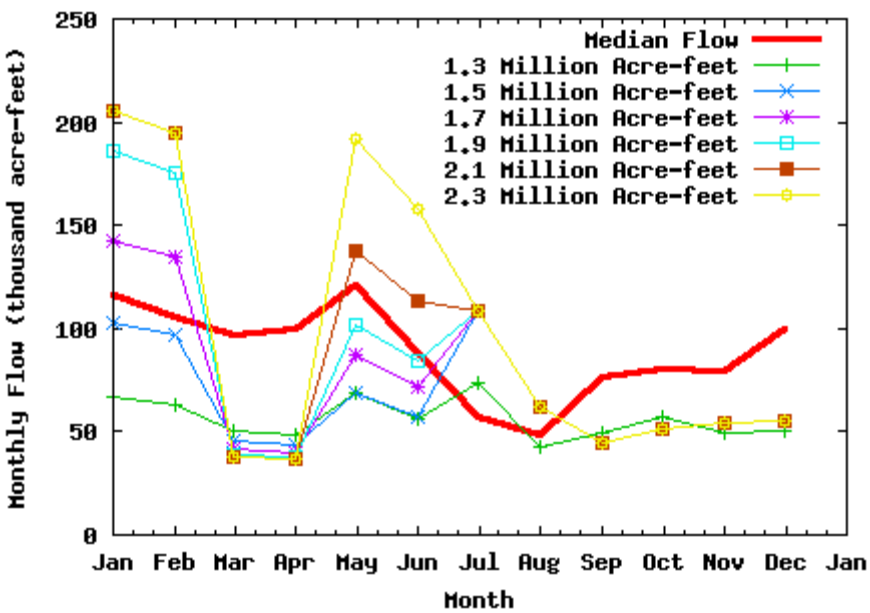


Figure 7.4 Total System Productivity versus Total Annual Inflow for Intermediate Flow Runs.



Note: Median monthly flows for the Colorado River Basin shown in red for reference.

Figure 7.5 Intermediate-Flow Solutions – Colorado Basin Monthly Flow Distributions for Selected Total (Colorado, Lavaca and Coastal Basins) Annual Flows from 1.3 to 2.3 Million Acre-Feet per Year.

7.7 Findings

The current application of the State Methodology has led to a calculation of a Target flow of 1.428 million acre-feet/year for the Colorado River basin, 593,000 acre-feet per year for the Lavaca River basin, and 729,000 acre-feet per year for the coastal basin. Over the past three decades there have been three other studies addressing the freshwater inflow needs of Matagorda Bay. The first was completed in 1980 by the Texas Department of Water Resources (TDWR, 1980) (now Texas Water Development Board) and proposed monthly inflows from the Lavaca and Colorado rivers to "maintain the fisheries harvest." Matthews and Mueller (1987) presented their recommendations at "Coastal Zone '87" in Seattle, Wash. Ten years later in 1997 LCRA, TWDB, TCEQ and TPWD finished the first Freshwater Inflow Needs of the Matagorda Bay System utilizing the State Methodology. Each successive study illustrates the need to continue to use an adaptive management approach when assessing freshwater inflow needs. Figure 7.6 depicts the total annual inflows recommended for Matagorda Bay from these four studies. Figures 7.7 and 7.8 depict the recommended river inflow volumes by month for the Lavaca and Colorado rivers, respectively. Lastly, Figure 7.9 provides a summary of the 1997 FINS and the current 2006 FINS Target recommendations plotted with the historical monthly average flows for the Colorado River at the Bay City gage.

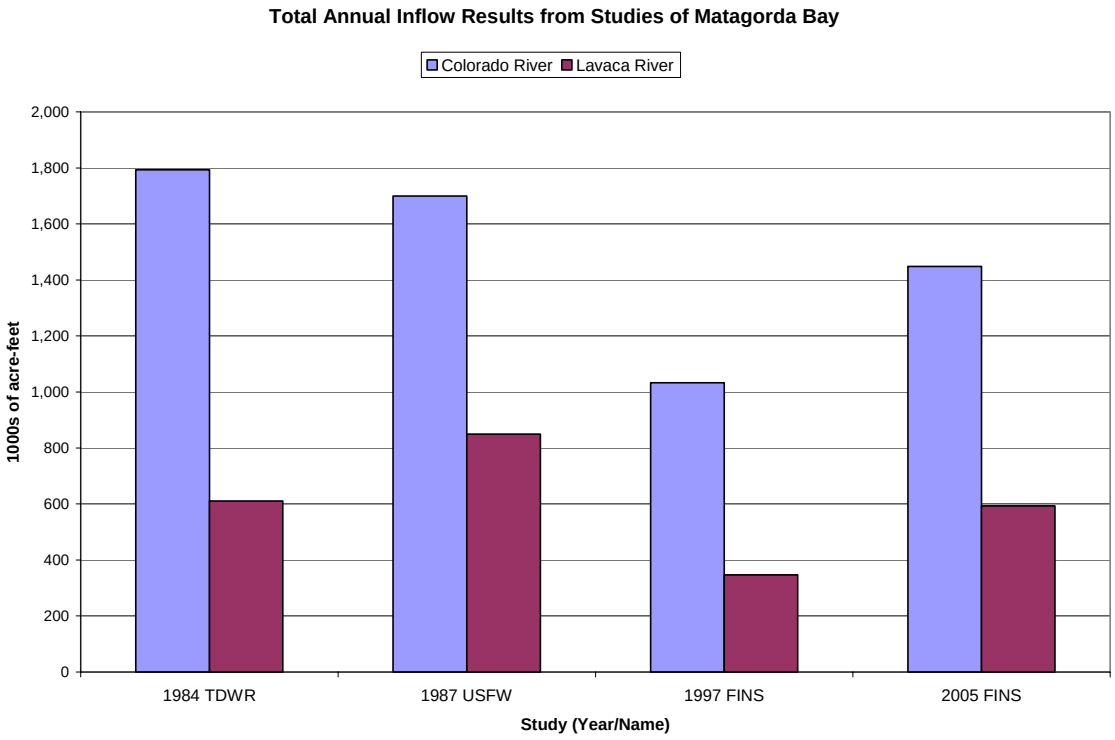


Figure 7.6 Comparison of Matagorda Bay Target Flows for Four Studies.

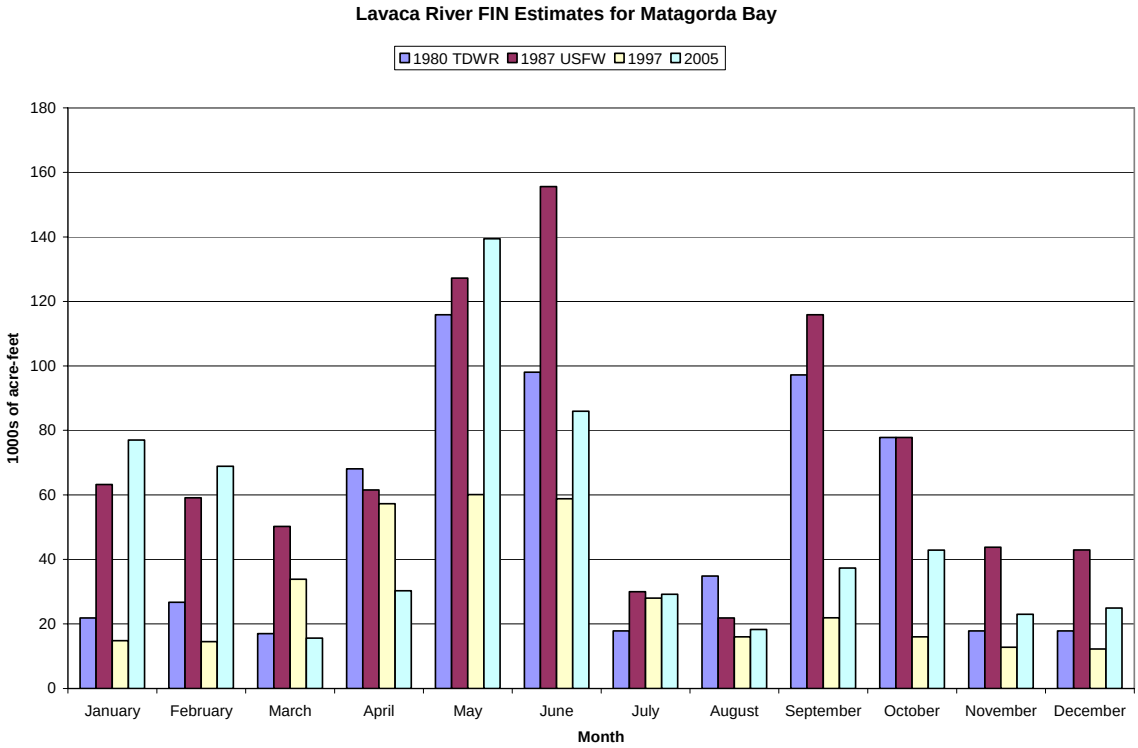


Figure 7.7 Lavaca River Freshwater Inflow Needs Estimates for Matagorda Bay.

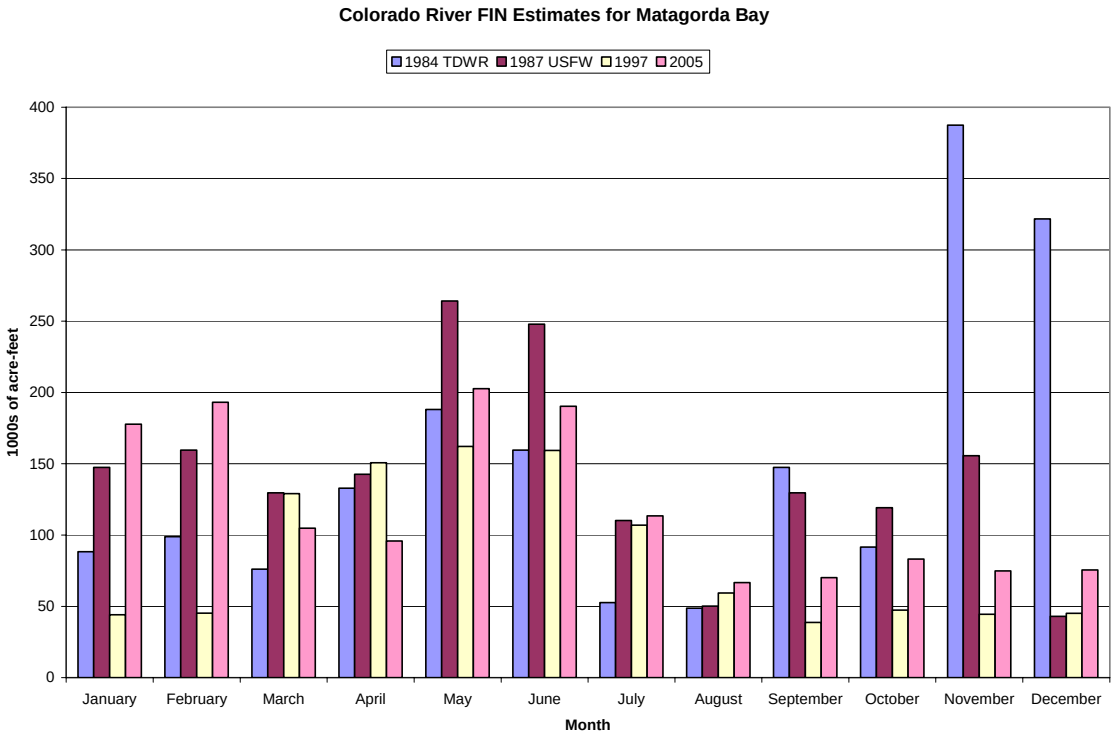


Figure 7.8 Colorado River Freshwater Inflow Needs Estimates for Matagorda Bay.

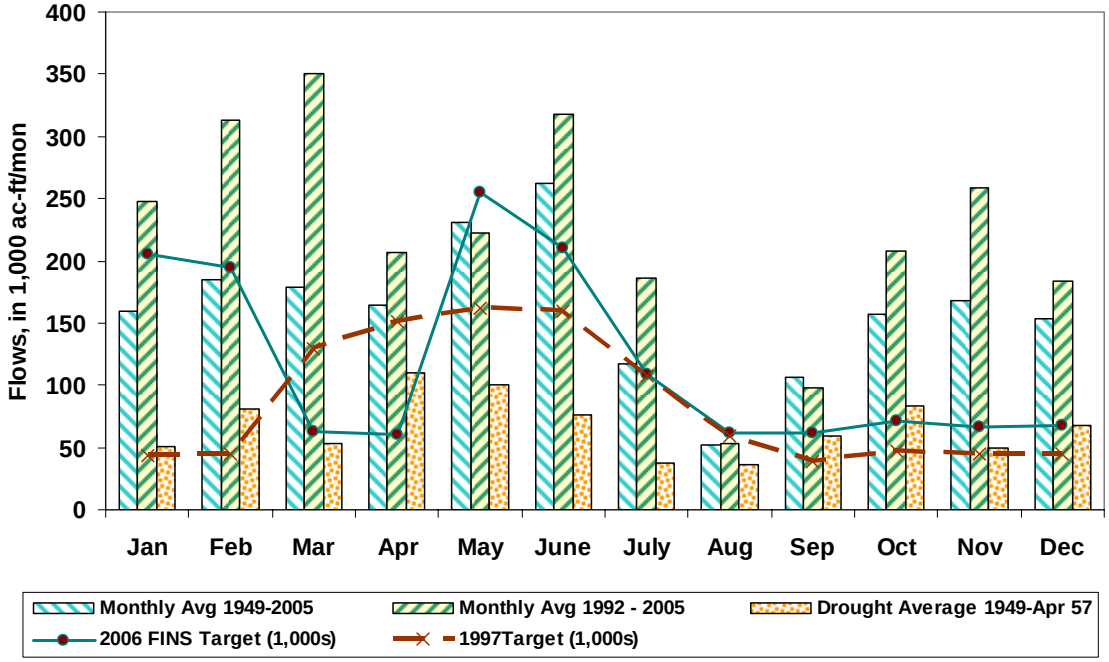


Figure 7.9 Comparison of 1997 and 2006 FINS Estimates for Matagorda Bay with Colorado River Historical Monthly Average Flows at Bay City.

Each study had different methodologies and results. The original inflow recommendations were designed to "maintain the fisheries harvest," while the recommended river flows in 1987 were designed to "maintain the mean shrimp harvest." The stated objective of the past two FIN studies has been to "optimize biological productivity at least at 80 percent of historical levels." While the monthly inflow distribution from each of the studies varies, there is consistency in the overall flow patterns (freshest in the spring and again in the fall). It has been hypothesized that the spring "freshet" has an immediate benefit to the estuary by lowering salinities and providing nutrients that drive the primary productivity of the bay for the current year-class juvenile organisms. Fall flows appear to act as a flushing mechanism to push the current year-class from the marshes and nursery areas into the open bay and Gulf. The fall flows are also thought to benefit the next year's juvenile year-class.

While management objectives for Intermediate flows have not been clearly developed, monthly flow solutions derived from TXEMP using widened constraints were presented in this section. Several Intermediate flow solutions, i.e. solutions representing annual inflow amounts lying between Target and Critical, were presented for consideration when developing Intermediate flow objectives and solutions.

Chapter 8

Hydrodynamic and Salinity Transport Model

8.1 Introduction

The TXEMP optimization model (Chapter 7) was used to compute monthly target flows for Matagorda Bay. Statistical equations were used (Chapter 9) to develop critical flow requirements. This chapter describes the use of a hydrodynamic and salinity transport model, TXBLEND, to evaluate the effect on bay salinity of providing these flows. The model calculates temporal and spatial variations in salinity using inflows, tides and meteorological inputs.

8.2 Model Description

TXBLEND is an adaptation of a finite-element hydrodynamic and conservative transport model developed in the 1980s (Gray, 1987) to simulate tidally driven circulation in estuaries. The model has been applied to freshwater inflow needs studies of estuaries in Texas (LCRA, 1997; Kuhn and Chen, 2005), and is currently used to predict currents in Galveston Bay, Corpus Christi Bay and Sabine Lake to support the Texas General Land Office's Oil Spill Prevention and Response Program[1].

TXBLEND solves the two-dimensional, vertically averaged form of the equations of motion for a fluid, the equations for conservation of mass and the advection-diffusion equations applied to transport of salt. Model inputs include inflows for major rivers and streams that drain into Matagorda Bay and adjacent bays, Gulf of Mexico tidal elevations, wind, rainfall and evaporation. Given these inputs, the model computes the temporal variation of water velocity, water depth and salinity at each point in the numerical grid that describes the system. The computational time step applied in this study was 180 seconds. Model outputs were provided at hourly intervals.

[1] http://hyper20.twdb.state.tx.us/data/bays_estuaries/bhydpage.html

8.2.1 Model Domain

The numerical grid describing the model domain contains 10,608 triangular elements and 6,799 nodal points (Figure 8.1). The grid represents San Antonio Bay, Matagorda Bay, East Matagorda Bay and the Gulf of Mexico. It includes 15 inflow locations including the Colorado River, Lavaca River, Guadalupe River and major coastal tributaries (Figure 8.2). Bay bathymetry (Figure 8.3) was based on bathymetry data used in a modeling study by the Corps of Engineers (USACE, 2003). This data was provided to TWDB and subsequently modified using Surface Water Monitoring System (SMS) software to extend the grid westward to include San Antonio Bay and to make the Gulf of Mexico one continuous boundary.

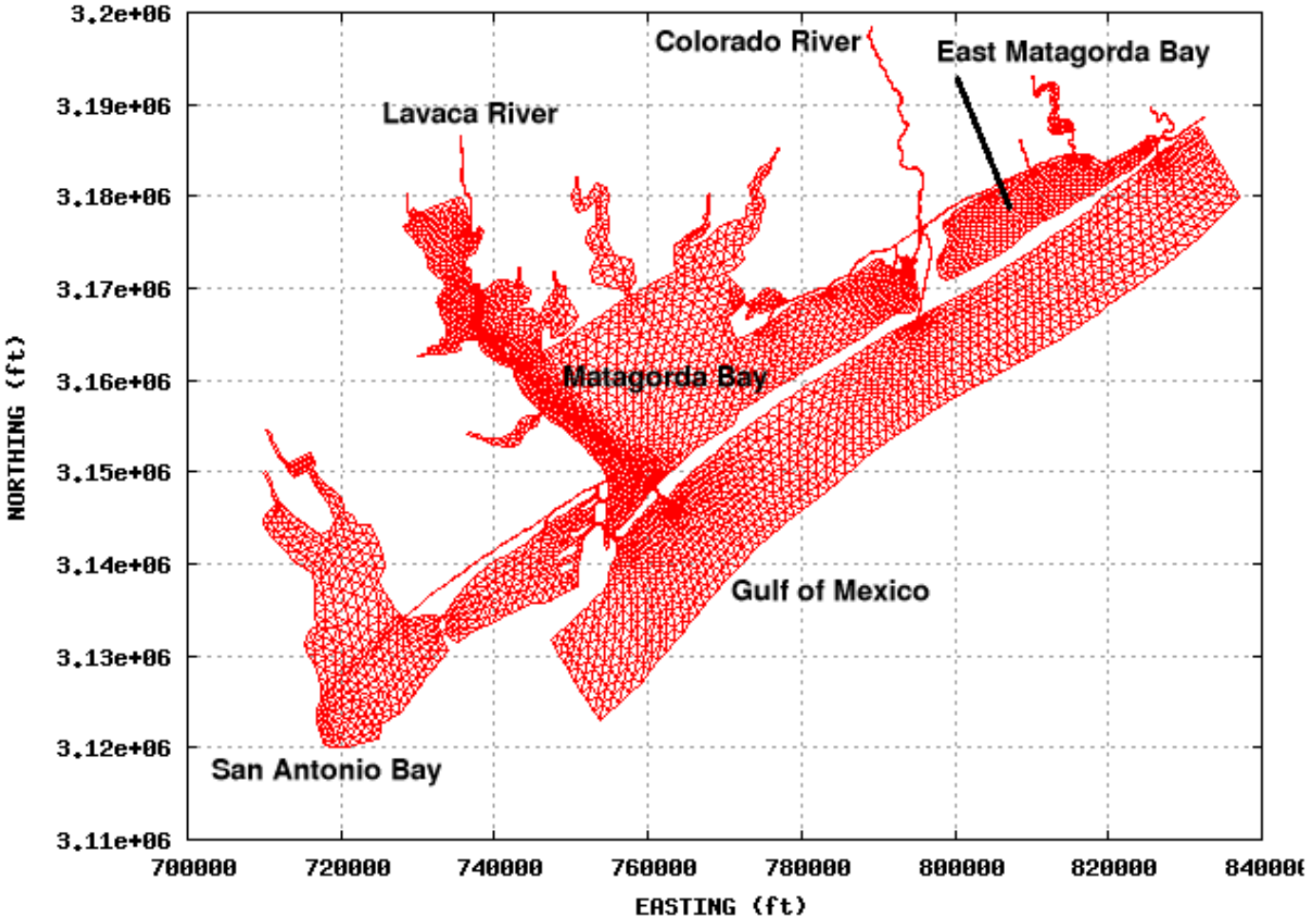


Figure 8.1 TXBLEND Numerical Grid.

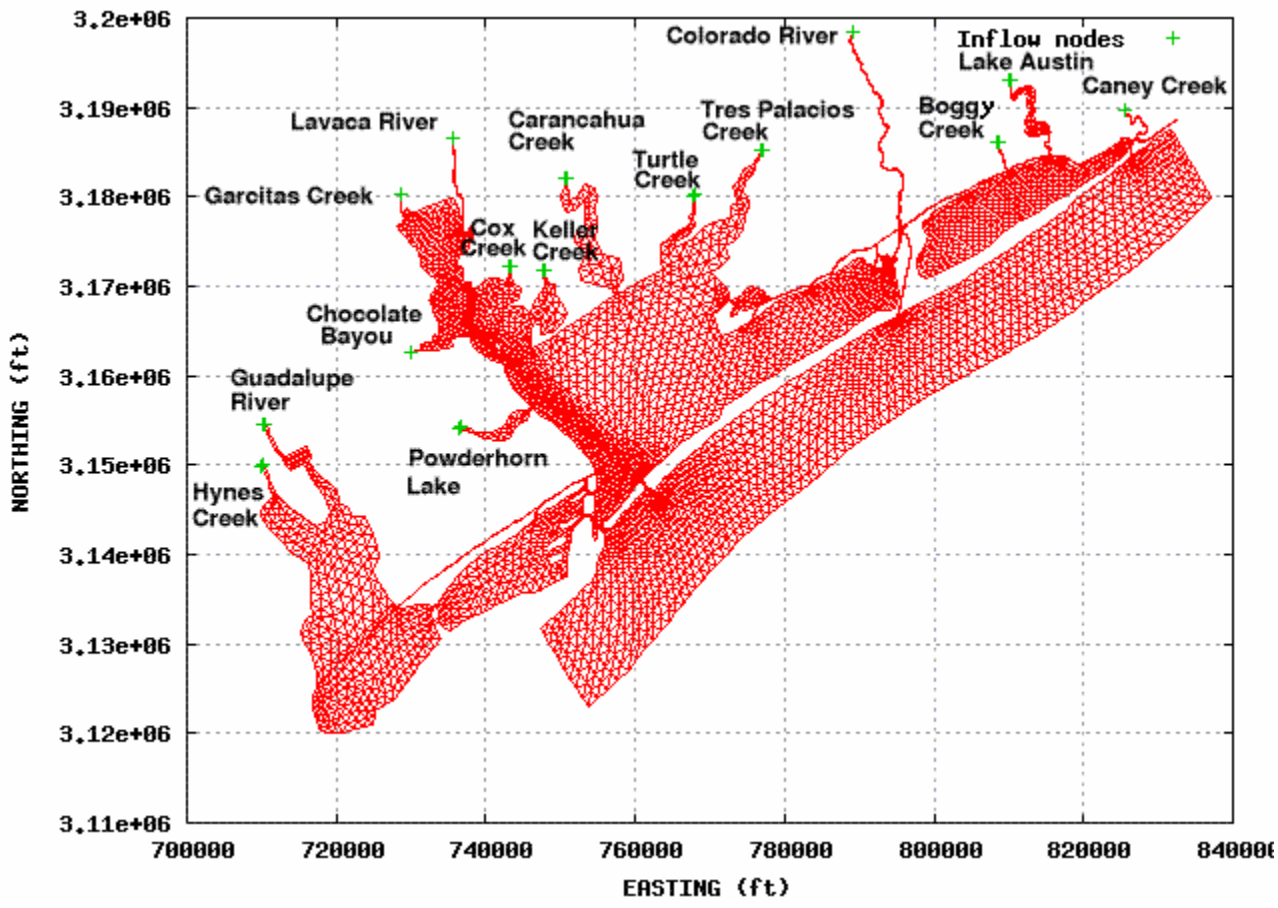


Figure 8.2 Inflow Locations (green markers) Used in Matagorda Bay TXBLEND Model.

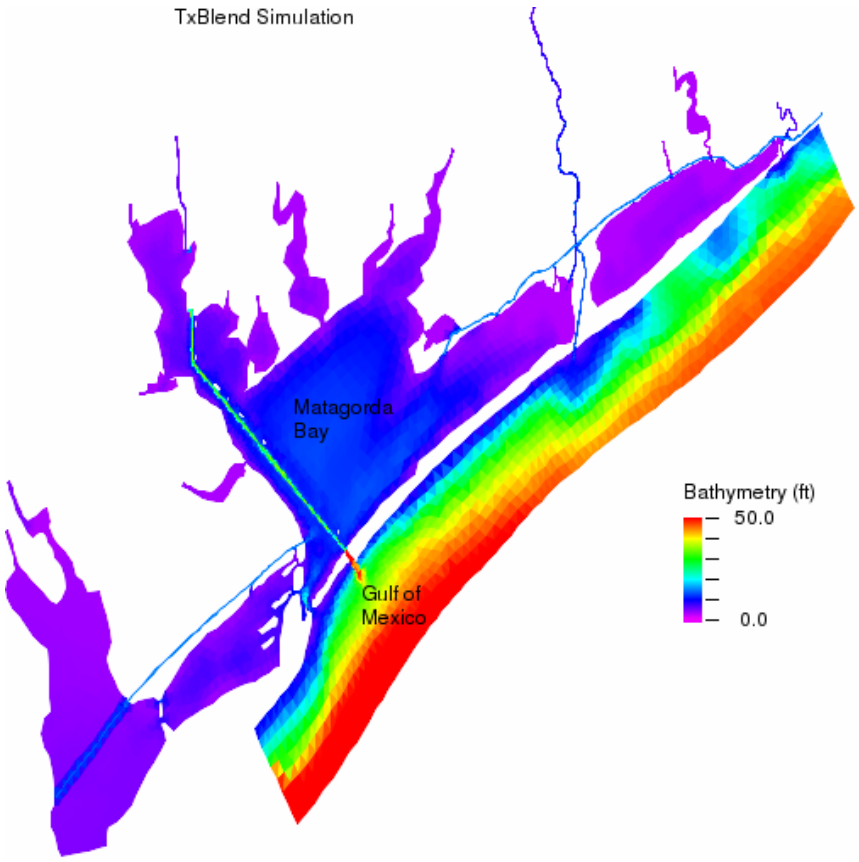


Figure 8.3 Bathymetry for Matagorda Bay used in TXBLEND.

8.2.2 Inflows

Daily inflow data for the fifteen inflow sites in the Matagorda Bay model grid was provided by TWDB. Inflows from 1997 through 2003 were used to calibrate TXBLEND (Figures 8.4.a to 8.4.o). Flows for the Colorado River and Guadalupe River were based on USGS streamflow gages at Bay City and Victoria, respectively. Flows for the Lavaca River were based on releases from Lake Texana. Daily inflows from the coastal watersheds for adjacent to the bay were computed with the TxRR rainfall runoff model with adjustments for known diversions and return flows in the watersheds.

Flows from 1997 through 2003 were highly variable. The second and third largest annual inflows to Matagorda Bay occurred in 1997 and 1998, respectively, surpassed only by flows in 1992 (Table 2.1). Flows for the two year period from 1997 through 1998 rank at the 95th percentile for bi-annual flows, and flows from 2001 through 2002 rank at the 90th percentile of bi-annual flows. Flows in 1999 and 2000 rank as the 22nd and 23rd percentile flows. Flows during this two year-period represent the 16th percentile flow for bi-annual flows. The large variability of flows during this period makes it well-suited for the purpose of calibrating TXBLEND.

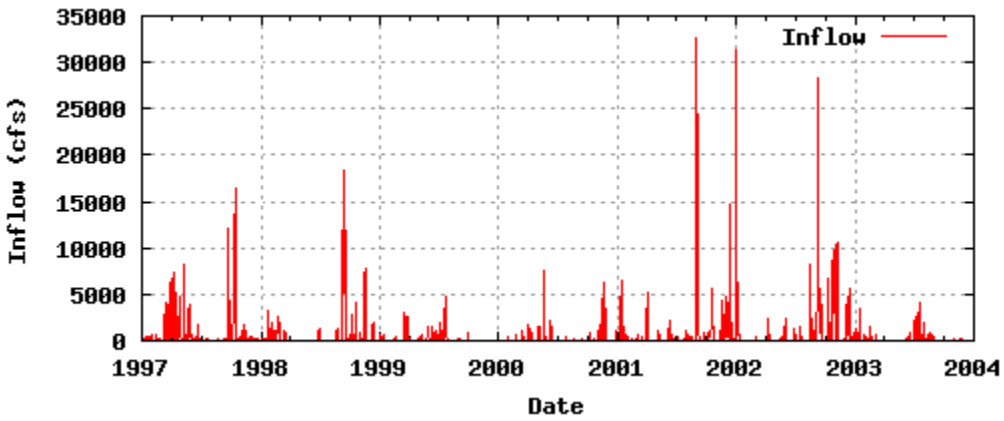


Figure 8.4.a Inflow Hydrograph for Caney Creek.

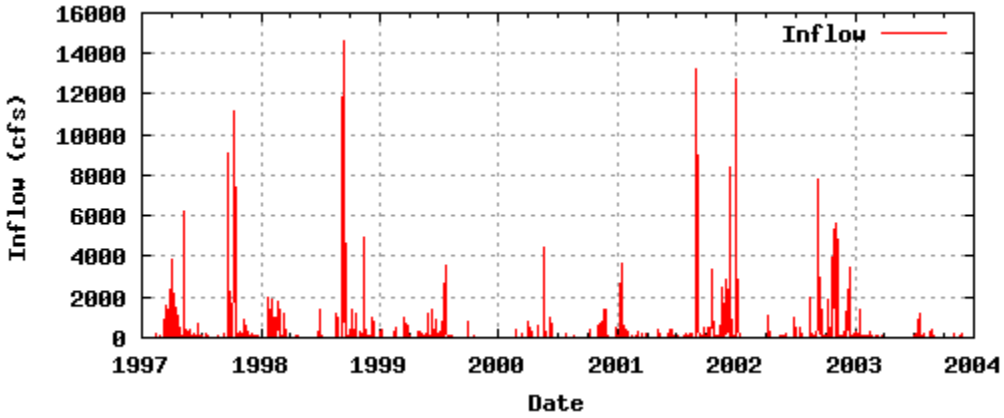


Figure 8.4.b Inflow Hydrograph for Lake Austin.

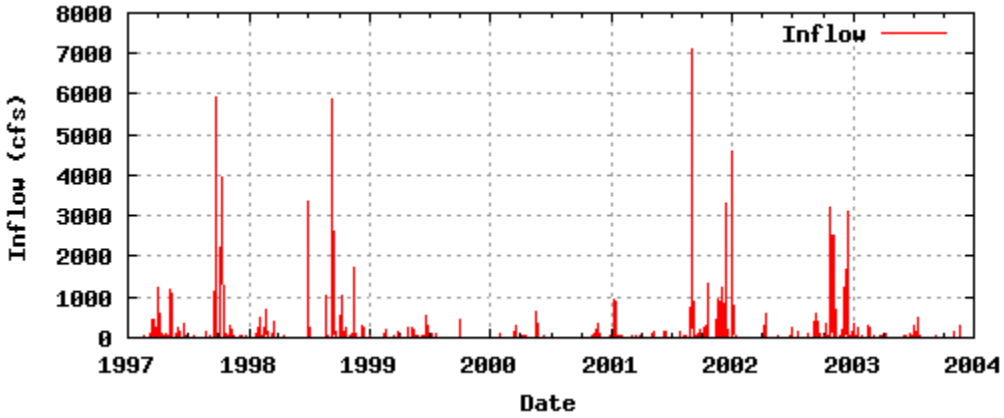


Figure 8.4.c Inflow Hydrograph for Boggy Creek.

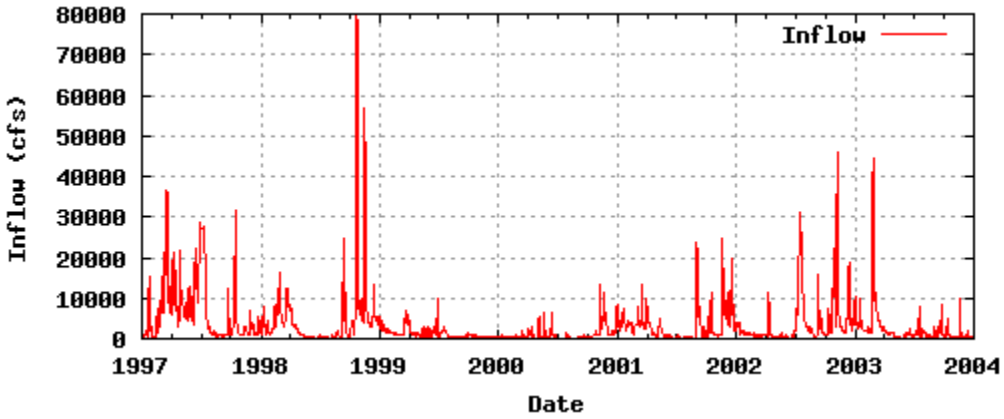


Figure 8.4.d Inflow Hydrograph for Colorado River.

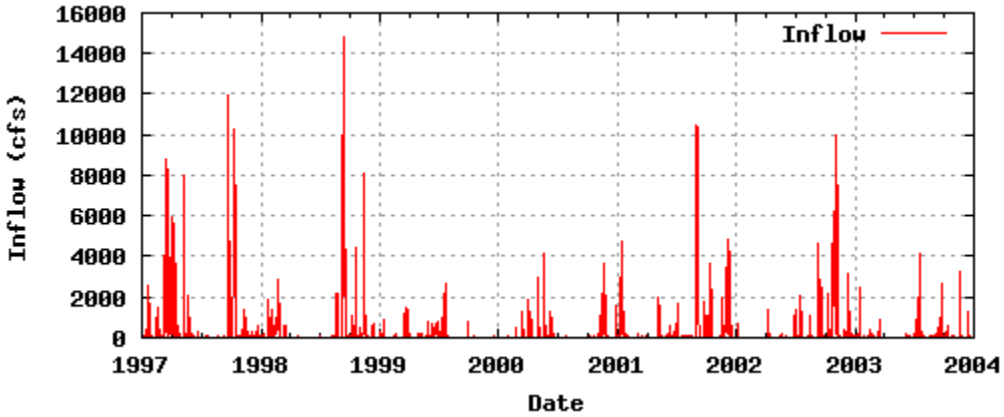


Figure 8.4.e Inflow Hydrograph for Tres Palacios Creek.

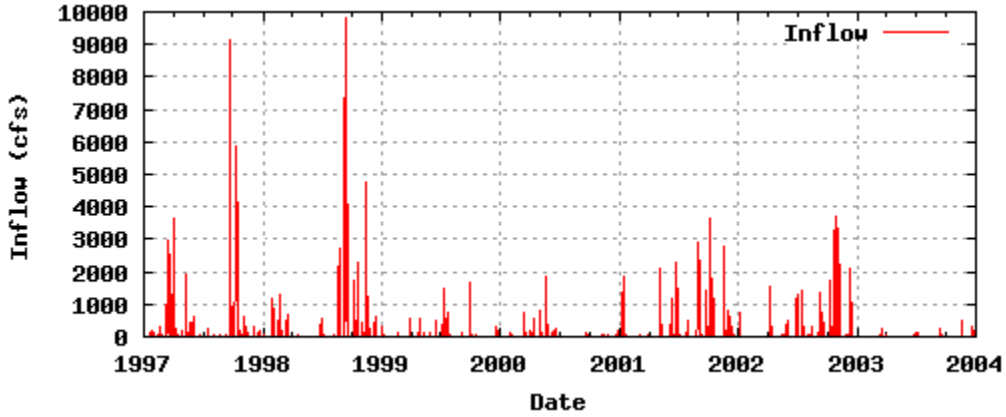


Figure 8.4.f Inflow Hydrograph for Turtle Creek.

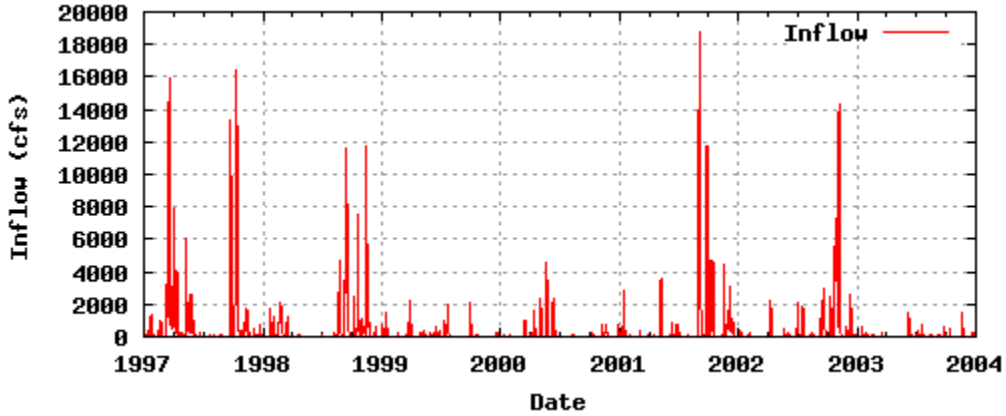


Figure 8.4.g Inflow Hydrograph for Carancahua Creek.

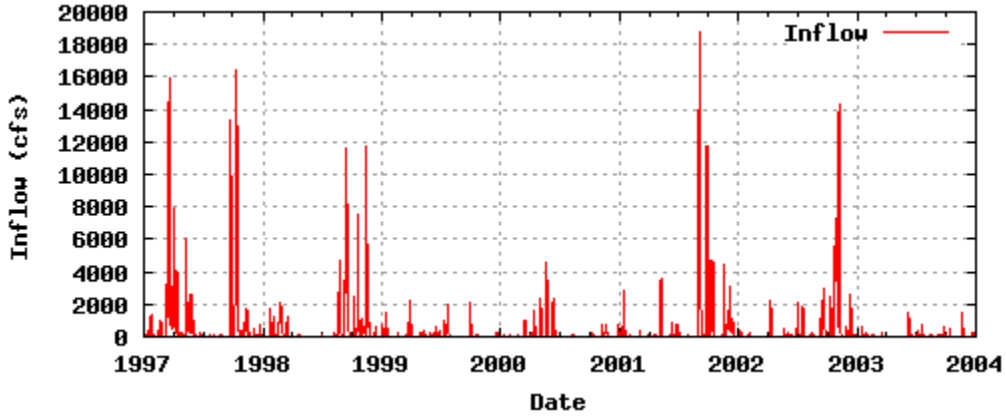


Figure 8.4.h Inflow Hydrograph for Keller Creek.

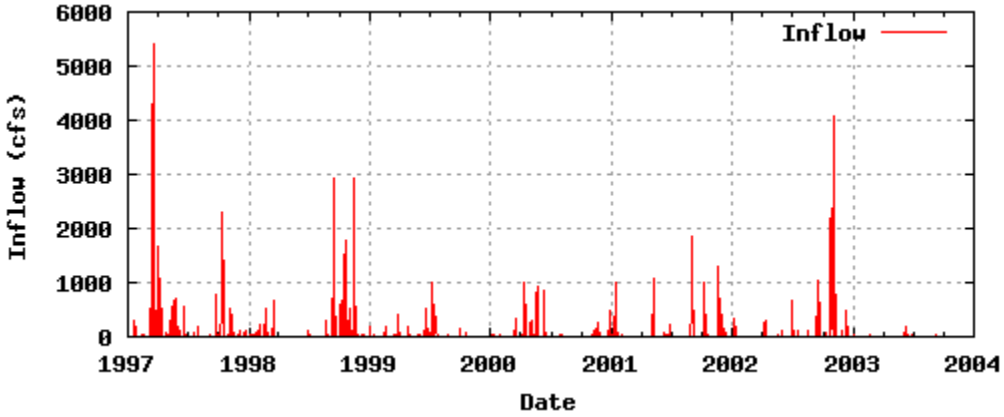


Figure 8.4.i Inflow Hydrograph for Cox Creek.

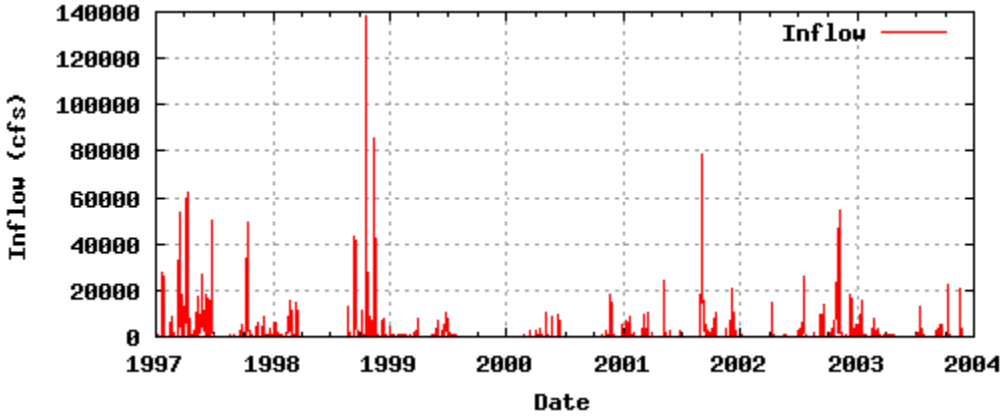


Figure 8.4.j Inflow Hydrograph for Lavaca River.

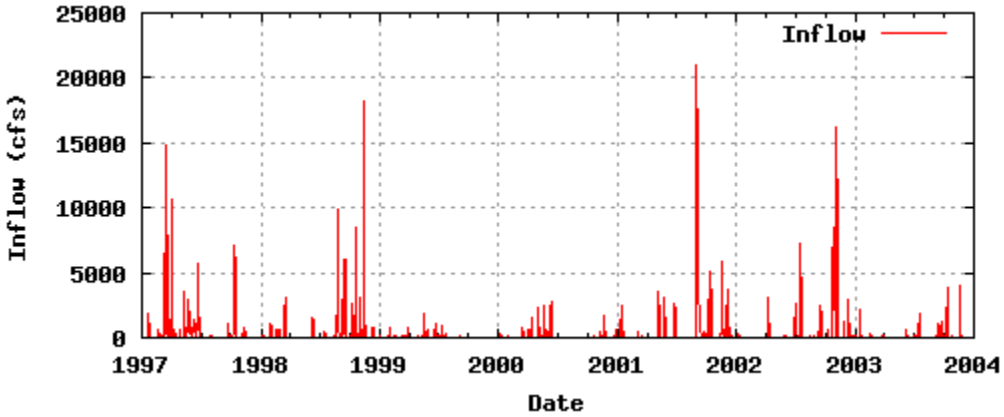


Figure 8.4.k Inflow Hydrograph for Garcitas Creek.

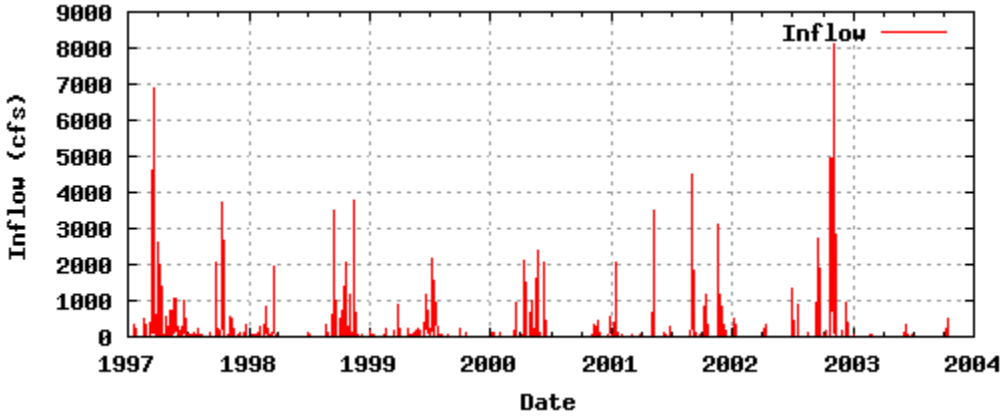


Figure 8.4.l Inflow Hydrograph for Chocolate Bayou.

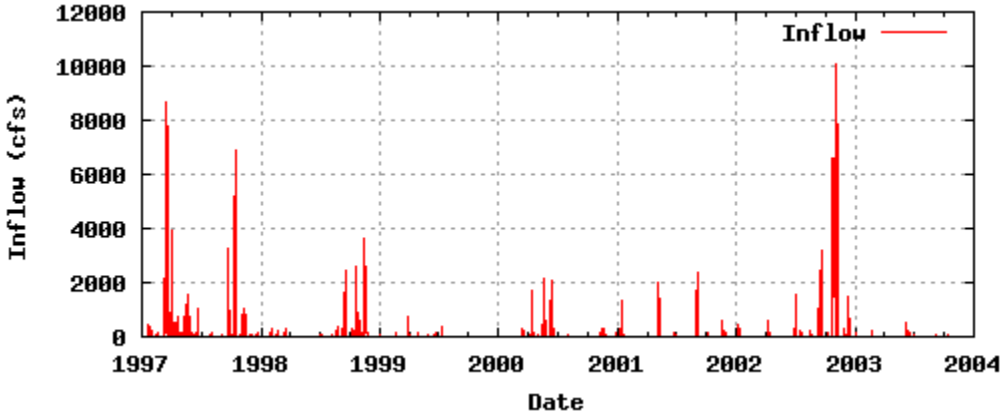


Figure 8.4.m Inflow Hydrograph for Powderhorn Lake.

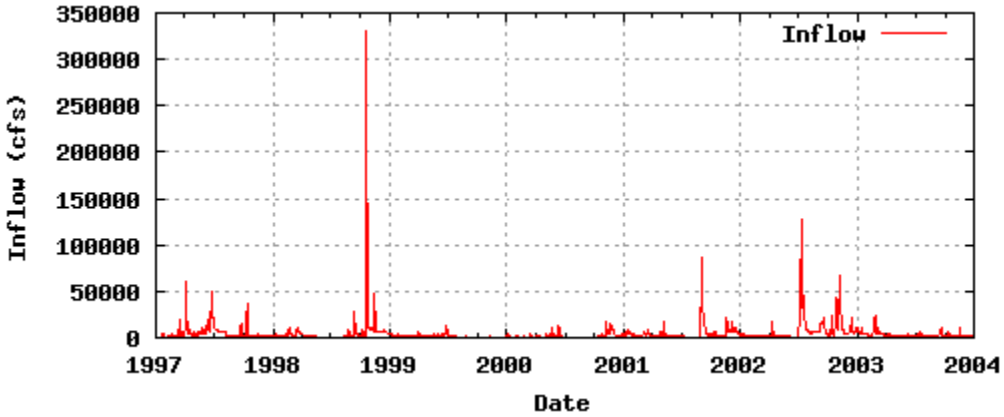


Figure 8.4.n Inflow Hydrograph for Guadalupe River.

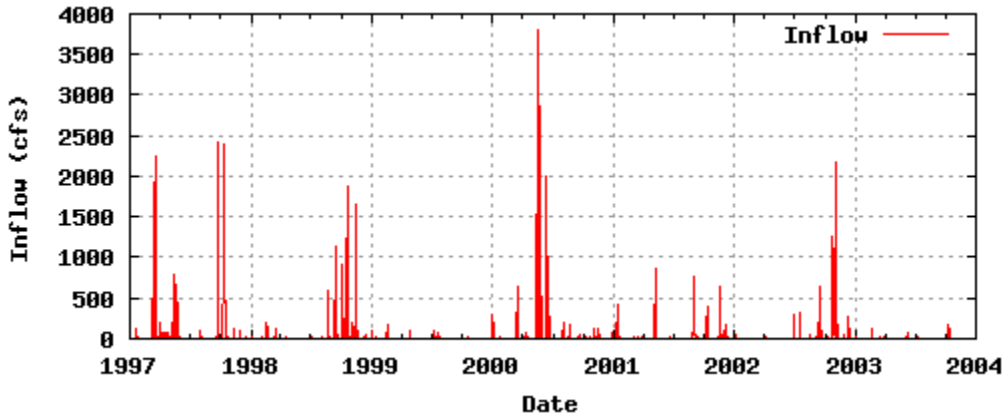


Figure 8.4.o Inflow Hydrograph for Hynes Creek.

8.2.3 Tides

Tidal elevations for Galveston Pleasure Pier were obtained from Conrad Blucher Institute[2] (Figure 8.5) and applied at the Gulf boundary in TXBLEND. Missing data was filled in using a least-squares method for computing harmonic constants (Dronkers, 1964). The data was reformatted to a bi-hourly format for use in TXBLEND. Tides in this region of the Gulf coast typically range from 3 to 4 feet, with occasional drops and surges due to passing tropical depressions and hurricanes. The time lag between the tide at Pleasure Pier and the coast off of Matagorda Bay is on the order of minutes. This was not considered significant in this study and was not incorporated into the model.

8.2.4 Meteorology

A time-varying, spatially uniform wind field (Figure 8.6) is applied in TXBLEND to compute wind stress at the water's surface. Wind speed and direction from January 1987 through November 2003 were obtained from the National Climatic Data Center for the Palacios Municipal Airport.

Rainfall and evaporation (Figure 8.6) are included in the water budget for Matagorda Bay by TXBLEND. Daily precipitation was provided by TWDB for the watershed WS15010

[2] http://lighthouse.tamucc.edu/overview/022

representing Matagorda Bay. Evaporation data was also provided by TWDB and is based on measurements of pan-evaporation.

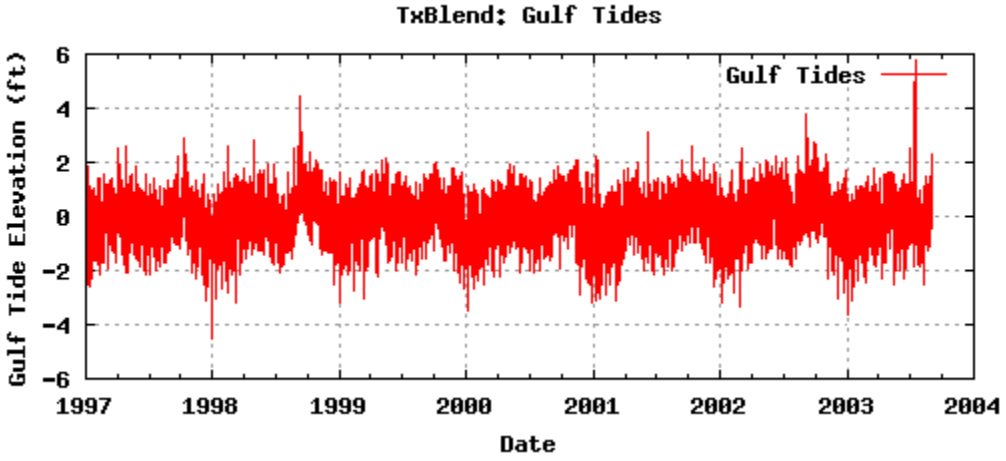


Figure 8.5 Tidal elevations, 1997 through 2003. Data obtained from Conrad Blucher Institute.

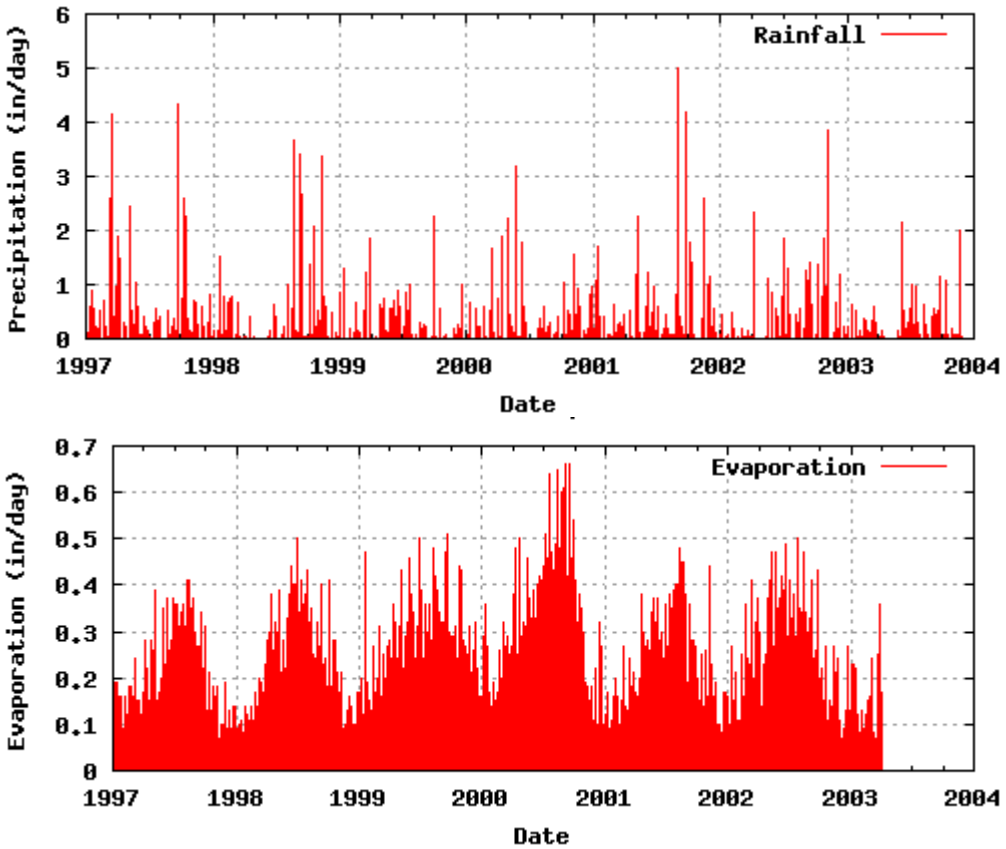


Figure 8.6 Rainfall (top) and Evaporation (bottom), 1997 through 2003. Data Provided by TWDB.

8.2.5 Gulf Boundary Salinity

A time-varying salinity boundary condition (Figure 8.7) was applied in TXBLEND at the Gulf boundary. This boundary condition was supplied by TWDB and was developed by averaging TPWD data collected offshore of the Entrance Channel and Pass Cavallo. Salinity varies significantly at this boundary, ranging from less than 24 ppt to over 37 ppt.

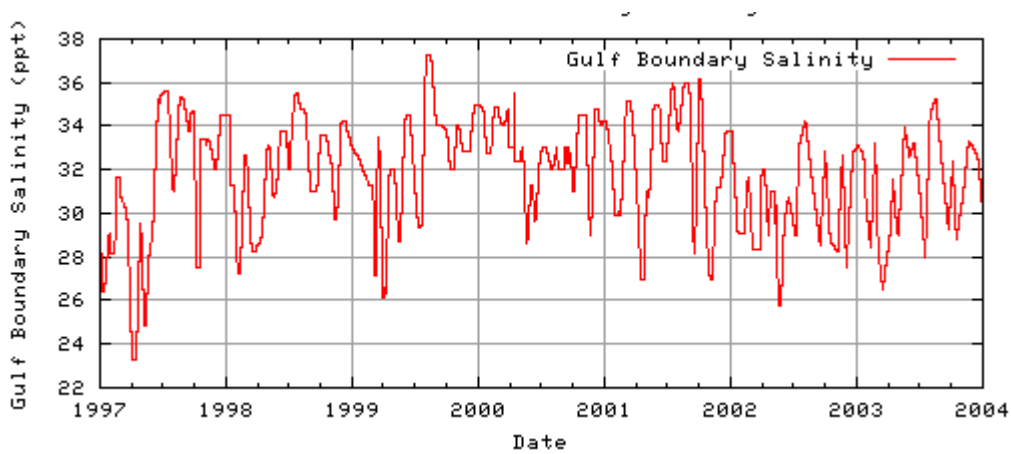


Figure 8.7 Gulf Salinity Boundary Condition, 1997 through 2003. Data provided by TWDB.

8.3 Model Calibration

Hydrodynamics in TXBLEND were calibrated by comparing computed water surface elevations and flows to data collected at eighteen sites (fourteen for flow, four for water surface elevation) in Matagorda Bay during a March 2003 field study (Figure 8.8, Table 8.1, Figures 8.9.a to 8.9.m, Figures 8.10.a to 8.10.d). Flow was measured during this study using acoustic Doppler profilers (ADCP) whereby velocity data is collected across the entire channel cross section. For the Magnolia Beach (Site 4) and Eastern Arm of Matagorda Bay (Site 6A) sites, the ADCP transects covered wide sections of the bay and were useful in monitoring movement of water into the far reaches of the bay.

Manning's n was adjusted during the calibration process and varied from 0.0211 to 0.0244 in the final calibrated model. Channel depths and widths were also adjusted at some sites within acceptable ranges. These adjustments to depths and widths were

considered reasonable given the dynamic nature of channels in the system and the lack of recent bathymetric data for these sites.

Both the flow amplitude and phase match well in the calibrated model at major flow locations including the Matagorda Entrance Channel (Site 1), Pass Cavallo (Site 2A), Magnolia Beach (Site 4), the Eastern Arm of Matagorda Bay (Site 6A), and the Bypass Channel (Site 8C). Flows at the intersection of the Colorado River and GIWW do not match as well, likely because the model simulates open lock conditions, while the locks were closed during most of the field study.

Modeled water surface elevations were compared to measured elevations obtained from the Texas Coastal Ocean Observation Network (TCOON) for sites at Rawling's Bait Stand (mouth of the Bypass Channel, TCOON Site 54), Port Lavaca (Lavaca causeway, TCOON Site 33), Port O'Connor (TCOON site 57), and Seadrift, (San Antonio Bay, TCOON Site 31). Modeled elevations matched measurements well at all sites.

Transport and mixing processes were calibrated in the model using long-term salinity data collected at eleven sites (Figure 8.11) in the bay from 1997 through 2003 (8.13). This period experienced a wide range of inflows and salinity, making it desirable for calibration purposes. Also, multiple monitoring sites were available for this period, while only three sites were available prior to 1997. The model matches long-term rises and falls in observed salinity well at all points in Matagorda Bay and East Bay, but is not as successful in matching the ranges of observed high frequency variations following flood events and large salinity drops (see e.g. West Bay Tripod and Shellfish Marker B, Figures 8.12.g, and 8.12.h). Additional statistical comparisons between computed and observed salinities are presented in Appendix G.

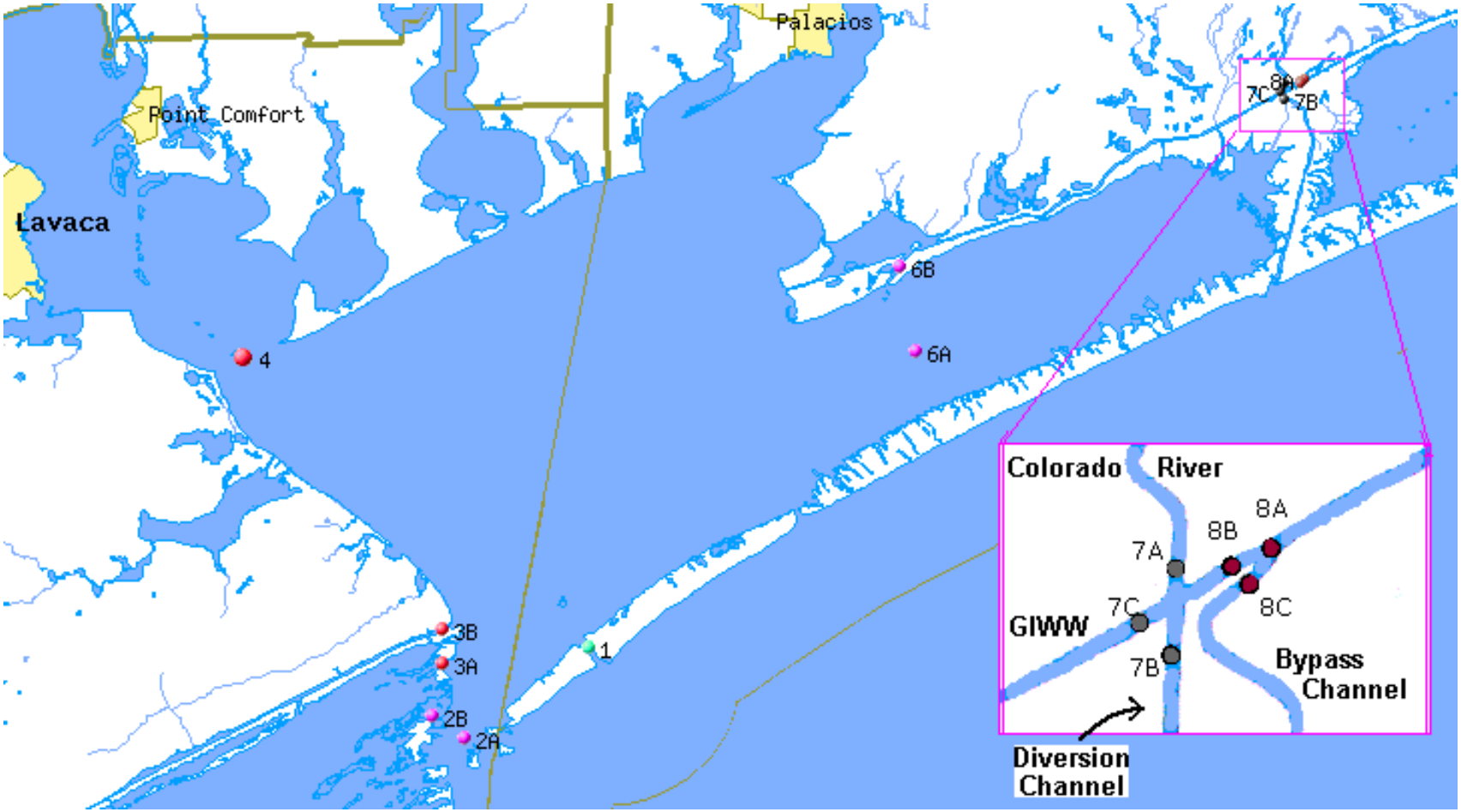


Figure 8.8 Site Map for March 2003 Field Study Measurement Locations.[3]

[3] http://hyper20.twdb.state.tx.us/data/bays_estuaries/studies/mat03main.html

Table 8.1 Site Names and Number for March 2003 Field Study.

Site Name	Site Number
Matagorda Entrance Channel	1
Pass Cavallo	2A
Saluria Bayou	2B
Big Bayou	3A
GIWW at Port O'Connor	3B
Magnolia Beach	4
Eastern Arm of Matagorda Bay	6A
GIWW at Oyster Lake	6B
North Colorado River	7A
South Colorado River	7B
GIWW West of Locks	7C
GIWW East of Bypass Channel	8A
GIWW West of Bypass Channel	8B
Bypass Channel	8C

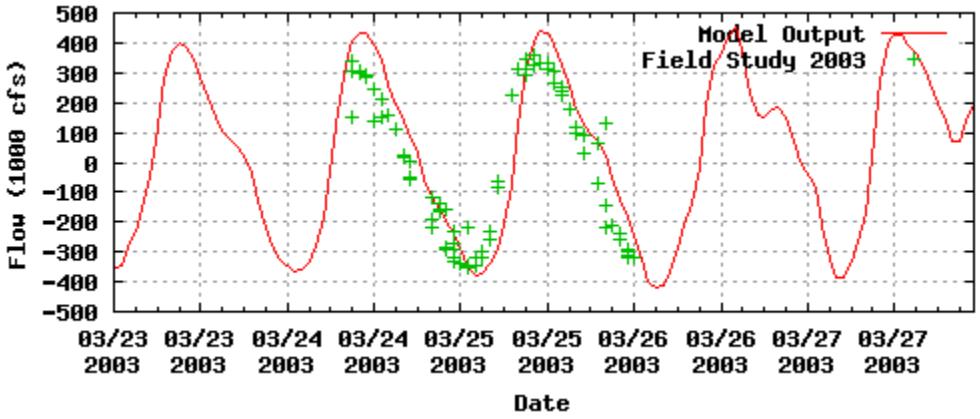


Figure 8.9.a – Measured (green crosses) and Computed (red line) Flows at Matagorda Entrance Channel (Site 1).

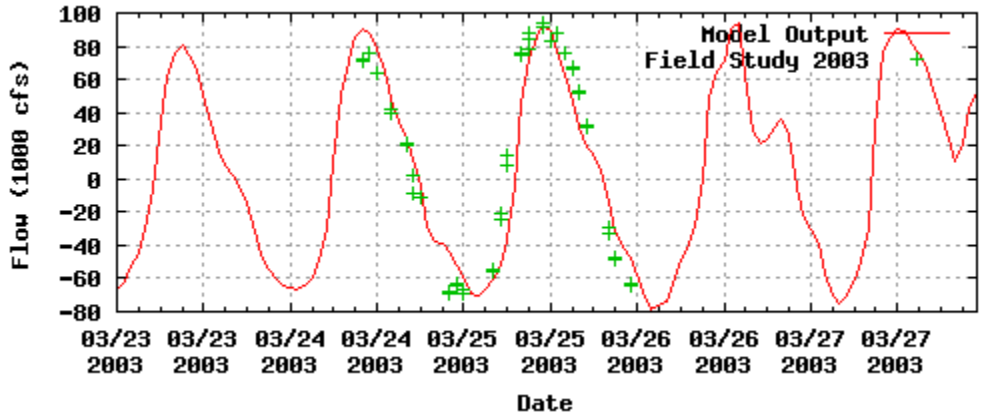


Figure 8.9.b Measured (green crosses) and Computed (red line) Flows at Pass Cavallo (Site 2A).

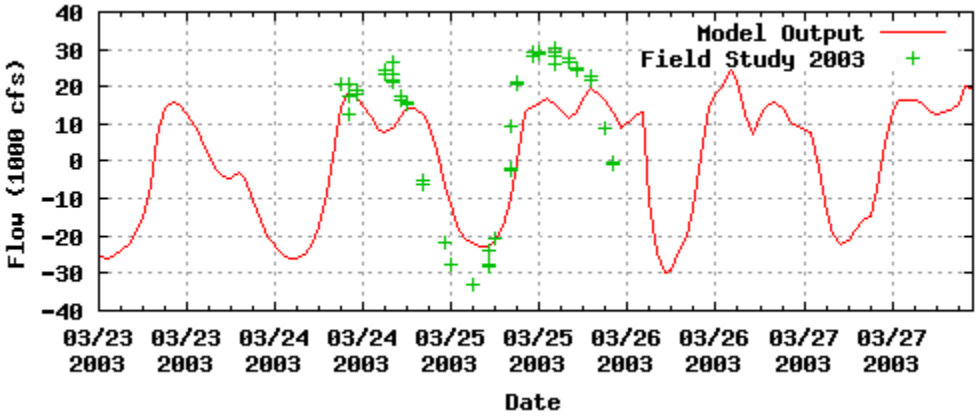


Figure 8.9.c Measured (green crosses) and Computed (red line) Flows at Saluria Bayou (Site 2B).

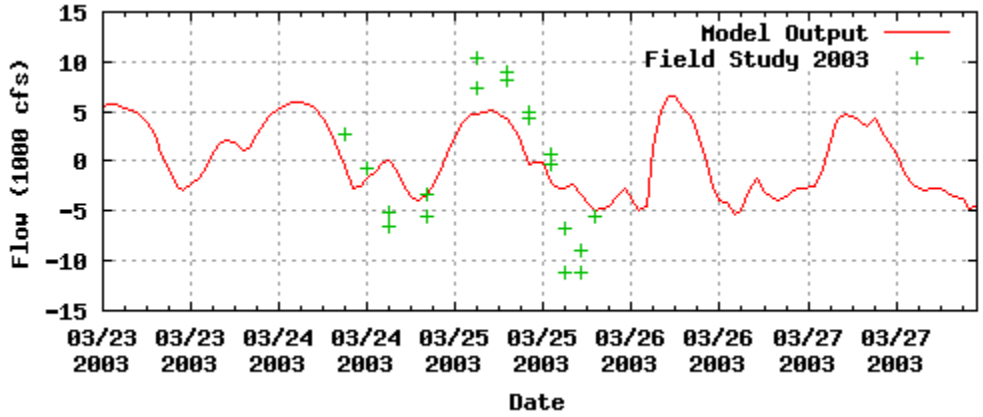


Figure 8.9.c Measured (green crosses) and Computed (red line) Flows at Big Bayou (Site 2C).

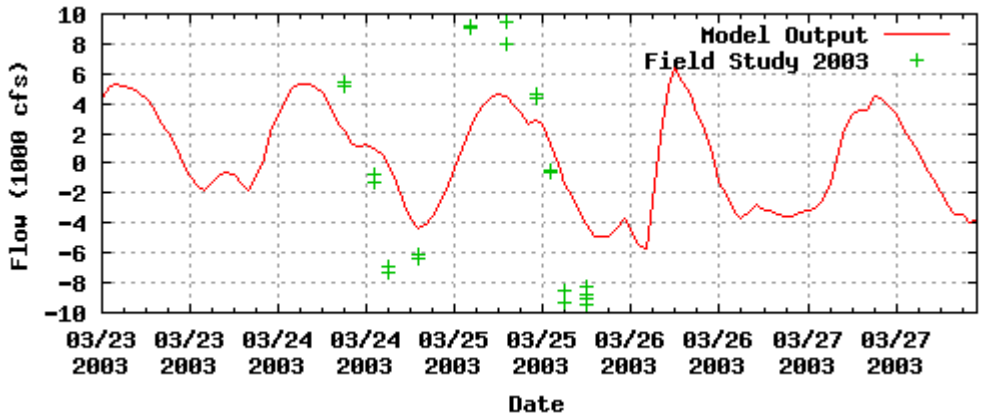


Figure 8.9.d Measured (green crosses) and Computed (red line) Flows at GIWW at Port O'Connor (Site 3B).

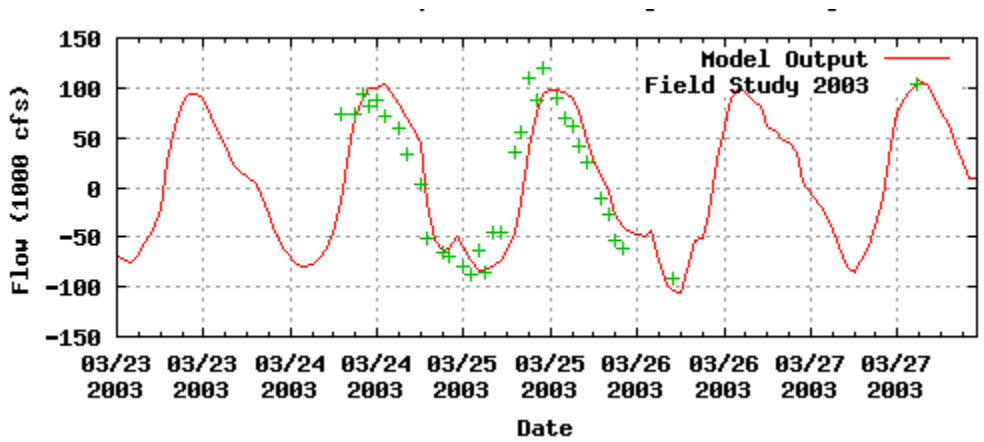


Figure 8.9.e Measured (green crosses) and Computed (red line) Flows at GIWW at Magnolia Beach (Site 4).

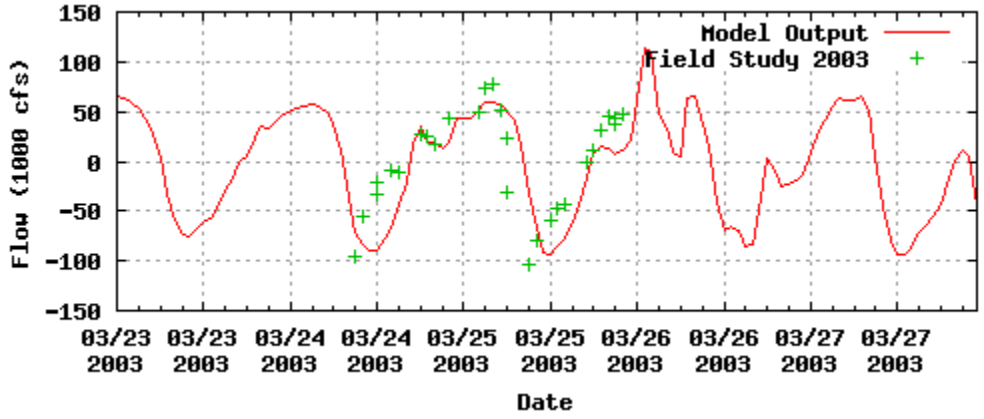


Figure 8.9.f Measured (green crosses) and Computed (red line) Flows at Eastern Arm of Matagorda Bay (Site 6A).

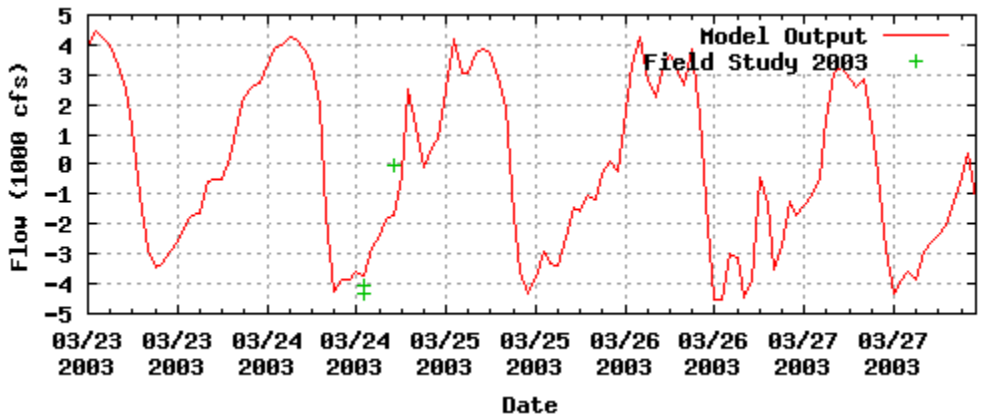


Figure 8.9.g Measured (green crosses) and Computed (red line) Flows at GIWW at Oyster Lake (Site 6B).

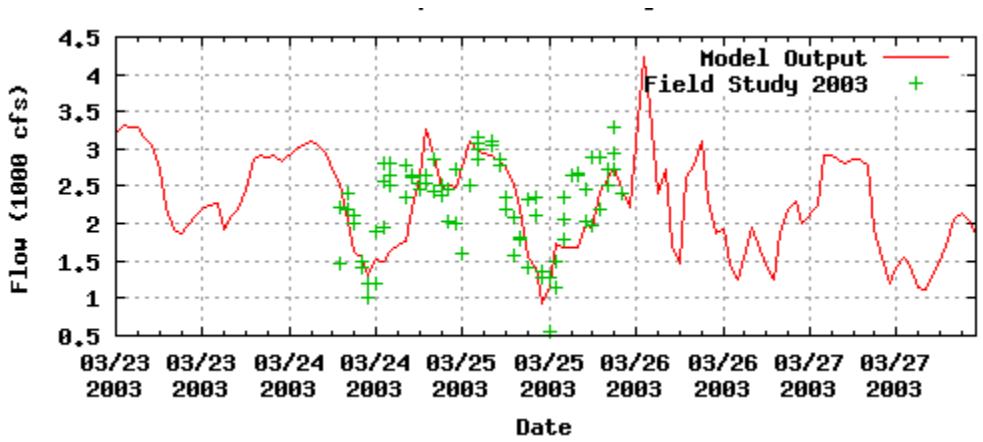


Figure 8.9.h Measured (green crosses) and Computed (red line) Flows at North Colorado River (Site 7A).

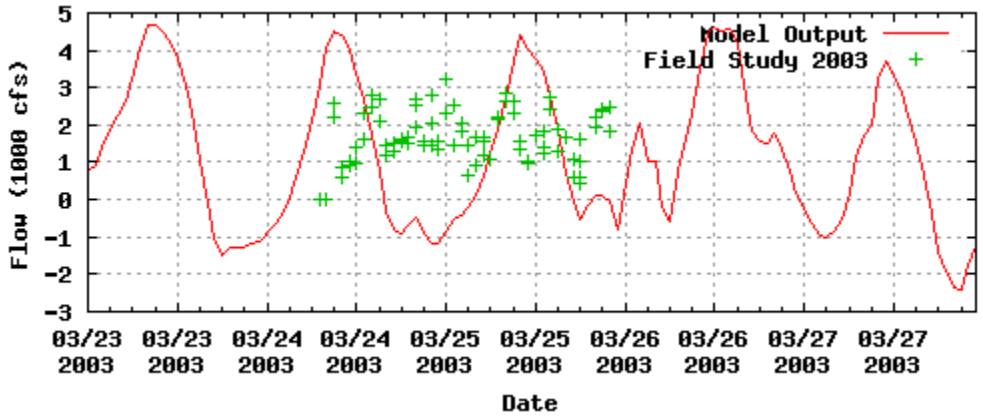


Figure 8.9.i – Measured (green crosses) and Computed (red line) Flows at South Colorado River (Site 7B).

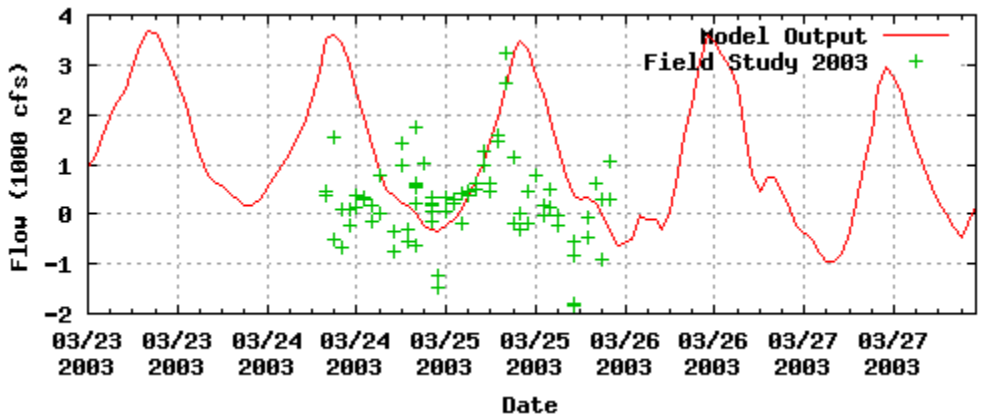


Figure 8.9.j Measured (green crosses) and Computed (red line) Flows at GIWW West of Locks (Site 7C).

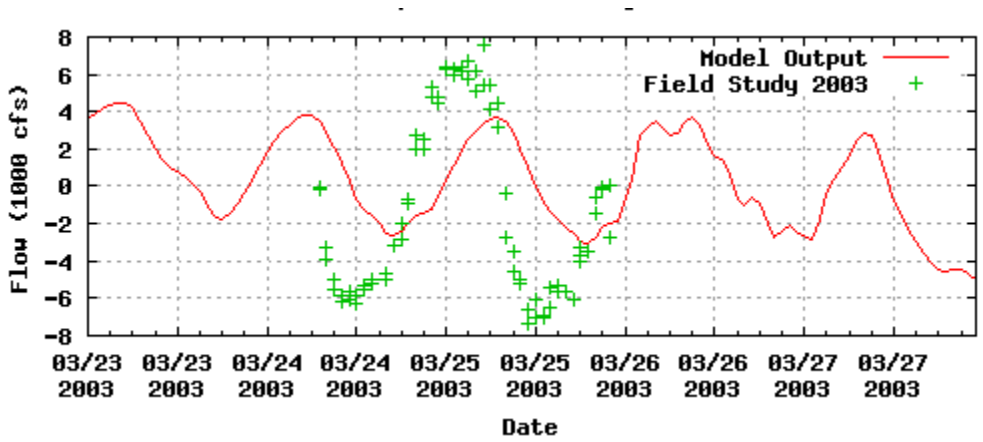


Figure 8.9.k Measured (green crosses) and Computed (red line) Flows at GIWW East of Bypass Channel (Site 8A).

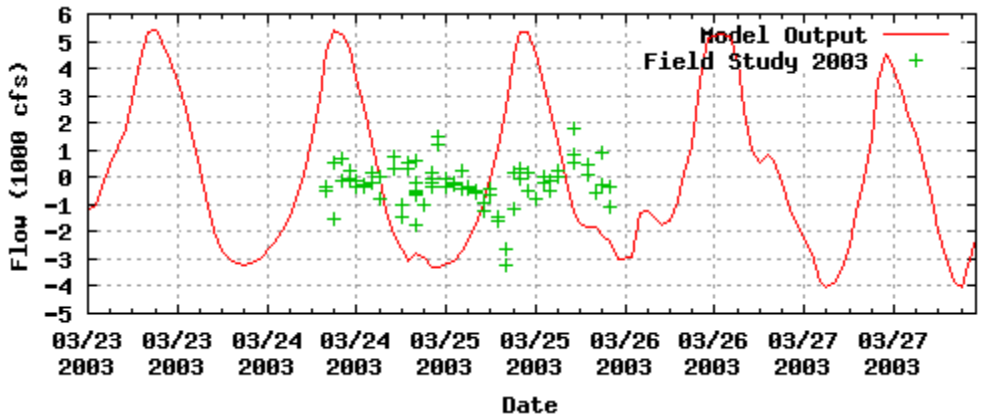


Figure 8.9.l Measured (green crosses) and Computed (red line) Flows at GIWW West of Bypass Channel (Site 8B).

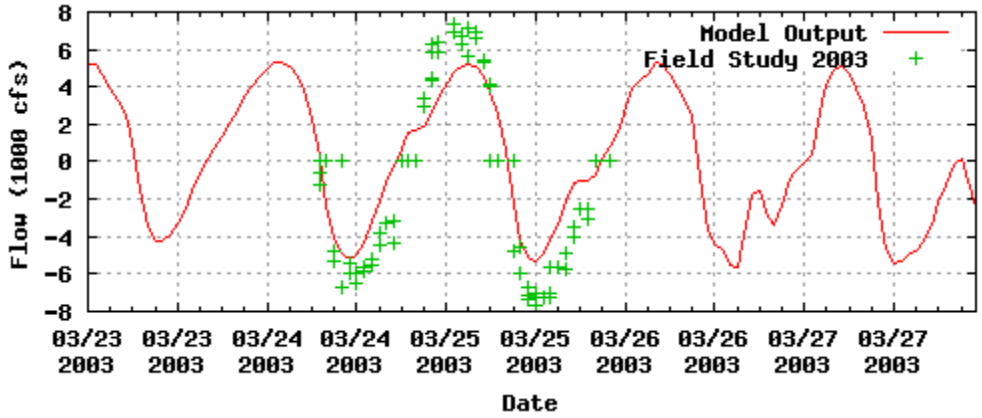


Figure 8.9.m Measured (green crosses) and Computed (red line) Flows at Bypass Channel (Site 8C).

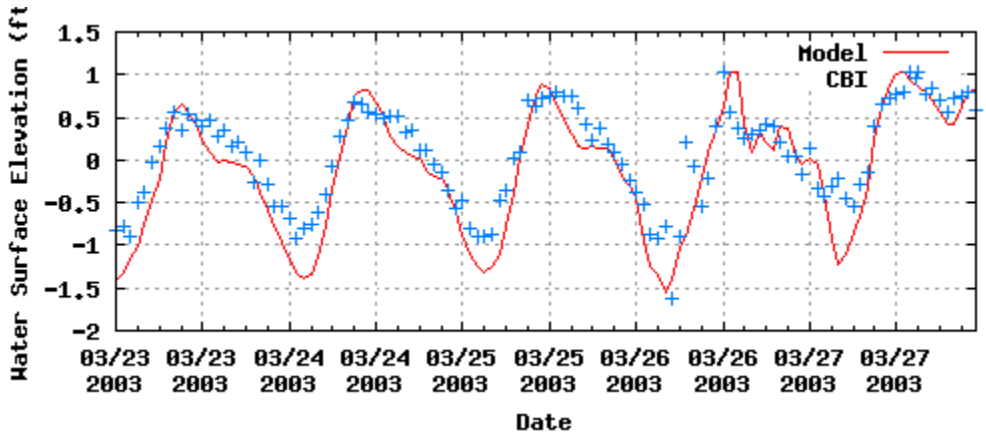


Figure 8.10.a Measured (blue crosses) and Computed (red line) Water Surface Elevation at Rawling's Bait Stand (TCOON site 54).

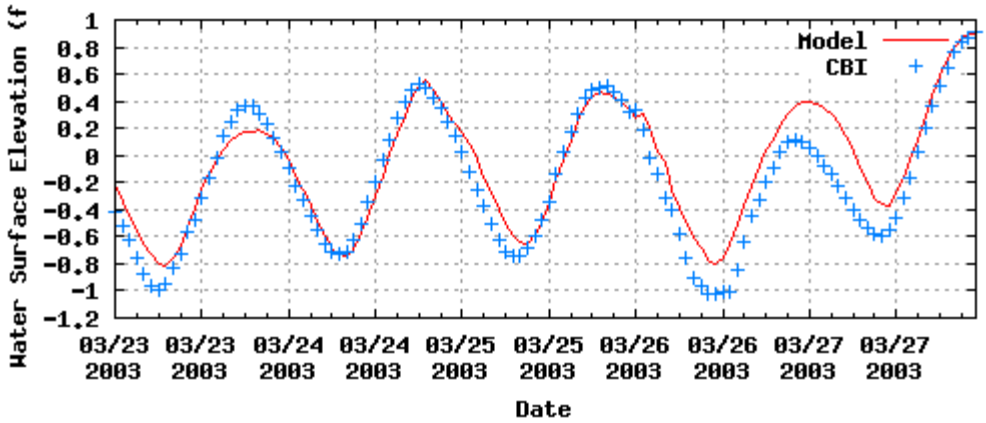
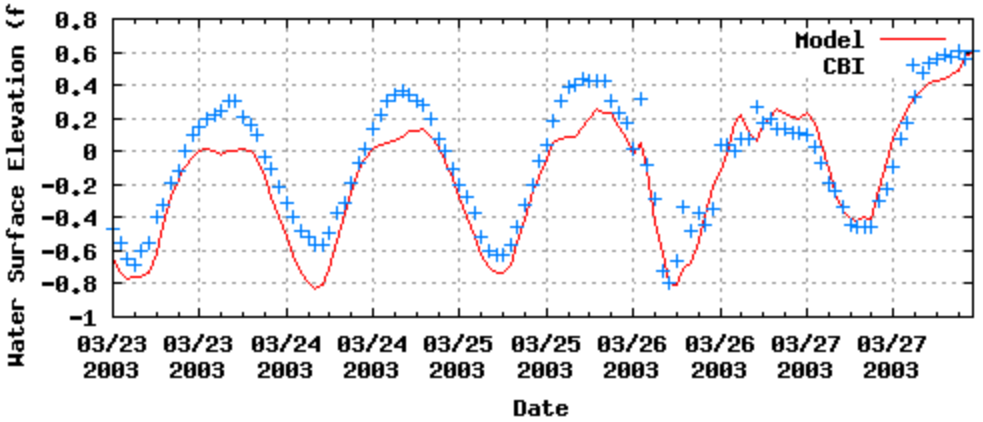
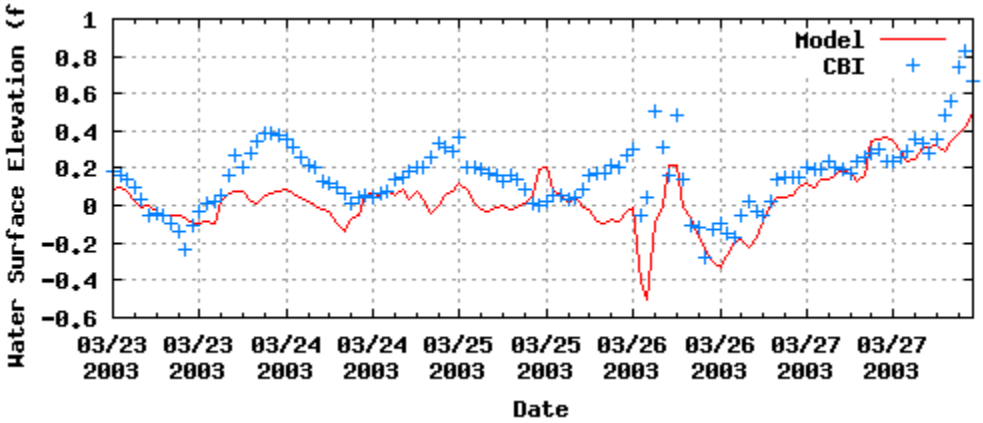


Figure 8.10.b Measured (blue crosses) and Computed (red line) Water Surface Elevation at Port Lavaca (TCOON site 33).



8.10.c Measured (blue crosses) and Computed (red line) Water Surface Elevation at Port O'Connor (TCOON site 57).



8.10.d Measured (blue crosses) and Computed (red line) Water Surface Elevation at Seadrift (TCOON site 31).

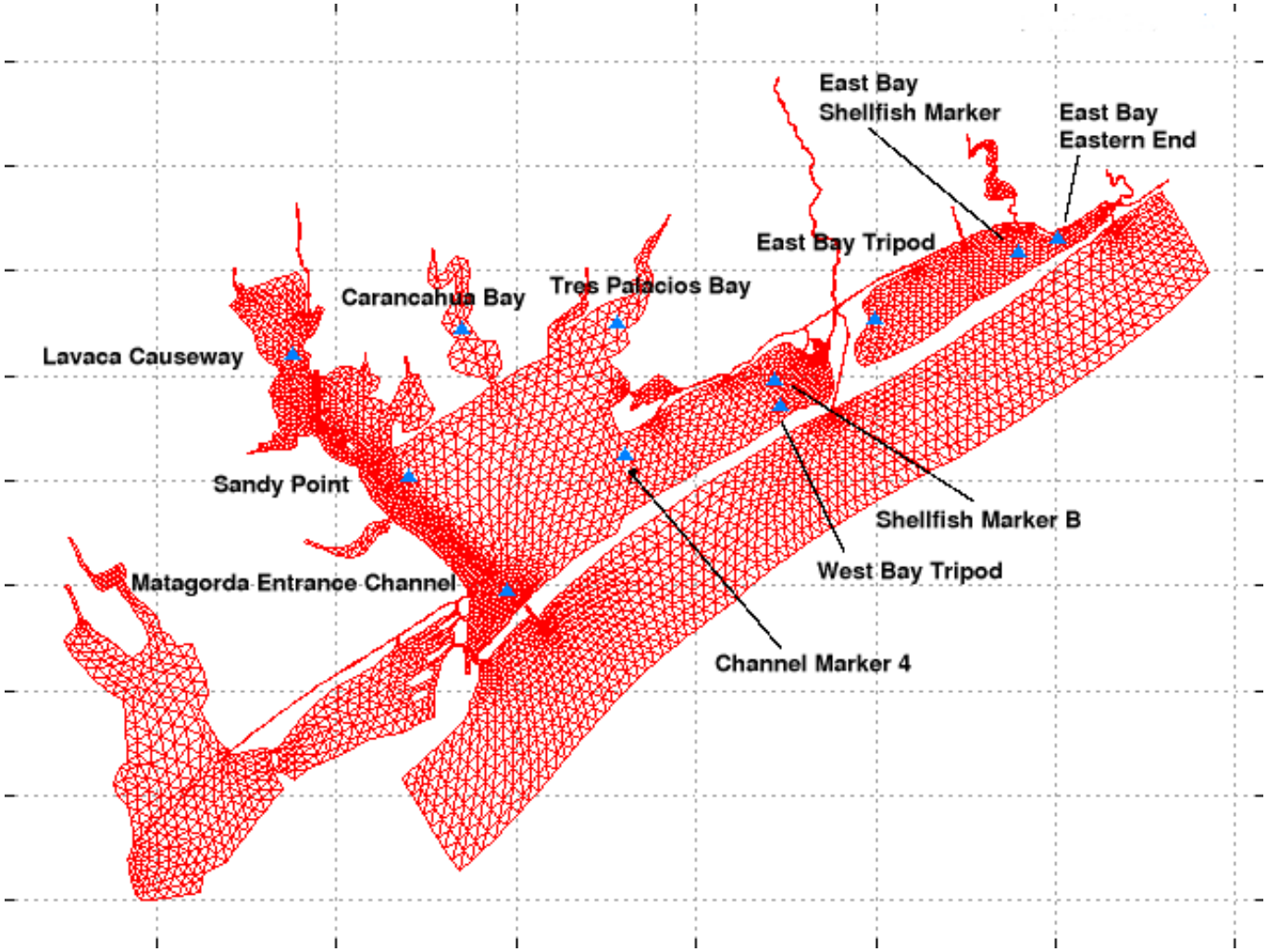


Figure 8.11 Locations of Datasonde Sites (blue triangles) Used in Calibrating TXBLEND.

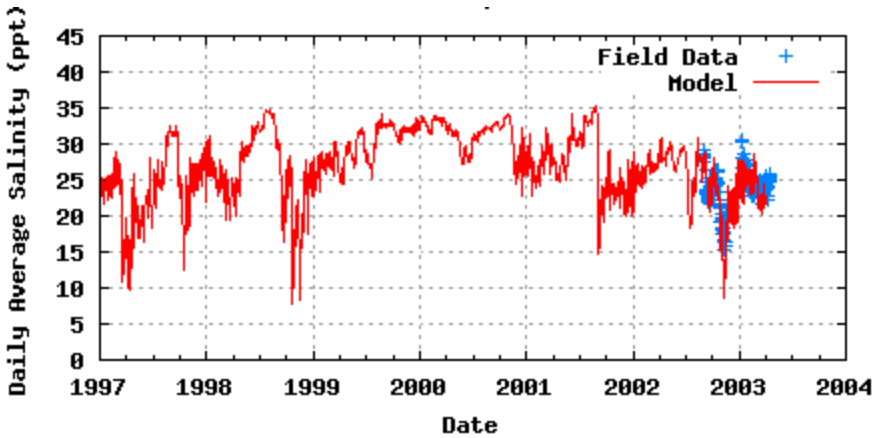


Figure 8.12.a Model (red) and Measured (blue) Daily-Average Salinity at Matagorda Entrance Channel.

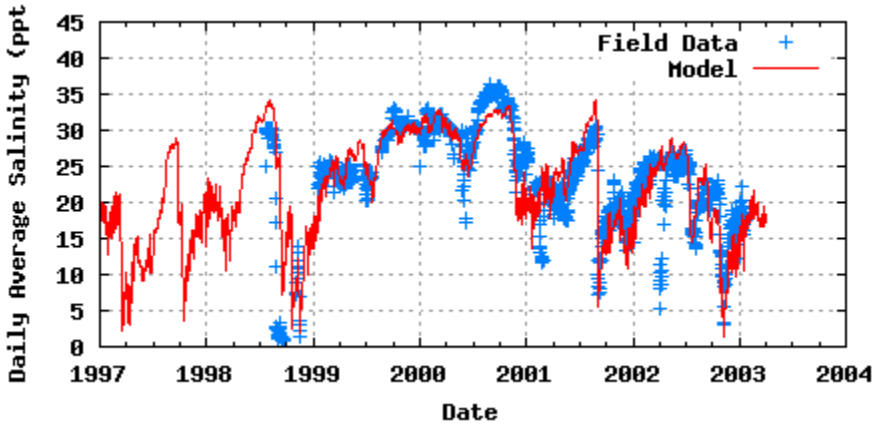


Figure 8.12.b Model (red) and Measured (blue) Daily-Average Salinity at Sandy Point.

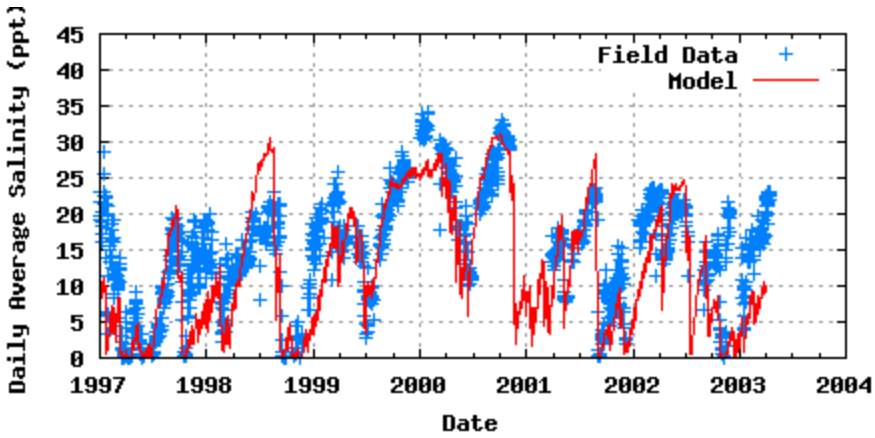


Figure 8.12.c Model (red) and Measured (blue) Daily-Average Salinity at Lavaca Causeway.

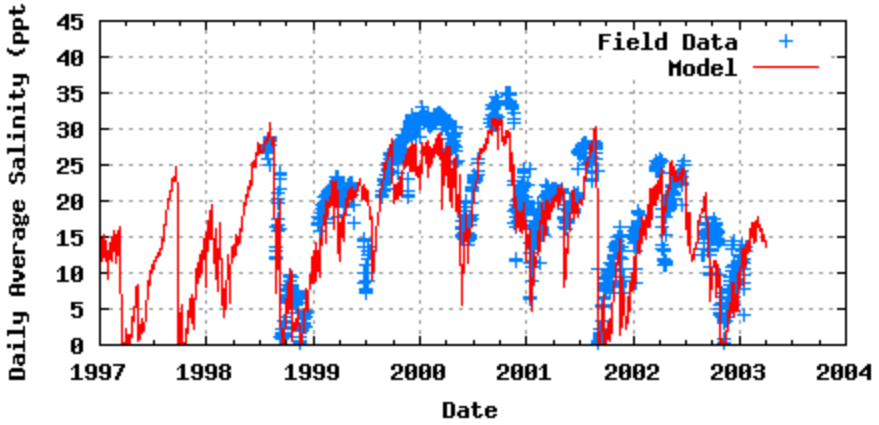


Figure 8.12.d Model (red) and Measured (blue) Daily-Average Salinity at Carancahua Bay.

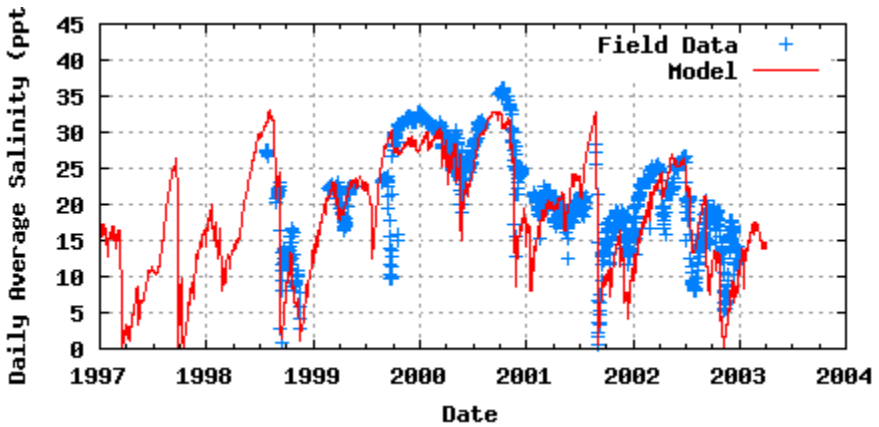


Figure 8.12.e Model (red) and Measured (blue) Salinity at Tres Palacios Bay.

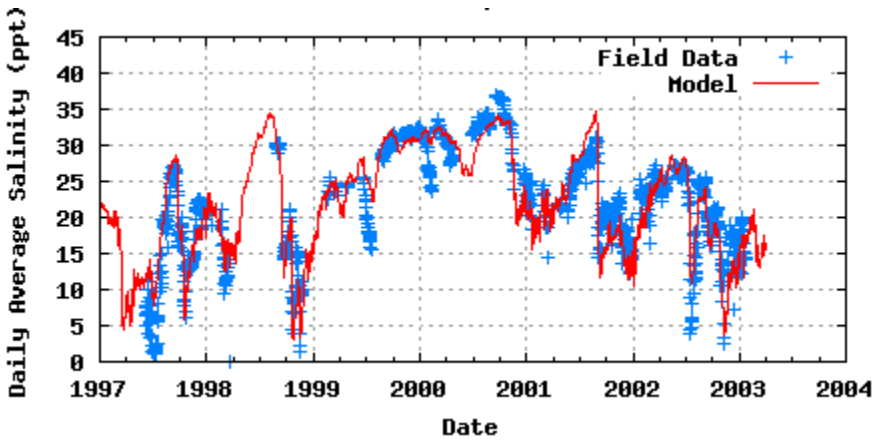


Figure 8.12.f Model (red) and Measured (blue) Daily-Average Salinity at Channel Marker 4.

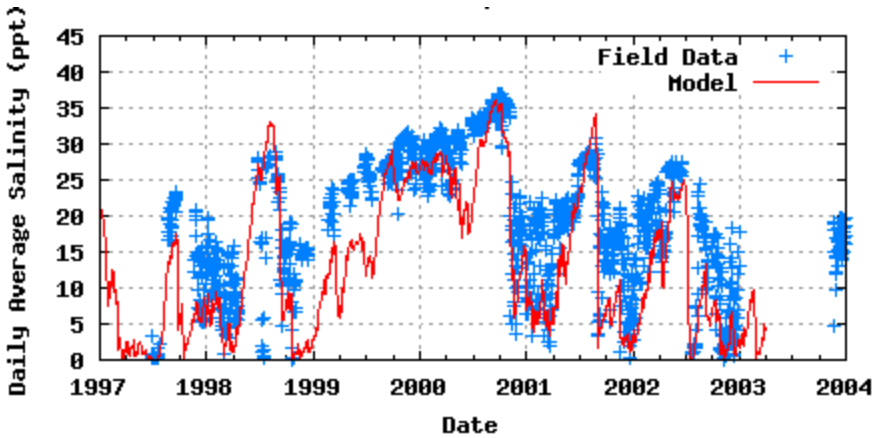


Figure 8.12.g Model (red) and Measured (blue) Daily-Average Salinity at West Bay Tripod.

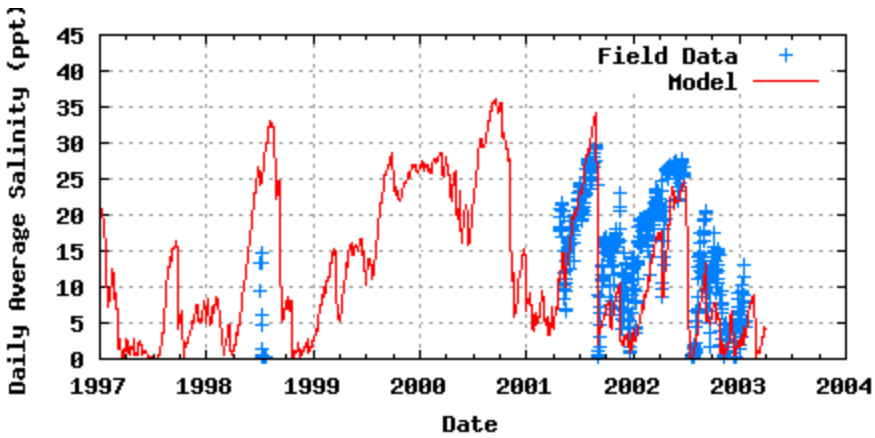


Figure 8.12.h Model (red) and Measured (blue) Daily-Average Salinity at Shellfish Marker B.

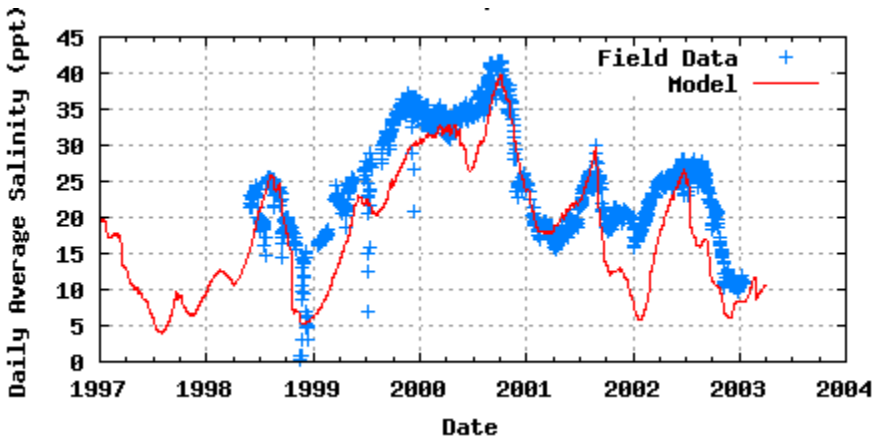


Figure 8.12.i Model (red) and Measured (blue) Daily-Average Salinity at East Bay Tripod.

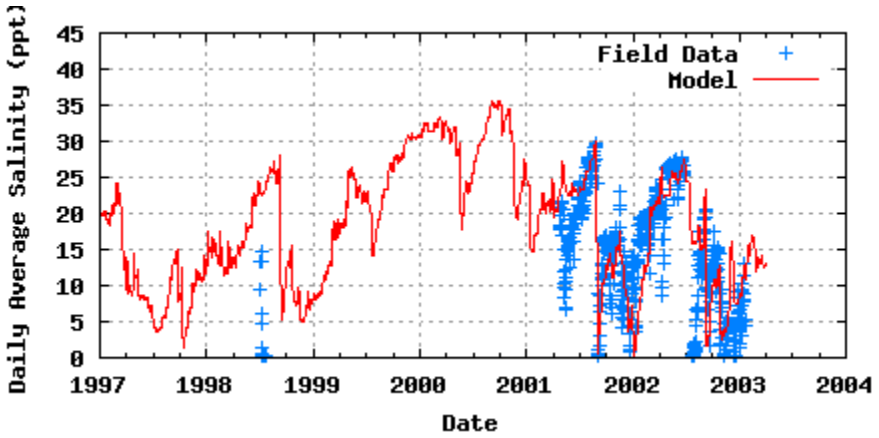


Figure 8.12.j Model (red) and Measured (blue) Daily-Average Salinity at East Bay Shellfish Marker.

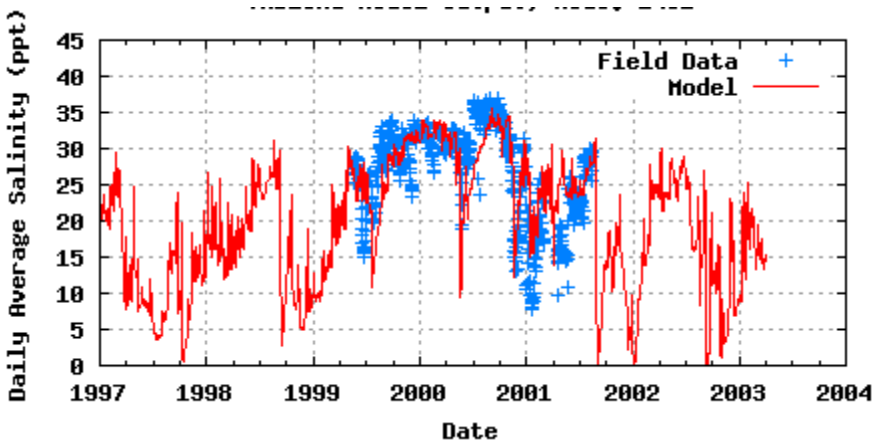


Figure 8.12.k Model (red) and Measured (blue) Daily-Average Salinity at East Bay Eastern End.

8.4 Target Flow Evaluation

The effect of releasing target flows on salinity in Matagorda Bay was evaluated with TXBLEND. Estimated Target Flows for the Colorado River and the Lavaca River, as discussed in Chapter 7, were applied as inputs to TXBLEND in a repeating fashion in a six-year simulation (Figure 8.13). Coastal basin flows used in this simulation were based on adjusted flows for the period 1997 through 2003 (Figure 8.4). During that period, annual average flow for the eight coastal basins contributing directly to Matagorda Bay was 1.09 million acre-feet/year. Target flows for the coastal basins were computed to be 729 thousand acre-feet/year (Chapter 7). For this simulation, the coastal inflows from

1997 through 2003 were reduced by multiplying by 0.729/1.09 = 0.669 in order to achieve an annual average inflow of 729 thousand acre-feet, corresponding to the Target Flow for coastal basins. The actual temporal pattern of the coastal inflows was maintained in these simulations - only the magnitudes were adjusted as described.

Tidal elevations applied in the simulation were actual tides for the period from 1997 through 2003 (Figure 8.5). Wind, precipitation, and evaporation were also based on records from 1997 through 2003 (Figure 8.6).

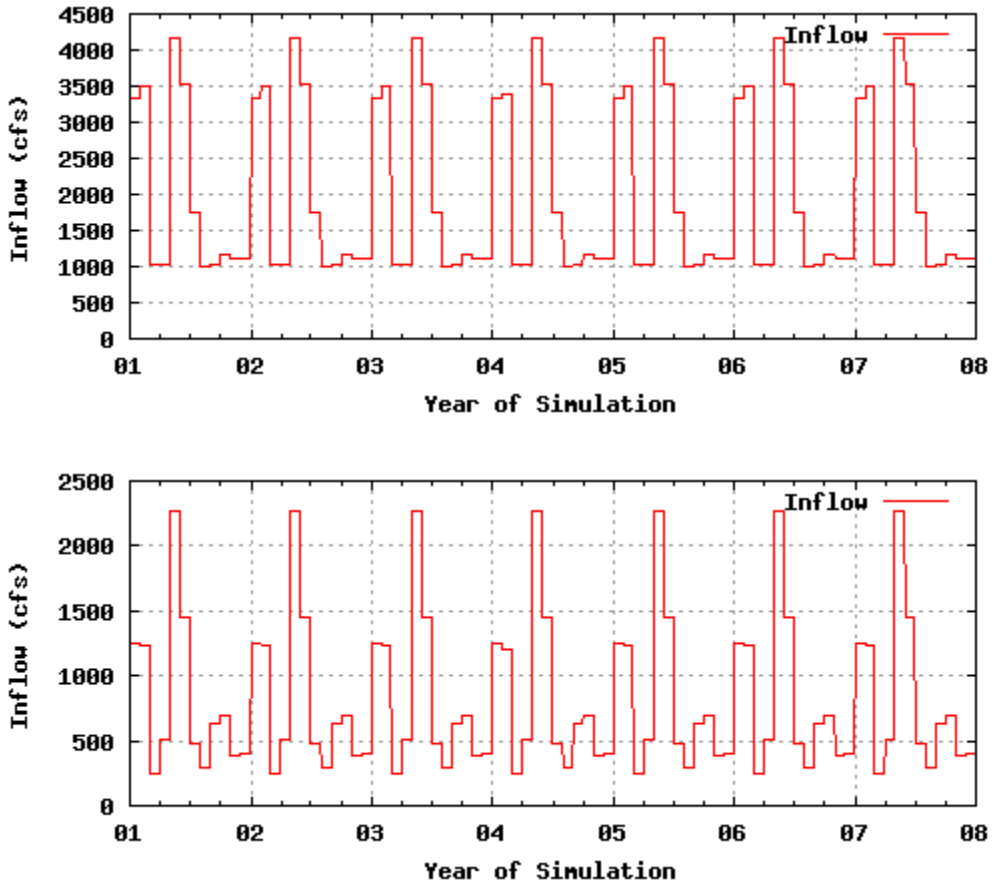


Figure 8.13 Monthly Inflows Applied in Target Flow Scenario. Colorado River (top) and Lavaca River (bottom) Flows.

Under the target flow scenario, computed salinity for the West Bay Tripod and Lavaca Causeway sites remains within the desired salinity constraints applied in TXEMP (Figure 8.14) for all but a few months, primarily during summer and fall. Salinities are highest

during year 03 (third year of the evaluation) of the simulation, corresponding to a time of reduced coastal inflows. These results indicate that Target Flows generally should meet desirable salinity conditions for these sites. Specific guidelines for frequency or duration of exceedance, however, were not developed and is an area for future study.

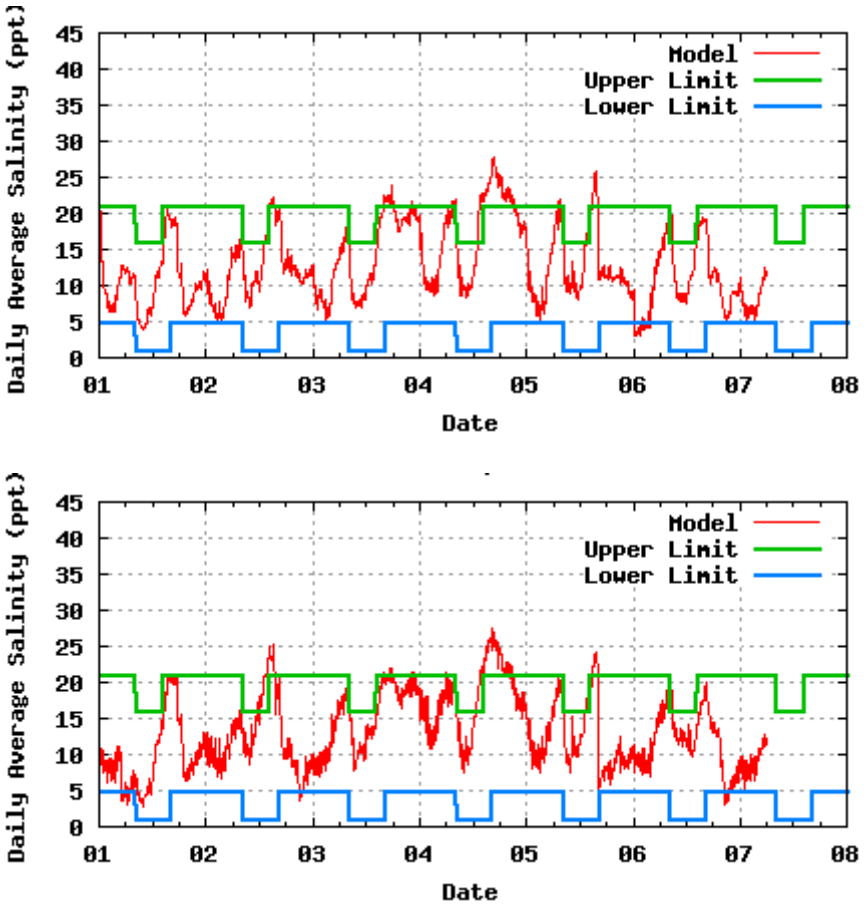


Figure 8.14. Computed Salinity (red) Compared to Target Flow Upper Salinity Constraint (green) and Lower Salinity Constraint (blue) Applied in TXEMP. Model Output for West Bay Tripod (top) and Lavaca Causeway (bottom) Sites.

8.5 Critical Flow Evaluation

Critical flows were also evaluated using TXBLEND. Flows on the Colorado River and the Lavaca River were input as constants equal to their critical flow values of 1,200 acre-feet/day (605 cfs) and 143 acre-feet/day (72 cfs), respectively (See Chapter 9).

Coastal basin flows were again adjusted in proportion to their historical ratio relative to the river basin flows in a similar fashion to adjustments made for the target flow analysis. Critical flows for the Colorado River and Lavaca River total 490.2 thousand acre-feet/year. The historical ratio of coastal basin to river basin flows applied in TXEMP, 0.361, was maintained in this simulation by adjusting coastal basin flows for the 1997 to 2003 period to average 0.361 * 490.2 = 177.0 thousand acre-feet/year. Coastal flows for the period averaged 1.09 million acre-feet/year, so for this simulation these flows were adjusted by multiplying by 0.177/1.09 = 0.162 (16.2 percent).

Tidal elevations applied in the simulation were actual tides for the period from 1997 through 2003 (Figure 8.5). Wind, precipitation, and evaporation also were based on records from 1997 through 2003 (Figure 8.6).

Although constant inflows were applied for the Colorado River and Lavaca River, computed salinities under this scenario are highly variable (Figure 8.15), indicating the strong influence of evaporation, coastal inflows, and Gulf salinity on local salinity. The periodic increase in salinity during summer months is associated with increased evaporation (Figure 8.6), and longer term trends are associated with changes in coastal inflows (Figure 8.4). These figures reinforce the idea that if constant flows are provided at volumes equal to critical flows, observed salinities at the West Bay Tripod and Lavaca Causeway will reach 25 ppt only "on average." Based on this simulation, computed daily salinities exceeded 25 ppt 32% of the time at the West Bay Tripod and 38% of the time at the Lavaca Causeway.

Reduction of the coastal flows to 16.2 percent of their original values in this simulation is significant, particularly for the years 1999 and 2000 (third and fourth years of this simulation). Coastal flows in 1999 rank at the 24th percentile of the 1941 to 2003 historical record (Table 2.2), and in 2000 rank at the 29th percentile. Reducing flows for this simulation drops them below the lowest observed from 1941 to 2003. Thus, this simulation models extremely low flows. During the most extreme conditions, salinity levels can rise significantly above 25 ppt. Attempts to limit salinity to 25 ppt or less would require consideration of and response to these additional factors.

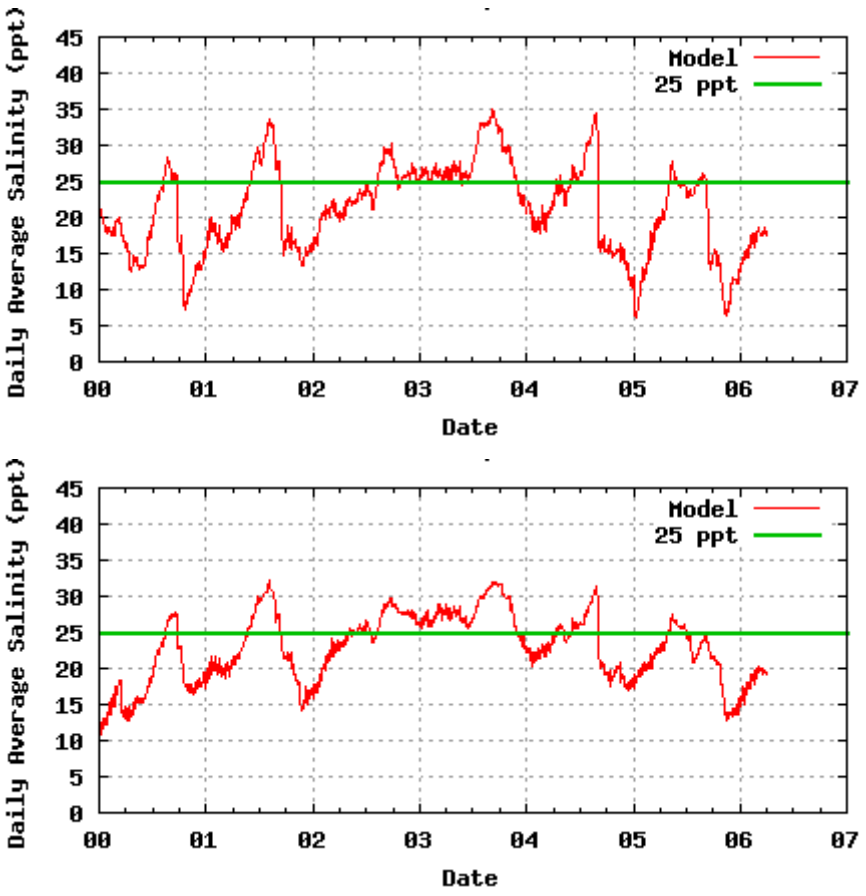


Figure 8.15 Computed Salinity (red) Compared to Critical Flow Salinity Constraint (green) of 25 ppt. Model Output for West Bay Tripod (top) and Lavaca Causeway (bottom) Sites.

8.6 Findings

The TXBLEND hydrodynamic and conservative transport model was calibrated for water surface elevation, flow and salinity with data collected in Matagorda Bay. The calibrated model was used to simulate salinity throughout the bay using target flows and critical flows developed in Chapters 7 and 9 of this report. Results for target flow simulations show that salinities remain within target salinities at the West Bay Tripod and Lavaca Causeway sites during most of the six year simulation. The critical flow simulation showed that under constant critical flow releases from the Colorado and Lavaca rivers, salinity is "on-average" 25 ppt, exceeding this level 32% of the time at the West Bay Tripod, and 38% of the time at the Lavaca Causeway under extreme low-flow conditions.

CHAPTER 9

Development of Critical Freshwater Flow Estimates

9.1 Introduction

Similar to most Texas estuaries, Matagorda Bay receives highly variable inflows due to extremes of the regional hydrological climate. Native species have adapted to survive in this highly variable environment. For example, the oyster responds to stressed environmental conditions by increasing the release of juvenile spat to improve the odds of survival.

Historically, the bay has been stressed by extreme floods and extended wet periods that have driven salinity down to near freshwater levels. For example, high flows in the summer and winter of 2004 led to salinity levels that were below 5 ppt in the eastern arm of Matagorda Bay for more than a month each. Since the construction of the Colorado River diversion, this condition is more frequently observed in the eastern arm of the bay.

Similarly extended dry periods also stress the bay, such as the one that occurred during the 1950s drought and more recently in year 2000. During 2000 the region experienced a summer of high heat, low precipitation and record evaporation. Portions of the bay reached hypersaline (> 32 ppt) conditions that summer. Productivity of some species is impacted by the severity and duration of these events. For example, TPWD staff reported a decline in white shrimp, menhaden, Atlantic croaker, mullet and oysters during this period. (Balboa, 2004).

While these stresses on the bay produce natural and perhaps even beneficial results, such as promoting oysters to release more spat, if extended over long periods of time they pose the threat of critically harming or destroying economically and ecologically important species. Therefore it has been determined prudent to identify critical flows for maintaining a finfish and shellfish sanctuary for juveniles during extended low flow periods to speed the recovery of the bay to ecologic health and economic productivity.

Critical freshwater flows from the Colorado River are particularly beneficial because TPWD has designated and posted the most eastern half of the eastern arm of Matagorda Bay, shown in Figure 9.1, as a nursery. Commercial fishing in this part of the bay is now prohibited.

Additionally, the Colorado diversion delivers freshwater flows from the Colorado basin directly into this region of the bay. From this sanctuary, it is generally expected that the finfish and shellfish species, particularly oysters, could recover and repopulate the bay when normal weather conditions return.

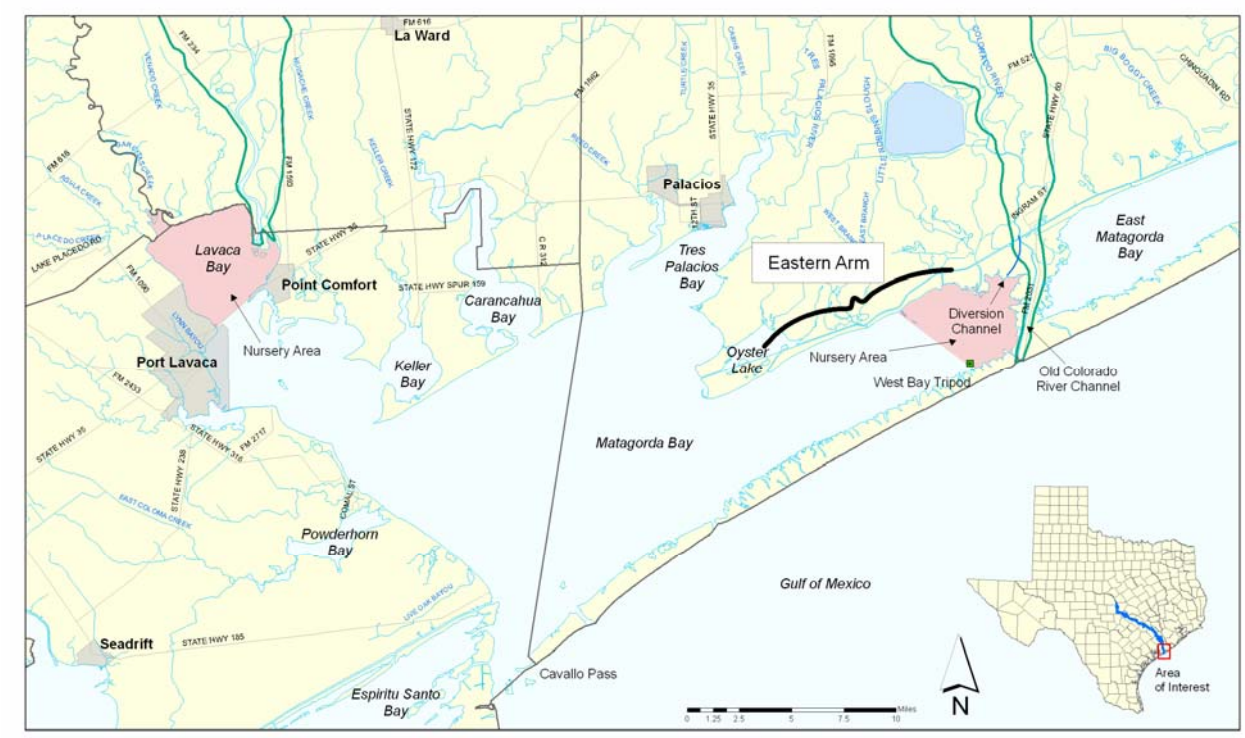


Figure 9.1 Location of Eastern Arm of Matagorda Bay and TPWD Nursery.

9.2 Establishment of Maximum Salinity Target in the Matagorda Bay Nursery

For purposes of the 1997 FINS, a desired salinity of 25 ppt was established largely through consensus as a reasonable target during extended periods of high salinity. It was agreed that this level of salinity would provide a refuge near the mouth of the river during low flow conditions. This determination was largely based on review of species tolerances. This determination was not revisited as part of this update.

In general, many estuarine species spawn in the Gulf of Mexico where salinity remains near seawater levels (above 34 ppt). Larvae then move into estuarine habitats to grow and seek

refuge from predators. The information in the following table was taken from several sources including the Galveston Bay Freshwater Inflow Study and Freshwater Inflows to Texas Bays and Estuaries.

Table 9.1 Salinity Preferences and Tolerances for Estuarine Species.

Species	Preferred Salinity (ppt)[1]	Preferred Salinity (ppt)[2]	Juvenile Salinity (ppt) Tolerance [2]
White Shrimp	10 – 15	3 – 7	10-25
Brown Shrimp	10 – 20	24 – 26	10-20
Blue Crab	0 – 15	< 20	6-21
Menhaden	10 – 15	0 – 12	0-12
Atlantic Croaker	None	No info	No info
Bay Anchovy	10 – 20	No info	No info
Finfish	20 – 25	No info	No info
Oyster		10 – 24	10 - 30
Smooth Cordgrass		10 – 20	

Sources:

1. Galveston Bay Freshwater Inflow Study (TPWD, 1998).
2. Freshwater Inflows to Texas Bays and Estuaries (Longley, 1994).

It was determined that the eastern oyster, *Crassotrea virginica*, represents a good keystone species for Matagorda Bay since it is relatively abundant and is both commercially and ecologically important. In 2001 (the latest figures available), more than 160,000 pounds of oyster valued at $370,000 were harvested from Matagorda Bay (Culbertson et al., 2004).

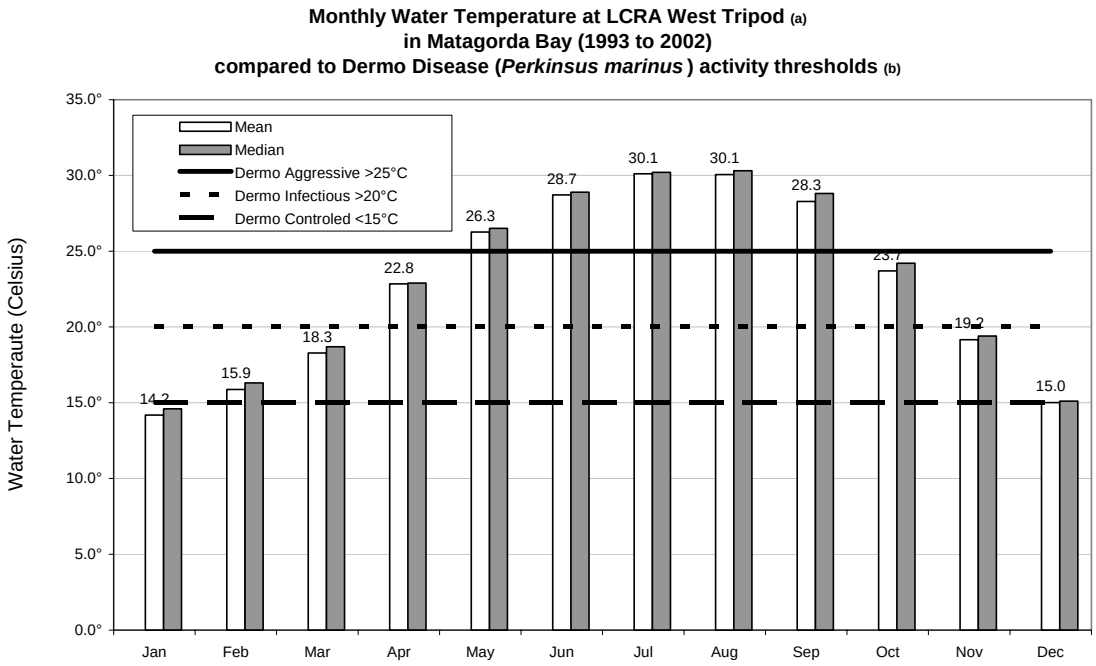
In addition to their direct benefit on the ecology of the bay system as filter feeders, oyster reefs provide a source of food and physical habitat for numerous other species. Furthermore, oysters represent a historically significant background condition within Matagorda Bay. Since the success of the oyster population depends on appropriate salinity conditions over immobile reef structures, salinity bounds for Matagorda Bay were set on the basis of the location of established oyster reefs (LCRA, 1997).

Oysters remain among the most ecologically important organisms in the estuarine system. In addition to their role in recycling nutrients, their shells form reefs that provide physical habitat and nursery areas for other species (Zimmerman et al, 1989). Suitable temperature and salinity ranges are both important conditions to the survival, growth and reproduction of the eastern

oyster. Many investigators have attempted to define the tolerance limits and optimum ranges, but with considerable divergence in results (Shumway, 1996).

Unlike most other organisms, oysters are sessile and restricted to areas with hard substrates, such as existing oyster shell. Oysters spawn year round in Texas bays, with peak spawning in June and July, at temperatures above 20°C and at salinities above 10 ppt (Hoffstetter, 1977, 1983). The larvae are free-floating for about 10 days before the final larval stage (spat) settle on hard substrate. Spat settling has been reported to be most successful at salinities from 17 ppt to 24 ppt. Once the spat have set, they remain in the same place for their adult lives. Juvenile and adults are capable of surviving a wide range of temperatures and salinities, but growth and survival is optimal with salinities fluctuating between 10 ppt and 30 ppt. Fluctuating salinities help reduce fouling and predatory organisms. Predatory gastropods, principally the oyster drill (*Thais haemostoma*), cause substantial mortality at sustained high salinities (>25 ppt).

The first oyster disease to be recognized in the United States was dermo disease, caused by *Perkinsus marinus*. This parasite is capable of killing 90 to 95% of the oysters within two to three years. Dermo can withstand a wide variety of environmental limits. The protozoan parasite develops the heaviest infections and kills most readily at salinities > 10 ppt and at temperatures >20°C (68°F), but survives at much lower salinities and temperatures (Chu and La Peyre, 1993). Thresholds of *Perkinsus marinus* activity are compared to monthly temperatures at the West Bay Tripod in Matagorda Bay in Figure 9.2.



Sources : a) LCRA Water Services, Resource Protection, monitoring data.
b) Oyster Diseases of the Chesapeake Bay, Dermo and MSX Fact Sheet, Virginia Institute of Marine Science.

Figure 9.2 Water Temperature at West Bay Tripod and Dermo Disease Activity.

B. D. King evaluated the condition of oyster populations in the eastern arm of Matagorda Bay in anticipation of the diversion of the Colorado River (King, 1989). He noted that Half Moon Reef, which was historically a highly productive reef, had high mortality of adult oysters and high incidents of predation. He noted only one successful spat set during his study in July 1987 following a flood when salinity conditions were around 10 ppt in the Colorado River the preceding month (LCRA, 1997).

Dog Island Reef, which was the largest oyster reef in Matagorda Bay, is nearly covered by the delta that is forming at the mouth of the Colorado River diversion. However, the Corps of Engineers has established three artificial reef complexes in the eastern arm of Matagorda Bay; 1) an extension of Shell Island Reef, 2) an extension of Mad Island Reef, and 3) at a point between Mad Island Reef and Half Moon Reef. These are shown in Figure 9.3.

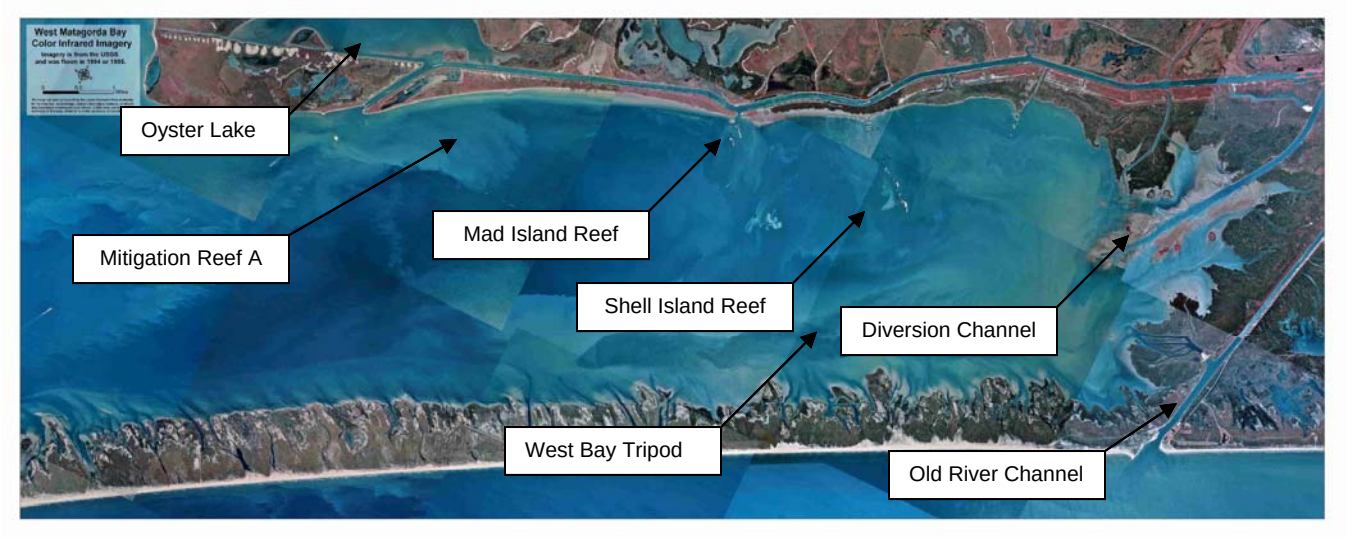


Figure 9.3 Eastern Arm of Matagorda Bay Features.

9.3 Development of Critical Flows of the Matagorda Bay East Arm Nursery

Development of critical flow equations for the bay was accomplished using multiple linear regression techniques described in Section 6.1. LCRA collected hourly salinity data from January 1993 to December 2003 at the West Bay Tripod monitoring station, although there are notable data gaps until 1998. The regression analysis was based on 62 monthly average observations. This regression analysis was not constrained by the application of TXEMP and therefore additional variables were used. Stepwise regression was performed for independent variables:

- average salinity for the prior month
- the natural log of average daily flow for each of the present month and the three prior months
- high water level in the Gulf of Mexico as measured at Galveston Pleasure Pier
- average daily precipitation
- average daily gross evaporation for each month
- average daily water temperature for each month
- mean daily wind speed

Of these variables stepwise regression found only the present month flow, prior month salinity, and present month gross evaporation to be statistically significant. Addition of the prior period

salinity largely resolved autocorrelation issues. A satisfactory Durbin Watson statistic of 1.7 was achieved. The resulting equation exhibits an adjusted R^2 of 85% and a standard error of 2.9 ppt.

Equation 9.1 Monthly Salinity-Inflow Relationship for West Bay Tripod

$$Sm_i = 38.364 + 0.436 \times Sm_{i-1} - 3.818 \times LN(Qm_i) + 20.605 \times Em_i$$

where: i = month

Qm_i = Average Daily Colorado Flow for month i (acre-feet)

Sm_i = Average Monthly Salinity at for month i (ppt)

Em_i = Average daily Evaporation for month i (inches)

Performance of this equation for the period of 1992 to 2003 is shown in Figure 9.4. It shows that errors tend to be within one standard error and never more than two standard errors. Additionally during the 2000 drought the error is almost uniformly positive. It is likely that nonlinear effects were involved in this extreme event that are not entirely captured by linear regression. Future studies may be able to develop nonlinear relationships with an improved error profile over a larger range of salinity.

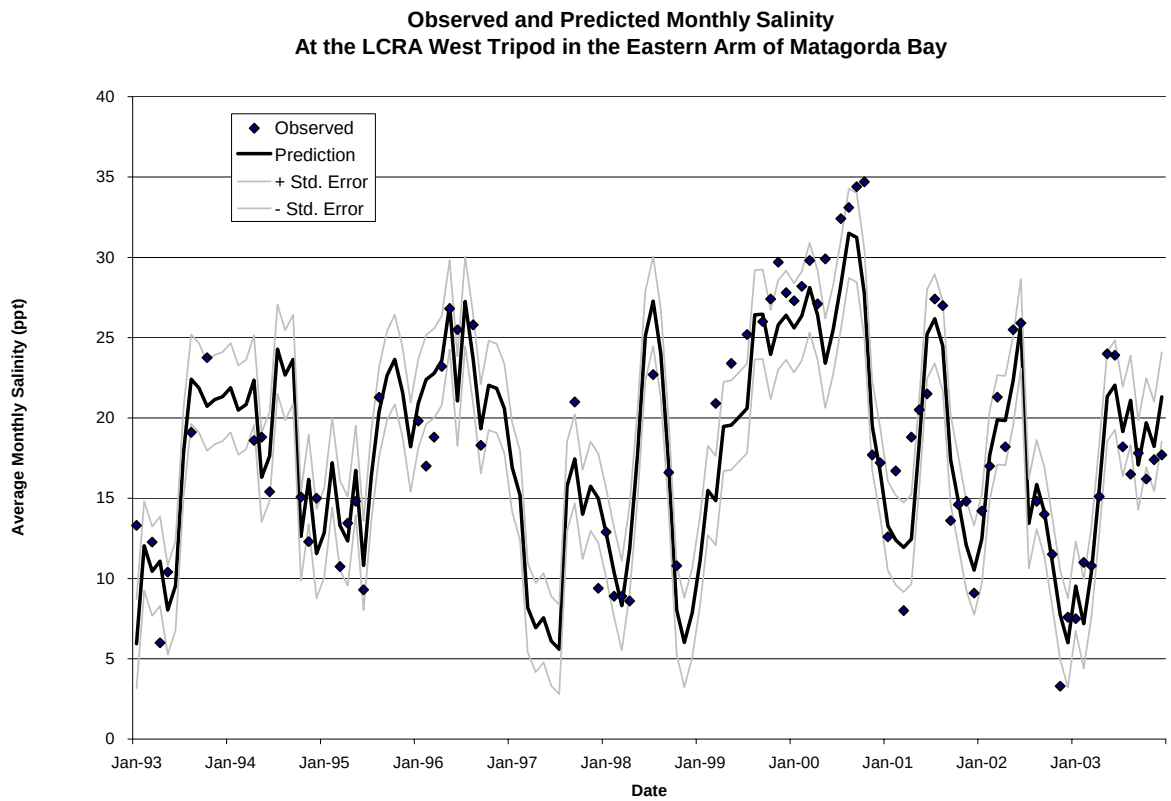


Figure 9.4 Performance of Equation 9.1.

The critical flow, Qcr, for the eastern arm of Matagorda Bay is obtained by using Equation 9.1 and assuming steady state condition, i.e. setting Sm_{i-1} and Sm_i to 25 ppt. Emi is set to the annual average of 0.136 inches/day. Solving for Qcr is shown below:

<u>Solution of Equation 9.1 for Steady State Flow to Maintain Salinity at West Bay Tripod</u>

$$Qcr = Qm_i = Qm_{i-1}$$

$$Qcr = \exp\left(\frac{Sm_i - 38.364 - 0.436 \times Sm_{i-1} + 20.65 \times Em_i}{-3.818} \right)$$

$$Qcr = \exp\left(\frac{25 - 38.364 - (0.436 \times 25) - (20.605 \times 0.1360)}{-3.818} \right)$$

Qcr = 1,200 acre-feet per day = 36,000 acre-feet per month

The equation indicates that supporting an annual average salinity of 25 ppt requires 36,000 acre-feet of inflows from the Colorado River on an average monthly basis. Salinity would still vary around this average as illustrated in Figure 8.14. Similarly the equation can be solved at plus or minus the standard error of 2.9 ppt to understand the range of uncertainty in the flow rate to achieve 25 ppt on an average monthly basis. The range of uncertainty at a 68% confidence is 23,000 to 55,000 acre-feet per month.

Alternately, Equation 9.1 can be solved for various maintenance salinities as well as relative initial salinity as illustrated in Figure 9.5.

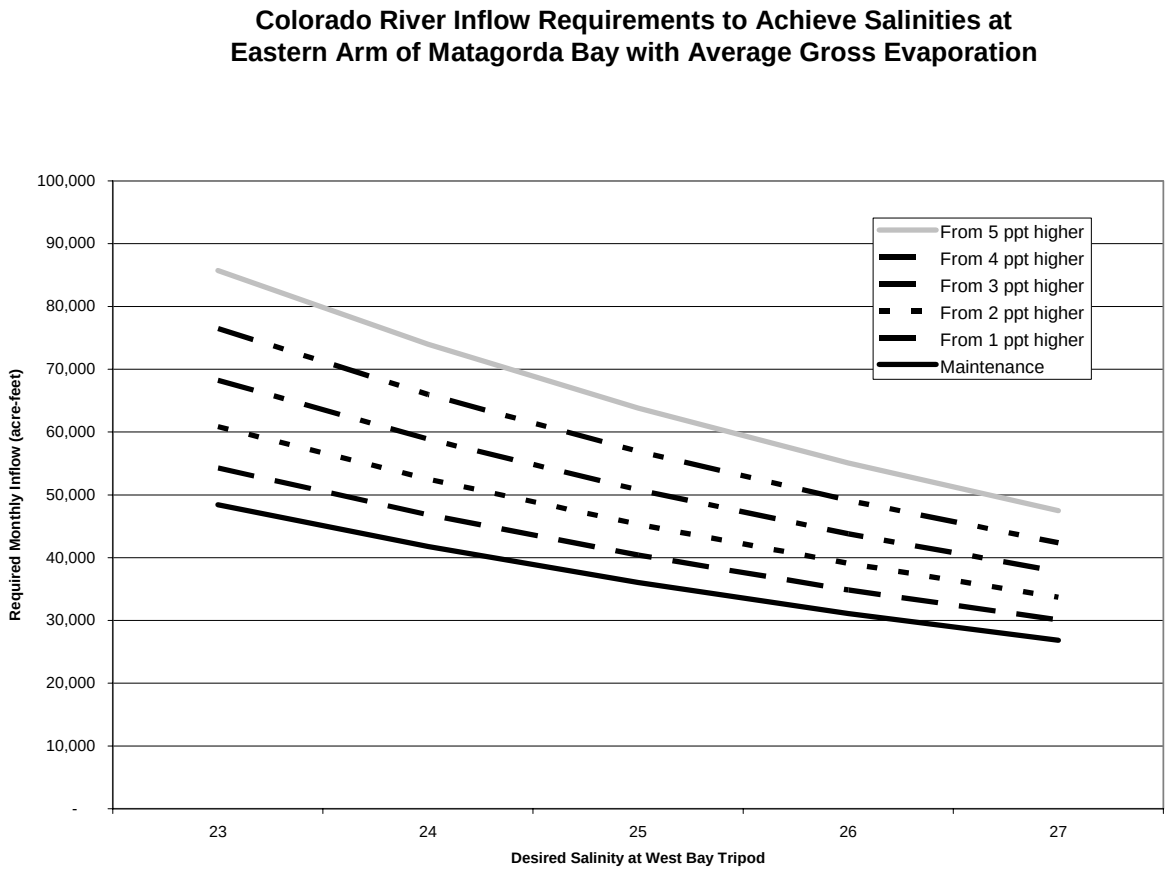


Figure 9.5 Inflow Requirements to Achieve Salinities at Eastern Arm of Matagorda Bay.

9.4 Development of Critical Flows of Lavaca Bay

Development of critical flow equations for Lavaca Bay was accomplished with multiple linear regression using techniques described in Section 9.5. Monthly salinity data from 1987 to 2003 was obtained from the TWDB. This regression analysis was not constrained by the application of TXEMP and therefore additional independent variables were investigated. Stepwise regression was performed for independent variables of:

- average salinity for the prior month
- natural log of the average daily flow for the present month and each of the prior three months
- average daily gross evaporation for the present month

Only the present month flow both prior month salinity and flow were found to be statistically significant. Addition of the prior period salinity resolved autocorrelation issues. An excellent Durbin Watson statistic of 1.94 was achieved. The resulting equation exhibits an adjusted R^2 of 82% and a standard error of 3.2 ppt.

Equation 9.2 Monthly Salinity-Inflow Relationship for Lavaca Bay

$$Sm_i = 25.7 + 0.51 \times Sm_{i-1} - 1.70 \times LN(Qm_i) - 1.04 \times LN(Qm_{i-1})$$

where: i = month
Qm_i = average daily Lavaca flow for month i (acre-feet)
Sm_i = Average monthly salinity at for month i (ppt)

The performance of this equation is shown in Figure 9.6.

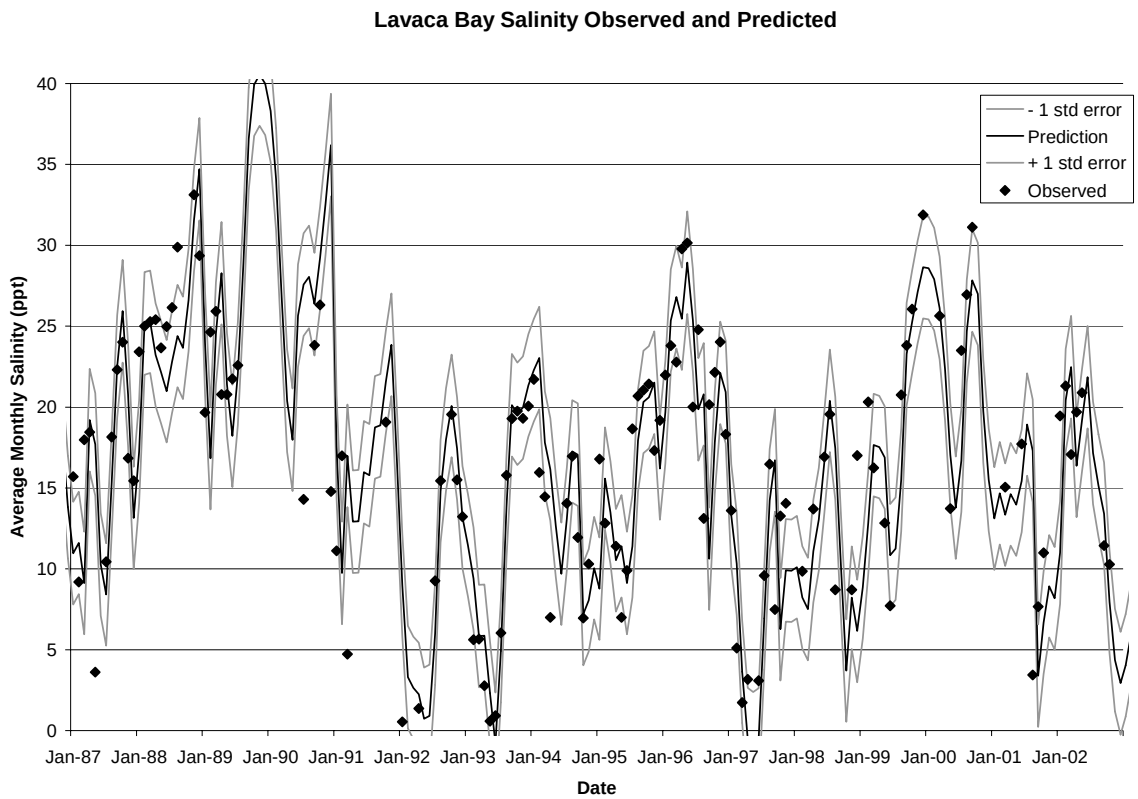


Figure 9.6 Observed and Predicted Salinity at Lavaca Bay.

Critical flow is solved using equation 9.2 by assuming steady conditions, i.e. by setting Sm_{i-1} and Sm_i to 25 ppt and setting $Qm_{i-1} = Qm_i$ then solving for Qcr as shown below.

<u>Solution to Equation 9.2 - Flow Needs to Maintain Salinity in Lavaca Bay</u>

$$Qcr = Qm_i = Qm_{i-1}$$

$$Qcr = e\frac{Sm_i - 25.7 - 0.51 \times Sm_{i-1}}{-2.74}$$

$$Qcr = e\frac{25 - 25.7 - 0.51 \times 25}{-2.74}$$

Qcr = 143 acft/day = 4,300 acre-feet per month

Use of this equation predicts that maintenance of 25 ppt requires 4,300 acre-feet of inflows from the Lavaca River on an average monthly basis. Similarly the equation can be solved at plus or minus the standard error of 3.2 ppt to understand the range of uncertainty in the flow rate to achieve 25 ppt on an average monthly basis. The range of uncertainty at a 67% confidence is 2,300 to 7,200 acre/feet per month.

Alternately, the equation can be solved for various maintenance salinities as well as relative initial salinity as illustrated in Figure 9.7.

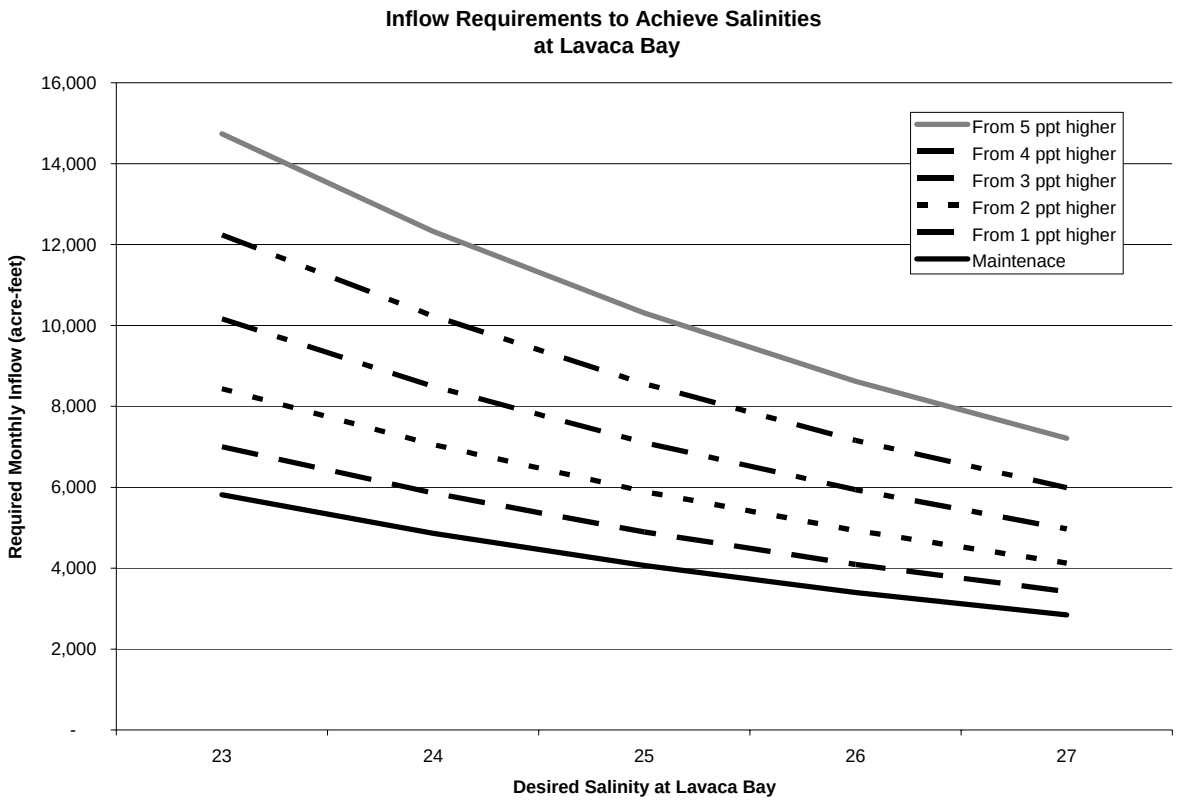


Figure 9.7 Inflow Requirements to Achieve Salinities at Lavaca Bay.

Chapter 10

Future Technology and Study Needs for Matagorda Bay

10.1 Introduction

Over the course of this three-year study, numerous technical issues were revisited or brought to light concerning insufficient data, shortcomings of analytical methods, and the potential impact of simplifying assumptions and constraints. The purpose of the current study was not to overcome all the shortcomings but rather to apply the methodology as reasonably as can be achieved with the resources available and analytical methods prescribed. In numerous areas, shortcomings identified in the 1997 study, such as the use of commercial harvest data rather than productivity data, were wholly or partially addressed. In others, such as nutrient analyses, little or no progress could be achieved.

For the benefit of future study activities, the issues identified specifically in this effort are discussed. This does not capture all of the current discussion on these methodologies that has been reported by others such as the Study Commission on Water for Environmental Flows (2004). These issues suggest significant additional data collection, analysis and research is needed to improve our understanding of the relationships between freshwater inflows and important indicators of estuarine conditions and to effectively determine the amount of inflow required to continue to maintain a healthy estuarine community.

10.2 Hydrology

- Better estimates of coastal inflows should be developed to take advantage of next generation rainfall-runoff models that incorporate NEXRAD data.

- Information should be collected on the operation of the GIWW locks.

- Data regarding irrigation return flows and diversions in the coastal areas should be revisited to more accurately account for this source of water to the bay.

- Estimates of ungaged flows may have a significant margin or error.

- Flows at the intersection of the Colorado River and Gulf Intracoastal Waterway should be measured to determine actual direct inflows to Matagorda Bay. Currently, gaged Colorado River flow at Bay City, which is upstream of the GIWW, is used to estimate freshwater inflow to the bay.

10.3 Nutrients, Sedimentation, and Primary Productivity

The current study effort identified very early that adequate additional sedimentation and nutrient data was not available to significantly improve on the limited analyses from the 1997 FINS. This is unfortunate because the lack of data was already known to be a limitation of the previous FINS effort. Instead, the contribution of this study was focused on documenting the breadth of understanding and complexities involved in determining nutrient requirements.

The recommendations previously made in the 1997 FINS (LCRA) include:

- *Additional information is needed of the nutrient concentrations and loadings per unit volume required to maintain a healthy algal population during critical periods for finfish and shellfish nourishment.*

- *Nitrogen measurements should be taken at near-shore locations in the Gulf to determine near-shore concentrations, and locations and concentrations of the bay plume water. Nitrogen measurements (DIN and TKN) should continue to be taken at sites in the bay and at critical river and creek sites. The USGS water quality monitoring site at Midfield should be re-established. TNRCC monitors should begin to collect TKN data at present stations on rivers, creeks, and in the bay. Bottom water samples should be taken at critical sites in the bay, rivers and creeks.*

- *Better estimates of ungaged flow nitrogen concentrations also need to be determined. Ungaged nitrogen concentrations could be determined by establishing monitoring sites on creeks that would be representative of the local watershed and that did not have a point source discharge located upstream of the sampling site.*

- *Nitrogen loading associated with stream bed load should be studied. This could be a significant source of nutrients for the estuary.*

- *Nitrogen dynamics in sediments of the Lavaca-Colorado Estuary should be studied to determine the storage capacity of nitrogen in the sediments, the flux of nitrogen in and out of the sediments, nitrogen fixation, denitrification, and permanent losses to the sediments. Uncertainty of the reliability of these values weakens the resolution of this analysis.*

- *A relationship between nutrients, primary productivity, and secondary productivity should be developed to better understand the impact of nutrient loading upon the fisheries. Primary productivity measurements should continue to be taken at the two bay sites influenced by the Colorado River. Additional primary productivity measurement sites should be established to measure the influences of the Lavaca River.*

- *The benthics study supported by the TWDB and the LCRA to determine the effects of freshwater inflows should continue at least through a two year dry period.*

- *Secondary productivity is measured effectively by the TPWD's ongoing fish and shellfish sampling program. The TPWD fish and shellfish monitoring program should continue.*

- *Additional data should be gathered on the development of emergent wetlands along and at the end of the USACE diversion channel into Matagorda Bay, the corresponding effect on bay productivity and overall ecological health, and the impact of freshwater inflows on the development of these wetlands.*

10.4 Salinity and Salinity-Inflow Relationships

- Further explore the TPWD Coastal Fisheries data. The TPWD Coastal Fisheries data provides a content rich and spatially diverse data set. It appears that considerably more can be learned about the bay through spatial analysis such as GIS. This study did not investigate the data extensively; however Chapter 4 introduces the potential of the data analysis. Further analyses could identify seasonal, regional norms and efficiencies in utilizing freshwater by tertiary bay.

- Investigate relationships to coastal inflows. For the development of statistical salinity relationship, this study only explicitly examined freshwater contributions from the Lavaca and the Colorado Rivers. Contributions from coastal inflows are therefore inherently assumed to be either highly correlated to the river flows and have identical influence on salinity, or uncorrelated to river flows and accounted for in the model error. However, it could be instructive to explicitly examine freshwater contributions from coastal basins in the salinity relationships. This may produce relationships with better predictive ability as well as provide insight into the relative influence of coastal inflows on salinity as compared to river flows. It may also be necessary to investigate regional relationships from secondary bays to obtain statistically significant relationships.

- Explore potential for use of additional salinity monitoring station located in the Eastern Arm of Matagorda Bay. It was reviewed as part of this study but the period of record was short and no utility for it was found so there was no use for it in this study. However with additional data collection and the use of coastal flows, future investigations at this station may prove useful.

- Continue data collection for out-of-set relationship validations. Verifying a statistical relationships predictive ability using an independent data set (out-of-set) is a widely accepted performance test. For the purposes of this study, the entire data set (in-set) was used to develop the equations due to the short history since the diversion project and the desire to include a wide range of extremes. However, additional data collection will provide

a new data set to use in testing the relationships developed in this study and hopefully a long enough period to enable future efforts to utilize a secondary dataset for out-of-set testing.

- The relationships used in TXEMP for this study include multiple monthly flows. It is instructive that the significance of the multiple months remained even after advanced regression methods reduced the effects of autocorrelation. This results in a predictive equation that is not highly responsive to inflows in the current month. While this captures the system behavior most of the time which is appropriate for TXEMP, it does not capture the physical observation of salinity dilution during extreme high flow periods. Shorter periods of analysis would be needed to capture this system response. Daily salinity linear relationships were attempted but the effort was abandoned due to poor predictive ability. Further investigation with non-linear or longer periods may be more successful at capturing this response.

- The role of coastal inflows on maintaining nursery conditions was not fully explored. In the development of the regression equations in Chapters 9 and 3, coastal inflows were not explicitly considered. To the extent they are random they would be included in the error term, but to the extent that they are correlated to the river flows they would be accounted for in the coefficient on the independent variable. In a managed system such as during a drought the flows may be less correlated due to management actives. This introduces a source of unknown error, hopefully small, in use of the regression equation for this purpose. A more robust method of exploring this effect would be in more detailed equations or use of TXBLEND for critical flow analyses.

10.5 Biological Productivity

- The Colorado River diversion project was intended to create additional marsh habitat for the purpose of increasing species abundance. The amount of marsh habitat created since the diversion should be quantified.

- The National Marine Fisheries Service (NMFS) has extensively collected biological data in

the Galveston Bay to develop nekton habitat models. The models utilize environmental factors (marsh habitat, salinity, temperature, etc.) to estimate species density in a particular habitat. Moreover, these models are predictive and potentially useful to managers seeking to optimize productivity. Future research should seek to apply these types of models in Matagorda Bay. Such models could help refine inflow needs of various regions within the bay.

- A conceptual model of the productivity-inflow relationships should be developed and refined. Models for each species or species with similar traits may be required.

- Smaller tertiary bays provide important habitat. Thus, coastal inflows into these areas should be considered in the productivity-inflow relationships in future studies.

- Productivity-inflow relationships were used to relate productivity directly to river inflows without explicit consideration of salinity, habitat, or spatial distribution; however preliminary analysis shows that the relationships are much more complex. More explicit consideration of these factors should be considered.

- Preliminary analysis suggests that the productivity-inflow relationship may be better explained using quadratic or higher order regressions, particularly over a wide range of flows. This analysis should be expanded to determine its usefulness in further inflow needs studies as well as investigate the inclusion of additional variables.

- Optimization models need to be updated to utilize more complex fisheries equations.

- The spatial variation in the relationship of inflows to productivity should be investigated. The biology data set is spatial, however this study lumped the data bay wide as required by the State Methodology. Important regional factors may have been lost due to this approach which disaggregating will hopefully reveal.

- Evaluation of the impact of the diversion on productivity was not a primary focus of this

study. Yet, preliminary analyses suggest that an in depth analysis could produce useful information on trends, the influence of flood flows, and influence of droughts. This investigation would benefit from additional post diversion data as well as more robust statistical analysis methods.

- Additional long-term biological and chemical data (temperature, dissolved oxygen, salinity, pH) is needed to augment the TPWD Coastal Fisheries Data. Targeted fixed station biological monitoring in the Colorado River diversion and in several tertiary bays, coupled with chemical data, would provide tremendous insight into species utilization and response to various inflow regimes.

- Additional data on nutrient, sediment and salinity requirements and preferences of marsh plant species would be useful to future studies.

10.6 Target Flow Methods

- Additional salinity locations should be included in future TXEMP evaluations to more adequately constrain a salinity gradient across the bay. This is contingent on establishing acceptable salinity constraints for the new locations.

- Use of location-specific inflow-productivity relationships should be used rather than a single bay-wide relationship in TXEMP.

- Practical use of information provided by probabilistic constraints on salinity and productivity should be further explored, or abandoned to simplify the analysis if no practical application of this information is found.

- For Lavaca Bay, use of hydrology following construction of Lake Texana should be considered for setting constraints.

- Current model uses juvenile abundance as a measure of productivity. Guidelines on when this or other life-stages are most appropriate for the analysis should be established.

- Management objectives for Lavaca and Colorado river flow ratio constraints should be reviewed.

- Role of TXBLEND in the validation process should be more clearly defined.

- Development of hydrological inputs used in TXBLEND analysis (Target flows, Critical flows) should be more clearly defined.

- Criteria for exceedance of salinity constraints should be established, i.e. the accepted number, frequency or length of time that a salinity constraint can or cannot be violated should be established.

- A new hydrodynamic and water quality (non-conservative transport) model of the bay is being developed during the LCRA-SAWS Water Project study period. The results of this new model should be compared with the performance of TXBLEND. Use of other models with improved numerical methods, non-conservative transport, and three-dimensionality should be evaluated for future studies.

10.7 Critical Flow Methods

- Further investigate piecewise and non-linear predictive relationships between salinity and inflow. In both this study and the prior study, the linear relationship for predicting salinity exhibits larger error at high and low salinities. This observation was made in the prior study and, while less prominent, is still a factor in this study. Process changes in the physical system in a non-steady state manner during these extreme conditions could explain why this occurs with a linear equation. For example, these process changes may be the effect of a flow restriction due to sedimentation at low flows that is not an impediment at higher flows. Some investigation was made in this study to develop piecewise relationships by flow,

salinity, and season. However no improvement in predictability was found over the single linear equation. Additional analysis may be more successful particularly as additional data is obtained in the extreme salinity conditions.

- Opportunities to enhance productivity by diverting flow to other habitats needs to be investigated. This work is currently being conducted by the LCRA-SAWS Water Project.

- Effect of exceeding 25 ppt criterion on survival over short (days), intermediate (months), and long (years) periods of time needs to be investigated.

- It would be useful to understand and quantify the beneficial and detrimental effects to the eastern oyster of different durations of extreme salinities. Also the recovery duration for various stress levels to oysters is uncertain. This type of information is notably not addressed in the research literature cited for this study.

10.8 Intermediate Flow Investigations

- Given that hydrological conditions are least often at Critical or Target conditions, management of flows during the more frequently occurring intermediate hydrological conditions needs to be emphasized. Use of TXEMP results for those flow conditions should be evaluated.

10.9 East Matagorda Bay

- The 1997 FINS suggested that a separate inflow study of East Matagorda Bay should be conducted. The TWDB has initiated a Freshwater Inflow Needs Study for East Matagorda Bay. In addition, the LSWP will include an evaluation of East Matagorda Bay during the six year study period (2004-2010) and should address the needs listed in the 1997 FINS.

10.10 General Methodology / Management Objectives

- Define more clear management objective and purpose for environmental flows and inflow needs studies.

- Determine the types of information required by water planning operations models of environmental flows.

- Determine how information provided by inflow needs studies can best be used or implemented.

- Determine whether the optimization approach is best suited to meet management, planning and operations objectives.

10.11 Summary

The current study effort has updated the 1997 FINS within reasonable conformance to the State Methodology. However, significant opportunity exists to refine the science and methodologies while also expanding the data collection efforts within the bay. Opportunity also exists to better relate inflows to biological health and to identify the range of validity and uncertainly in the freshwater inflow needs estimates for more informed consideration of bay needs in the process of balancing limited resources of freshwater.

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Appendix A
Study Agreement

MEMORANDUM OF AGREEMENT
AMONG THE LOWER COLORADO RIVER AUTHORITY
TEXAS PARKS AND WILDLIFE DEPARTMENT
TEXAS WATER DEVELOPMENT BOARD AND
TEXAS NATURAL RESOURCE CONSERVATION COMMISSION

WHEREAS, the Lower Colorado River Authority ("LCRA") is a conservation and reclamation district created by the State of Texas with statutory responsibility for control and management of the waters of the Lower Colorado River watershed; and

WHEREAS, the Texas Parks and Wildlife Department ("TPWD") is the state agency with primary responsibility for protecting fish and wildlife resources in the State of Texas; and

WHEREAS, the Texas Water Development Board ("TWDB") is the state agency with primary responsibility to plan and finance the water resource needs of Texas; and

WHEREAS, the Texas Natural Resource Conservation Commission ("TNRCC") is the state agency given primary responsibility for implementing the constitution and laws of the state related to water; and

WHEREAS, the bays and estuaries of Texas are vital economic and natural resources for all citizens of Texas, and freshwater inflows are critical to providing nutrients, sediments, and proper salinity balances to preserve and maintain the sound environment of the bays and estuaries; and

WHEREAS, the Lavaca-Colorado Estuary is a major estuary on the Texas Gulf Coast, ranking third in the state in surface area, and the Colorado River is the most important source of freshwater inflows to the Lavaca-Colorado Estuary; and

WHERAS, establishing the freshwater inflow needs from the Colorado River is vital to the LCRA's management of its water rights in the Colorado River Basin for all beneficial purposes; and

WHEREAS, pursuant to a Memorandum of Agreement dated October 20, 1993 ("1997 Freshwater Inflow Needs Study"), LCRA, TPWD, TWDB, and TNRCC cooperated to develop estimates of the freshwater inflow needs of the Lavaca-Colorado Estuary from the Colorado River, which estimates were then incorporated into LCRA's Water Management Plan; and

WHEREAS, LCRA, TPWD, TWDB, and TNRCC agree that the freshwater inflow needs estimates developed in the 1997 Freshwater Inflow Needs Study should be updated; and

WHEREAS, TWDB and TPWD are mandated by §16.058 of the Texas Water Code to study the ecology of the bays and estuaries and evaluate the needs for freshwater inflows; and

WHEREAS, TNRCC and TPWD are mandated by §11.1491 of the Texas Water Code to review studies prepared under §16.058, to determine inflow conditions necessary for the bays and estuaries; and

WHEREAS, TWDB is authorized by §6.190 of the Texas Water Code to enter into this agreement; and

WHERAS, TNRCC is authorized by §5.229 of the Texas Water Code to enter into this agreement; and

WHEREAS, TPWD is authorized by § 11.0171 of the Texas Parks & Wildlife Code to enter into this agreement; and

WHEREAS, LCRA is authorized by the Lower Colorado River Act of 1934, Ch. 74, Acts of the 64th Legislature, R. S., 1979, as amended; and

WHEREAS, consistent with Texas law and public policy, LCRA, TNRCC, TWDB, and TPWD mutually desire to protect and maintain a proper ecological environment and the health of related living marine resources in the Lavaca-Colorado Estuary.

NOW, THEREFORE, in consideration of the following promises, covenants, conditions, and the mutual benefits to accrue to the parties to this Agreement, the parties, desiring to cooperate in providing functions and services, agree as follows:

I. RESPONSIBILITIES OF EACH PARTY

A. Lower Colorado River Authority

1. LCRA agrees to adapt or modify existing methods and apply those methods to compute updated freshwater inflow needs for the Lavaca-Colorado Estuary by performing the tasks set forth in the Scope of Work in Attachment A, which is attached hereto and incorporated as if fully set forth herein (hereinafter referred to as the "study"). Completion of the study is contingent on the timely technical assistance to LCRA from the other participating parties. This assistance includes, but is not limited to, the transfer of technical information and procedures and advice on their usage to fulfill the purposes of this Agreement.

2. Project management responsibility for the study shall rest solely with LCRA. LCRA shall appoint an individual to serve as the Project Manager and Chair of the Advisory Committee for this Agreement.

3. LCRA agrees to make available to all parties to this Agreement all data, computer models, and information developed by LCRA in the study at any time upon reasonable written notice. At the completion of the study, LCRA will provide all data developed by LCRA to the Texas Natural Resources Information System in a computer-compatible format. Nothing herein shall be construed as limiting the LCRA's use, control, or ownership of any of the data developed in performing the study.

4. LCRA may solicit funding from the parties to this Agreement and from other sources to complete the study.

5. LCRA agrees to prepare a report on the methodology, data and results of the computation of updated freshwater inflow needs of the Lavaca-Colorado Estuary. LCRA shall consider any modifications to the draft of the final report recommended by any member of the Advisory Committee. If any party to this Agreement disagrees with any statements in the draft study

report, LCRA is obligated to include a rebuttal statement in the final report. There will be no recommendations in the draft or final study report regarding adoption of freshwater inflow needs presented unless all parties are in unanimous agreement. LCRA shall furnish all parties to this Agreement five (5) copies of the final report. The other parties in this Agreement reserve the right to take exception to any or all of the final report.

6. To the extent parties consider it appropriate based on the findings of the study, LCRA agrees to initiate a process for amending the Water Management Plan within six (6) months of completion of the study.

7. The LCRA will participate in updating the TWDB intensive inflow study of the estuary to collect tidal, flow, depth, and water quality data reflecting the new channel modifications at the Colorado River Delta. In cooperation with TWDB and TPWD, LCRA will use this information to revise and recalibrate the TWDB TXBLEND.G hydrodynamic model of the estuary to account for the new geomorphology

B. Texas Water Development Board

1. TWDB shall assist in the transfer of technical information and procedures to LCRA pertinent to the evaluation of the needs for freshwater inflows to the Lavaca-Colorado Estuary. TWDB shall advise LCRA in using such information and procedures to fulfill the purposes of this Agreement.

2. TWDB shall appoint an agency representative to serve on the Advisory Committee for this Agreement. This individual shall also act as the contact person for facilitating the transfer of technical information between TWDB and LCRA.

3. TWDB shall make available to all parties in this Agreement any existing data and analyses completed by TWDB related to freshwater inflow needs of Matagorda Bay and associated bays. These data and analyses shall be provided by July 1, 2002. TWDB will conduct and TPWD, TNRCC and LCRA will assist in updating gauged and ungauged inflows into Matagorda Bay as well as with the intensive inflow study and updating bathymetric survey.

4. TWDB shall make available to all parties in this Agreement any data and analyses collected or performed concerning the productivity of the Colorado-Lavaca Estuary, including but not limited to fisheries, shellfish, waterfowl, and other aquatic species (including plants).

5. TWDB shall assist LCRA in identifying data needs concerning the impacts of the Lavaca River on the Colorado-Lavaca Estuary

6. With assistance from TPWD, TNRCC and LCRA the TWDB will update the intensive inflow study of the estuary by collecting tidal, flow, depth, and water quality data reflecting the new channel modifications at the Colorado River Delta. The TWDB will assist LCRA in revising and re-calibrating the TXBLEND.G hydrodynamic model of the estuary to account for the new geomorphology. The TWDB will also assist with revisions to and execution of TXEMP model.

C. Texas Parks and Wildlife Department

1. TPWD shall assist in the transfer of technical information and procedures to LCRA pertinent to the evaluation of the needs for freshwater inflows to the Lavaca-Colorado Estuary. TPWD

shall advise LCRA in using such information and procedures to fulfill the purposes of this Agreement.

2. TPWD shall appoint an agency representative to serve on the Advisory Committee for this Agreement. This individual shall also act as the contact person for facilitating the transfer of technical information between TPWD and LCRA.

3. TPWD shall make available to all parties in this Agreement any data and analyses collected or performed concerning the productivity of the Colorado-Lavaca Estuary, including but not limited to fisheries, shellfish, waterfowl, and other aquatic species (including plants). These data and analyses shall be provided by July 1, 2002.

4. TPWD shall assist LCRA in identifying data needs concerning the impacts of the Lavaca River on the Colorado-Lavaca Estuary.

5. The TPWD will participate in updating the TWDB intensive inflow study of the estuary to collect tidal, flow, depth, and water quality data reflecting the new channel modifications at the Colorado River Delta. The TPWD will assist LCRA in revising and re-calibrating the TXBLEND.G hydrodynamic model of the estuary to account for the new geomorphology. The TPWD will also assist with revisions to and execution of TXEMP model

D. Texas Natural Resource Conservation Commission

1. TNRCC shall assist in the transfer of technical information and procedures to LCRA pertinent to the evaluation of the needs for freshwater inflows to the Lavaca-Colorado Estuary. TNRCC shall advise LCRA in using such information and procedures to fulfill the purposes of this Agreement.

2. TNRCC shall appoint an agency representative to serve on the Advisory Committee for this Agreement. This individual shall also act as the contact person for facilitating the transfer of technical information between TNRCC and LCRA.

3. The TNRCC will participate in updating the TWDB intensive inflow study of the estuary to collect tidal, flow, depth, and water quality data reflecting the new channel modifications at the Colorado River Delta. The TNRCC will assist LCRA in revising and re-calibrating the TXBLEND.G hydrodynamic model of the estuary to account for the new geomorphology.

II. ADVISORY COMMITTEE

A. Membership

The Advisory Committee shall consist of one representative from each participating party to this Agreement and the Lavaca-Navidad River Authority ("LNRA") should that agency choose to participate. LCRA shall appoint an individual to serve as Chair of the Advisory Committee for this Agreement.

B. Duties

The purpose of the Advisory Committee is to: (1) review study scope, schedule and technical methods; (2) facilitate inter-agency communication and cooperation; (3) formulate alternative estuarine inflow management objectives required for the analyses; and (4) evaluate results of the analyses and make consensus recommendations on freshwater inflows and estuarine inflow management alternatives. The Committee shall be chaired by LCRA and shall meet quarterly at times and places chosen by the Advisory Committee. LCRA shall provide the Committee quarterly written status reports. LCRA shall provide draft reports to the Committee on each of the three major tasks identified in Appendix A according to the approximate dates shown in Figure 2. These reports will include the methodology, data and results of these tasks. The Committee members shall have a minimum sixty (60) day review period to review, comment, and make recommendations for changes. LCRA shall provide copies to the Committee of the draft final report on the methodology, data and results of the computation of updated freshwater inflow needs of the Lavaca-Colorado Estuary. The Committee members shall have a minimum sixty (60) day review period to review, comment, and make recommendations for changes. LCRA will review the comments and recommendations with the Committee to attempt to resolve any differences.

III. GENERAL CONDITIONS

A. Final Report

The final report under the terms of this Agreement is not intended to replace the reporting requirements on the TWDB and TPWD under §11.1491 of the Texas Water Code. The results from the studies conducted under this Agreement may be used by TWDB and TPWD to fulfill the obligations under §11.1491.

B. Term of Agreement

The term of this Agreement shall be from April 1, 2002 until December 31, 2004.

C. Ability to Perform

Should any party's ability to perform its obligation under this Agreement depend upon the appropriation of funds or budget approval of funds from any governing body for the term of this Agreement and the funds are not appropriated or budget is not approved, upon written notice by the affected party to all other parties, this Agreement, or part thereof not funded, shall be terminated.

D. Notice of Termination

Any party may terminate its participation in this Agreement upon thirty (30) days written notice to the other parties for any reason or for no reason.

E. Contractors and Subcontractors

Any use by any party of contractors or subcontractors in the performance of this Agreement shall be by unanimous consent of all parties.

F. Cooperation of Parties

1. It is the intention of the parties that the details of providing the services in support of this Agreement shall be worked out, in good faith, by the parties.

2. All parties shall continue their planned data collection programs in the Lavaca-Colorado Estuary during the duration of this Agreement. All data collected to complete this Agreement shall be shared among the participating parties.

G. Notices

Any notices required by this Agreement to be in writing shall be addressed to the respective party as follows:

Texas Natural Resource Conservation Commission
Attn. Mr. Doyle Mosier
P.O. Box 13087
Austin, Texas 78711

Texas Water Development Board
Attn. Mr. Gary Powell
1700 North Congress Ave.
P.O. Box 13231
Austin, Texas 78711-3231

Texas Parks and Wildlife Department
Attn. Ms. Cindy Loeffler
3000 S. IH 35, Suite 320
Austin, Texas 78704

Lower Colorado River Authority
Attn. Dr. Jobaid Kabir
P.O. Box 220
Austin, Texas 78767-0220

H. Effective Date of Agreement

This Agreement is effective upon execution below by all parties. By signing this Agreement, the signatories acknowledge that they are acting under proper authority form their governing bodies.

Texas Natural Resource Conservation Commission

By: _____

Title: Executive Director

Date: 9/4/02

Texas Water Development Board

By: _____

Title: Executive Administrator

Date: 3/4/02

Texas Parks and Wildlife Department

By: _____

Title: Interim Executive Director

Date: 1/25/02

Lower Colorado River Authority

By: _____

Title: Executive Manager, River Services

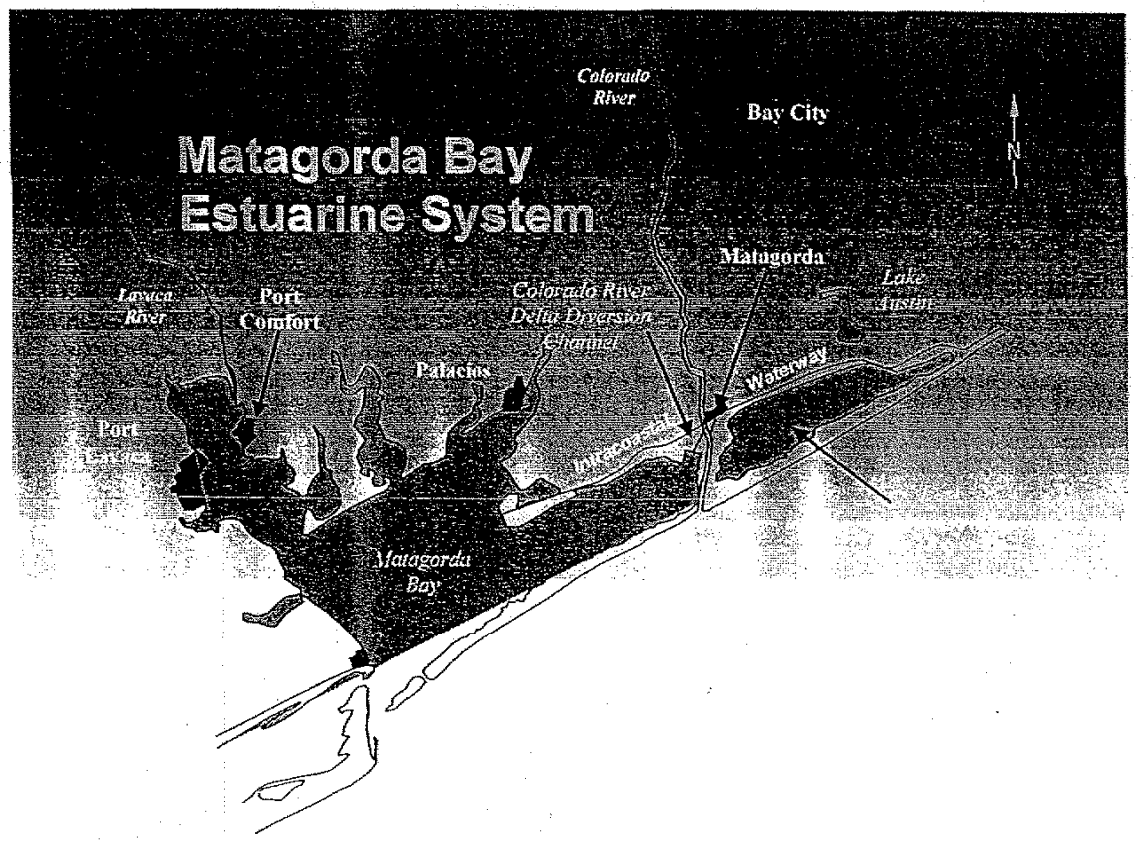
Date: 9/9/02

ATTACHMENT A

SCOPE OF WORK

INTRODUCTION

This study will be a comprehensive assessment of the need for freshwater inflows to maintain and enhance the natural ecology of the Lavaca-Colorado Estuary (Figure 1). Emphasis will be on the estuary west of the Colorado River in determining freshwater inflows from the Colorado and Lavaca Rivers and coastal basins. This assessment will use existing data and analyses from the Lower Colorado River Authority (LCRA), Texas Water Development Board (TWDB), and Texas Parks and Wildlife Department (TPWD), in combination with additional data collected and evaluated by LCRA during the course of this study. The inflow needs will be computed separately for each of the Lavaca and Colorado Rivers and un-gauged coastal areas except where the commingling of the impacts prohibits treating them in isolation. The freshwater inflow needs will be computed for a variety of alternative estuarine inflow management options. This study will be closely coordinated with the activities of the LCRA Water Resource Protection Program.



PROJECT TASKS

There are three major technical tasks in this project. These involve assessing the biological, chemical and hydrologic interrelations in the estuary. All three major tasks will include assessment of existing data and data needs. A detailed schedule is attached hereto at Figure 2.

Task 1: Technical Studies

1. **Hydrology:** LCRA will evaluate historical freshwater inflows to the estuary. This task will update, as necessary, the inflow estimates developed during the 1997 Freshwater Inflows Needs Study. In addition, LCRA will participate in updating the TWDB intensive inflow study of the estuary to collect tidal, flow, depth, and water quality data reflecting the new channel modifications at the Colorado River Delta. In cooperation with TWDB and TPWD, LCRA will use this information to revise and recalibrate the TWDB TXBLEND.G hydrodynamic model of the estuary to account for the new geomorphology.

2. **Water Quality**: LCRA will continue to monitor salinity and other water quality field parameters in the river at Bay City and at two points in the eastern arm of Matagorda Bay on a continuous basis. The LCRA will also assess the need for additional points in the bay for monitoring salinity and other water quality parameters. In the same part of the river and estuary, LCRA will conduct periodic sampling of nutrients, sediments and other water quality parameters. Data from these ongoing activities will be used in the analysis. TPWD routinely collects water quality date for the bay. TWDB and TPWD will supply data collected by respective agencies for the remainder of the estuary. LCRA, in concert with TWDB, will develop a nutrient balance for the estuary. LCRA will develop quantitative relationships between inflows salinity, nutrients and sedimentation for Colorado and Lavaca Rivers. LCRA will also evaluate sediment inflow needs from the Colorado River Basin. TWDB, in cooperation with LNRA and TPWD, will determine the sediment inflow needs from the Lavaca River Basin. In cooperation with TWDB and TPWD, LCRA will revise and recalibrate the TWDB TXBLEND.G salinity transport model of the estuary to account for modifications to the Colorado River Delta, as described under Task 2 below.

3. **Biology:** LCRA will use existing data, including any additional data provided by TPWD and TWDB, on freshwater inflows, salinity, harvest effort and other factors to revise, as necessary, estimates of fish productivity and viability developed in the 1997 Freshwater Inflow Needs Study. Adult and juvenile fin and shellfish salinity preferences and tolerance ranges will be revised and updated.

4. **Management Decision Model: LCRA** will re-evaluate the inter-actions between inflows and estuarine conditions. In cooperation with TWDB and TPWD, LCRA will modify, as necessary, the TWDB Estuarine Mathematical Programming (TXEMP)_Model to fit conditions in the estuary, which will then be used to execute the TXBLEND.G model, as described under Task 2 below.

Task 2. Computation of Freshwater Inflow Needs

LCRA, in conjunction with the Advisory Committee, will formulate a variety of estuarine inflow management alternatives. For each of these alternatives, LCRA staff will use the Estuarine Mathematical Programming Model (TXEMP) and associated models (TXBLEND.G), as revised under Task 1, or alternative methods if deemed appropriate, to compute monthly and seasonal freshwater inflow needs from both the Colorado and Lavaca River Basins. The Advisory Committee may select a range of estuarine inflow management alternatives to meet the freshwater inflow needs identified. The first alternative to be evaluated will be selected jointly by the LCRA, TNRCC, TWDB and TPWD.

Task 3. Review and Revision to Final Report

LCRA shall prepare a draft final report on the computation of inflow needs. There will be no recommendations in the draft or final study report regarding adoption of freshwater inflow needs presented unless all parties are in unanimous agreement. The Advisory Committee shall have 60 days to review the draft report and provide LCRA with comments and recommended changes. LCRA shall consider comments and suggested changes and may revise the final report as appropriate. If any party to this Agreement disagrees with any statements in the draft study report, LCRA is obligated to include a rebuttal statement in the final report. LCRA shall prepare and publish the final study report. The participating agencies reserve the right to publish their own findings and conclusions.

DELIVERABLE WORK PRODUCTS

1. Quarterly status reports
2. Draft and final reports on four subtasks of Task 1 and on Task 2
3. Draft and final technical report

PROJECT SCHEDULE

The estimated time for project completion is 36 months with the study to be initiated by April 1, 2002.

The time schedule for each major task is identified in Figure 2. The major milestones in the project are noted as follows.

Program initiation:	April 1, 2002
Quarterly status reports:	A quarterly progress report will be prepared every three months starting July 1, 2002.
Draft final report:	October 1, 2004
Final report:	December 31, 2004

TWDB Contract No. 2004-MOA-032

STATE OF TEXAS
TRAVIS COUNTY

Texas Water Development Board

and

Lower Colorado River Authority
Texas Parks and Wildlife Department
Texas Commission on Environmental Quality

AMENDMENT NO. 1

This Contract and Agreement fully executed on September 9, 2002, is hereby amended as follows:

1. Article III, B. Term of the Agreement is modified to read:

   "The term of this Agreement shall be from April 1, 2002 until June 30, 2005."

2. All other terms and conditions of Board Contract No. 2004-MOA-032 shall remain in effect.

IN WITNESS WHEREOF the parties hereto cause this Contract and Agreement to be duly executed in multiple.

TEXAS WATER DEVELOPMENT BOARD

By: Willi F Mullican
William F. Mullican, III
Deputy Executive Administrator

Date: 9/17/04

LOWER COLORADO RIVER AUTHORITY

By: Joseph J. Beal
Joseph J. Beal
General Manager

Date:

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

By: Glenn Shankle
Glenn Shankle
Executive Director

Date: 10·8·2004

TEXAS PARKS & WILDLIFE DEPARTMENT

By:
Robert L. Cook
Executive Director

Date:

FILE COPY

Appendix B
Dataset Summary

APPENDIX B

Dataset Summary

Maragorda Bay Salinity Data:

LCRA currently maintains eight continuous monitoring sites (Table B.1), including four height of tide gage sites, throughout the Matagorda Bay system. Multi-probe water quality instruments record hourly measurements for salinity, dissolved oxygen, pH, height of tide and temperature. Average daily salinity is calculated for each monitoring station.

Table B.1. LCRA Bay Monitoring Locations

Site Description	Period of Record	Latitude (Deg. decimal deg.)	Longitude (Deg. decimal deg.)	Height of Tide
West Bay Tripod	6/93 to present	28 5960	96 0396	Yes
West Bay Marker #4	6/93 to present	28 5620	96 2159	-
Palacios Marker #44	6/98 to present	28 6737	96 2320	Yes
Carancahua Bay	6/98 to present	28 6724	96 3998	-
Sandy Point	6/98 to present	28 5465	96 4649	Yes
East Bay Tripod	6/98 to present	28 6721	95 9326	Yes
East Bay Shellfish	6/98 to present	28 7233	95 7667	-
West Bay Shellfish #B	4/02 to present	28 3714	96 0301	-

Lavaca Bay Salinity Data:

The TWDB has maintained a program for the automated collection of water quality data in Texas estuaries since the fall of 1986. The purpose of this water quality monitoring effort is primarily to support calibration of estuary circulation and salinity simulation models and for development of inflow-salinity relationships for the estuaries. The program meets that need by providing high-frequency data (most measurements every 60

or 90 minutes), so that the pattern of salinity changes with changing river flow or meteorological events is accurately traced.

Data are collected by multi-probe, battery-powered, self-contained electronic instruments which can be programmed to collect and record a number of water quality parameters on a set sampling frequency. In addition to salinity, TWDB Datasondes are equipped to measure temperature, conductivity, dissolved oxygen and water level. Some sondes record pH, and turbidity as well.

Datasondes were deployed in the fall of 1986 in Corpus Christi, Nueces, Aransas, Mesquite, San Antonio, Lavaca, Matagorda, Galveston, and Trinity bays. After September, 1989 some new sites were established and old sites abandoned. Station locations were determined in part by the need for salinity data near the heads and mouths of major estuaries for purposes of salinity modeling. Locations were also determined by ease of access and availability of anchoring structures, in compromise with ideal locations.

The datasets and period of record used for the salinity analysis include:

- Colorado River basin Critical Flow Equation January 1993 to December 2002, LCRA West Bay Tripod
- Colorado River basin TXEMP equation, August 1993 to December 2003, LCRA West Bay Tripod
- Lavaca River basin Critical Flow and TXEMP Equation - February 1987 to March 2003, TWDB data

Biology Data:

1978 -2002 TPWD Coastal Fisheries Data was used for both pre- and post-diversion project comparisons. Equations were developed with the post diversion period sub-set, 1993 - 2002, by relating annual abundance to river inflows. Some data years were not

used for the analysis for some species. Table B.2 lists the coastal fisheries data used for each species by year.

Table B.2. Coastal Fisheries Data Used in Analysis (individuals/acre)

Year	Blue Crab	Brown Shrimp	White Shrimp	Gulf Menhaden	Striped Mullet	Red Drum	Oysters (number/dredge)
1992			257.02				
1993	20.50		234.00			4.83	4.89
1994	38.33		204.83	165.28	24.89	3.33	8.95
1995	25.44		242.83	287.11	11.00	3.22	13.51
1996	15.39	110.83	181.94	593.56	13.06	7.94	19.66
1997	25.11			918.83	28.39	7.72	16.70
1998	19.28	150.44	188.56	379.89	13.56	3.17	15.08
1999	13.94	192.44		159.72	7.44	5.11	19.14
2000	17.72	179.28	77.33	28.67	9.33	1.67	19.92
2001	14.39	141.89	137.72	1676.17	42.17	4.28	
2002	15.56	99.78		97.56	14.11	4.44	

Appendix C
Species Abundance Maps

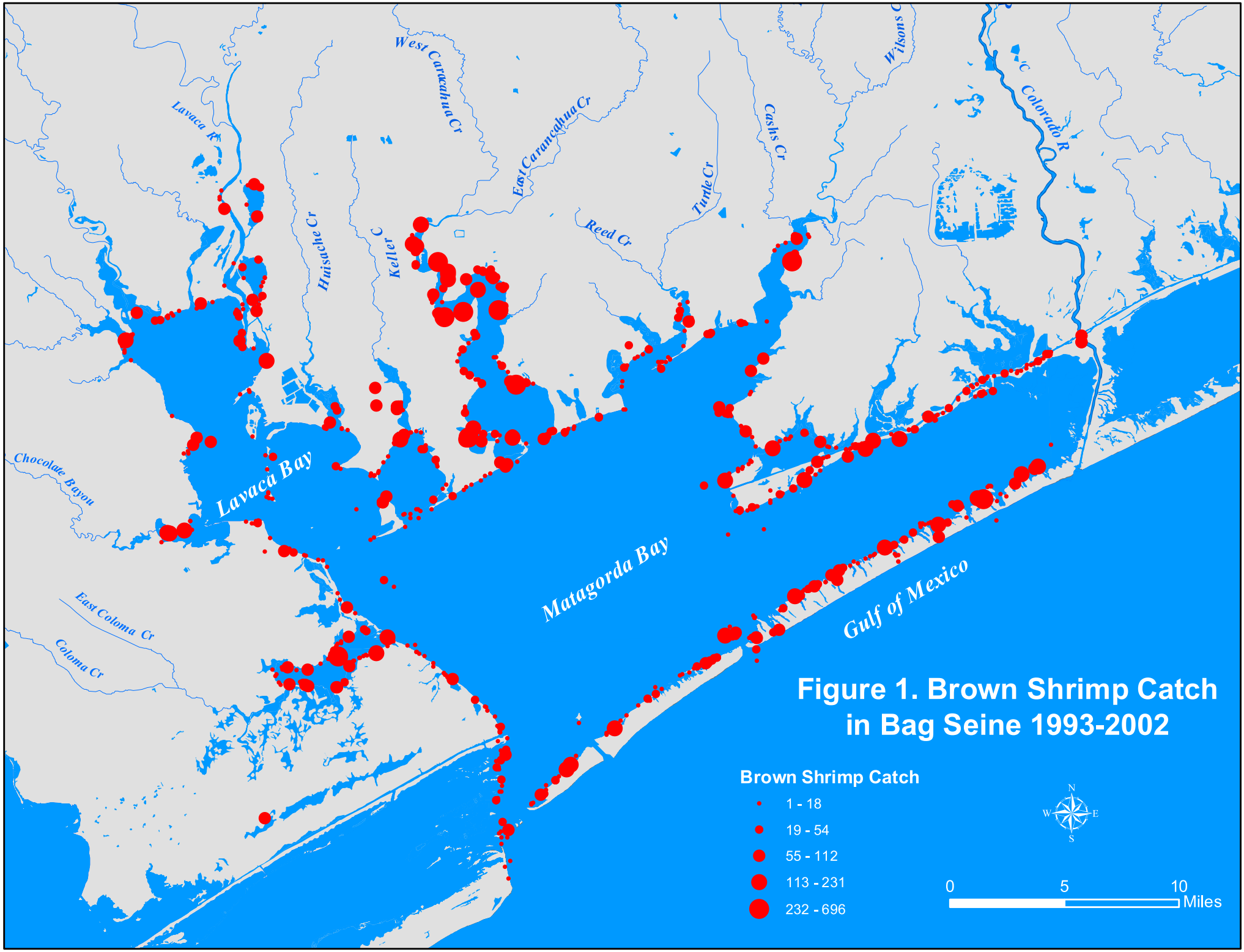


Figure 1. Brown Shrimp Catch in Bag Seine 1993-2002

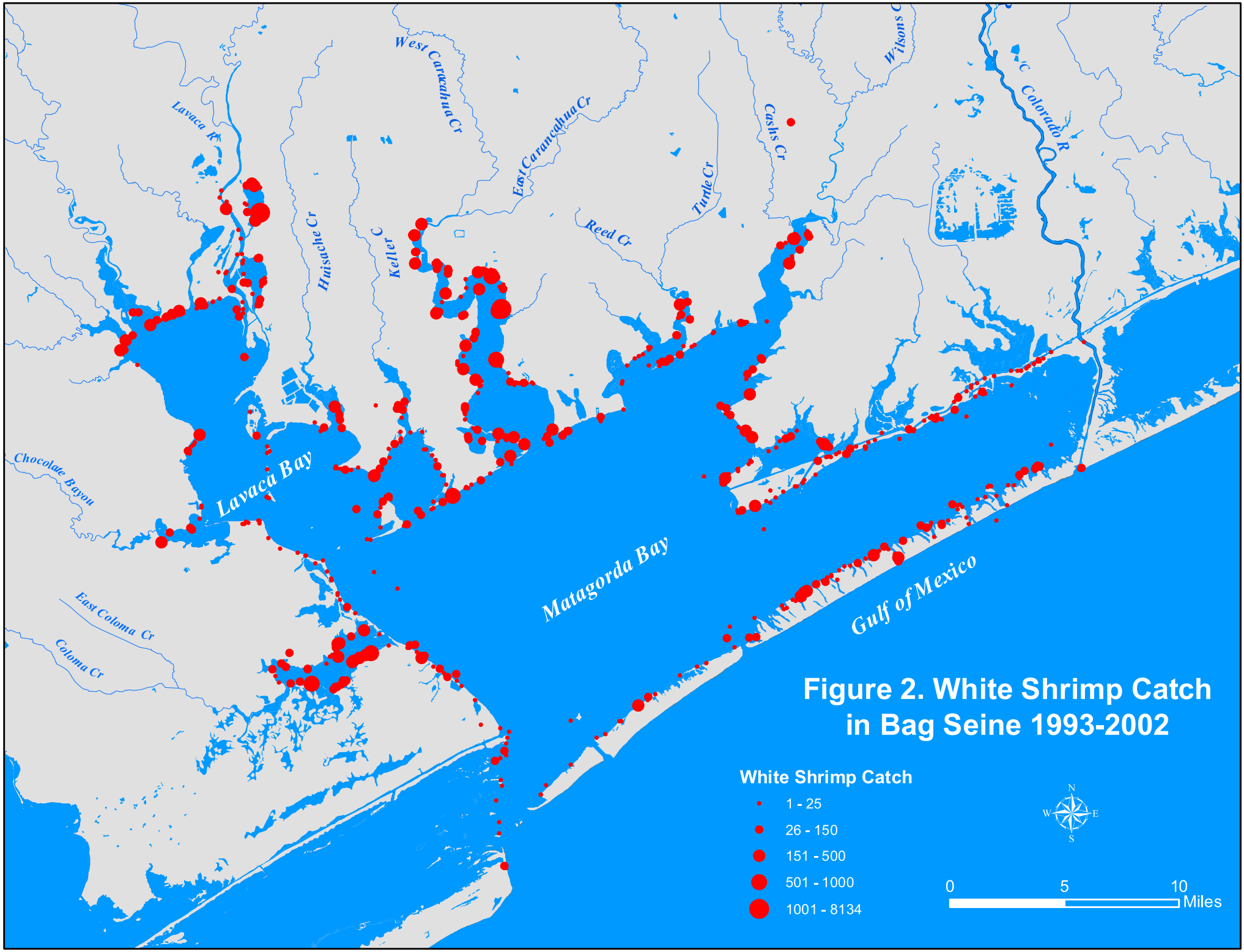


Figure 2. White Shrimp Catch in Bag Seine 1993-2002

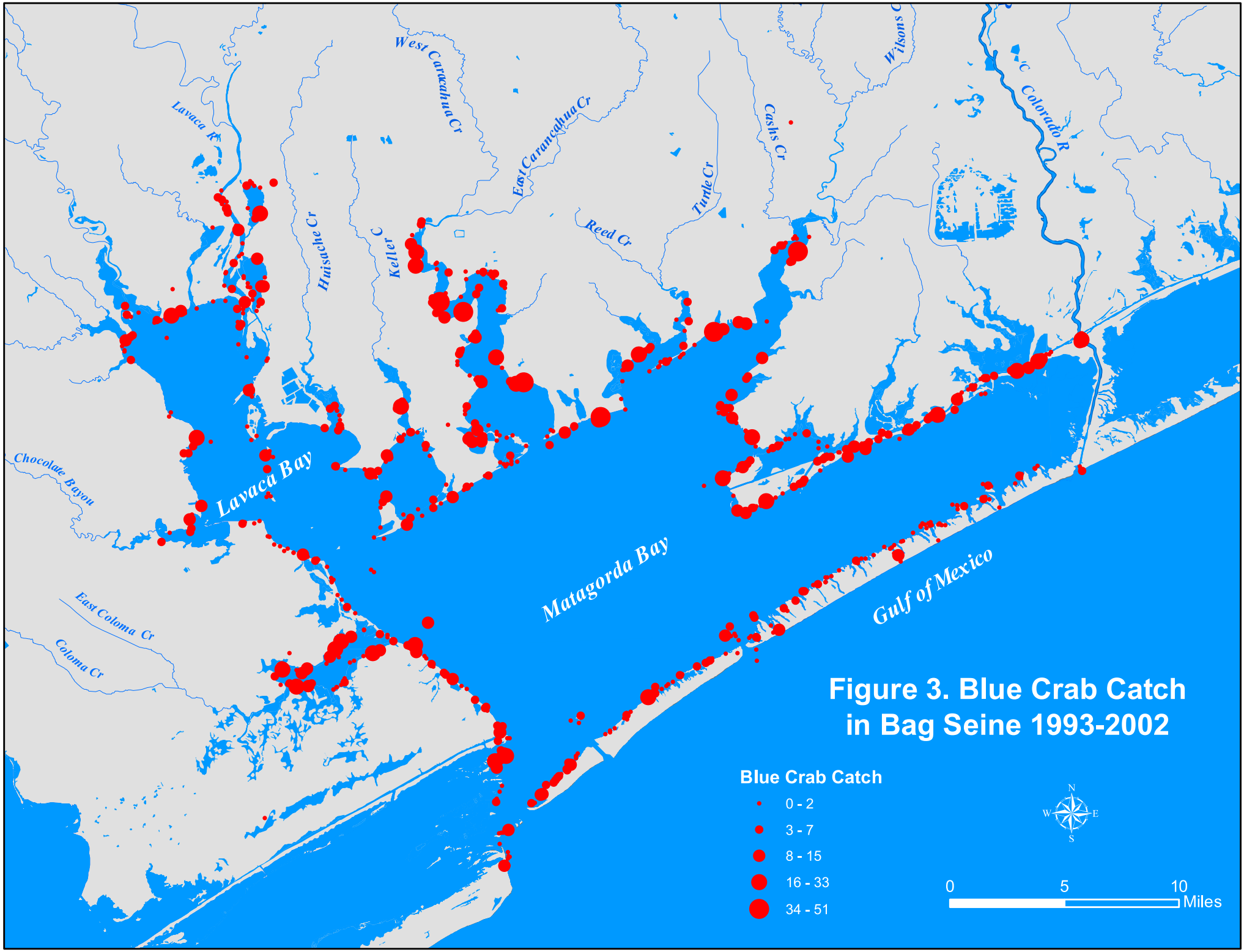


Figure 3. Blue Crab Catch in Bag Seine 1993-2002

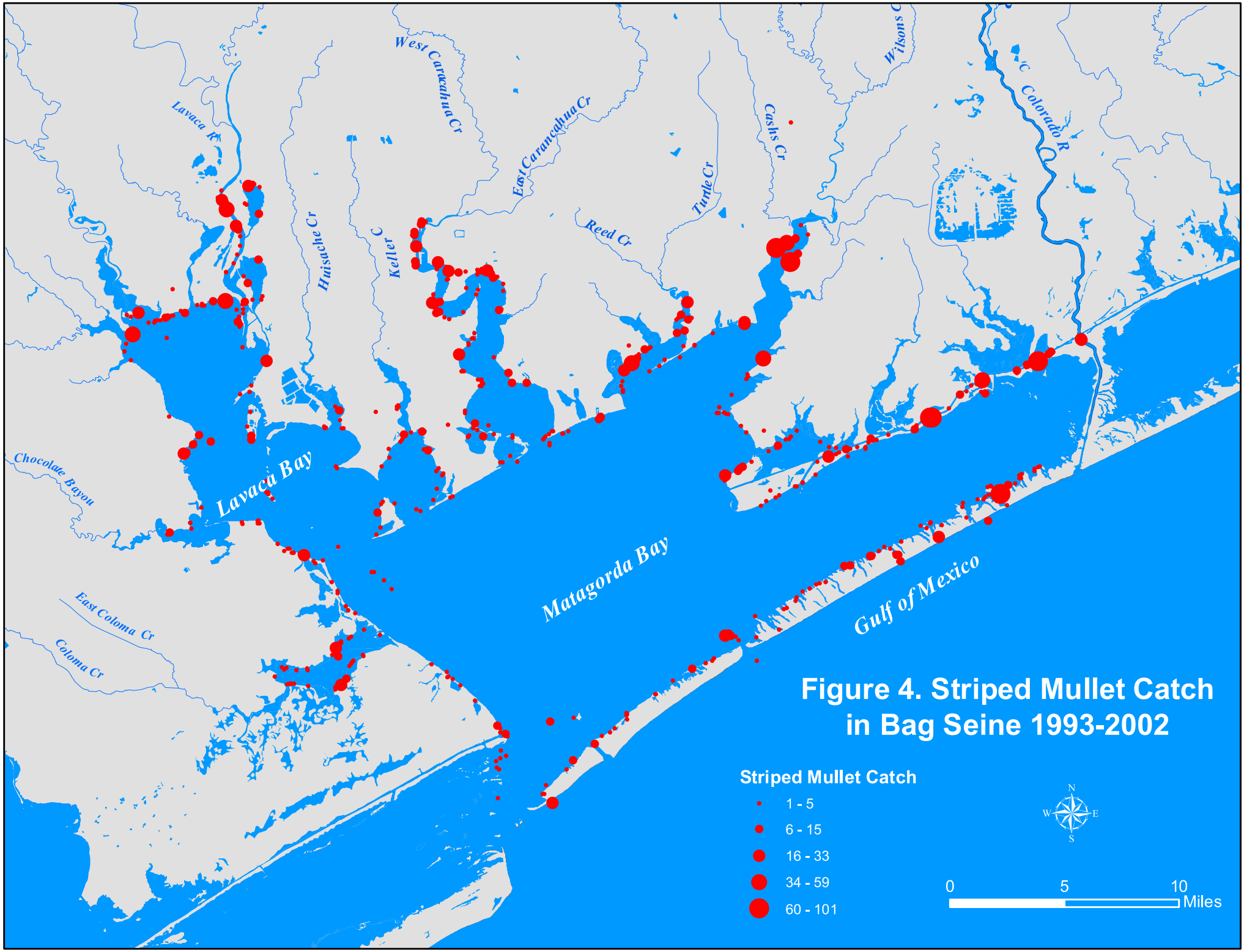


Figure 4. Striped Mullet Catch in Bag Seine 1993-2002

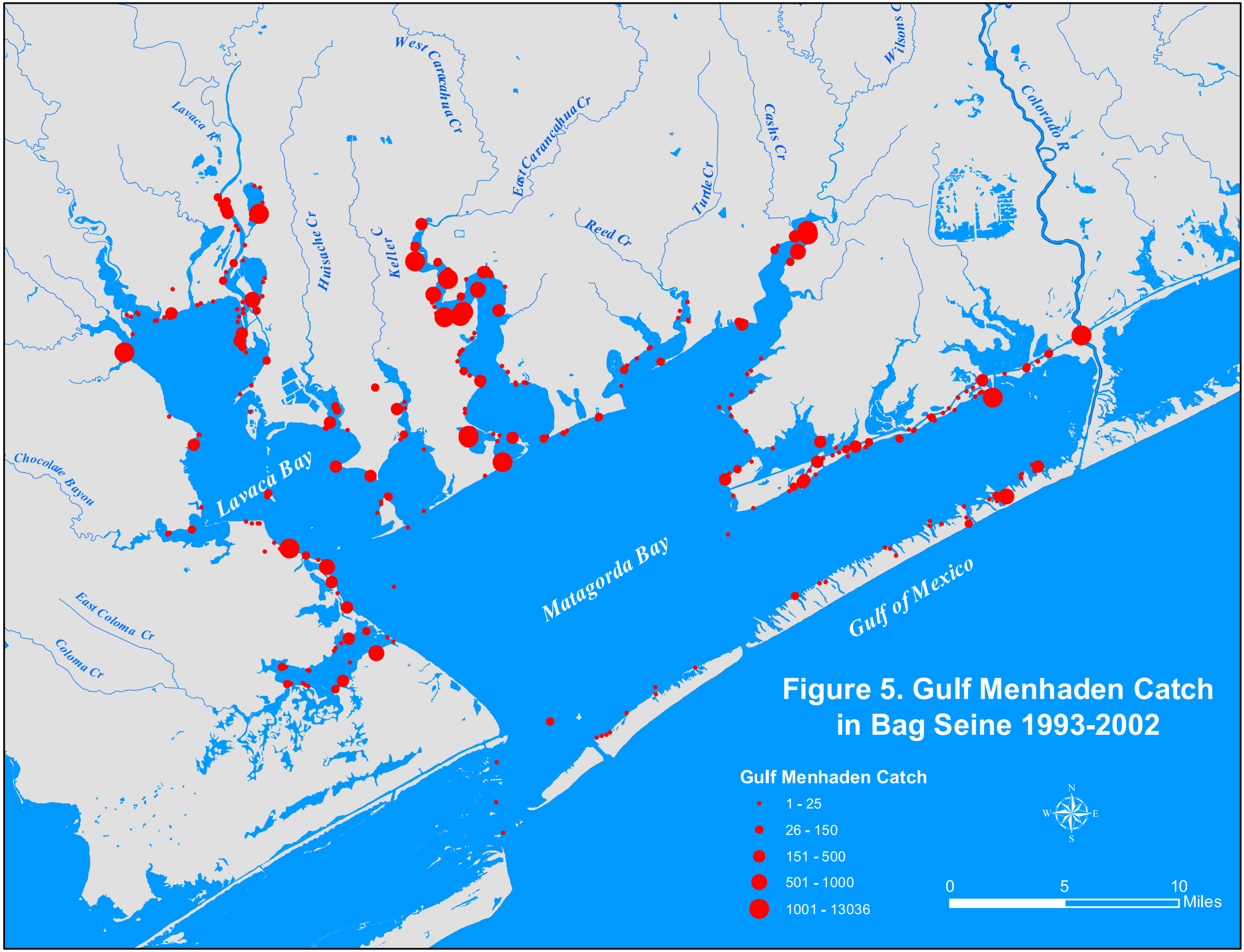


Figure 5. Gulf Menhaden Catch in Bag Seine 1993-2002

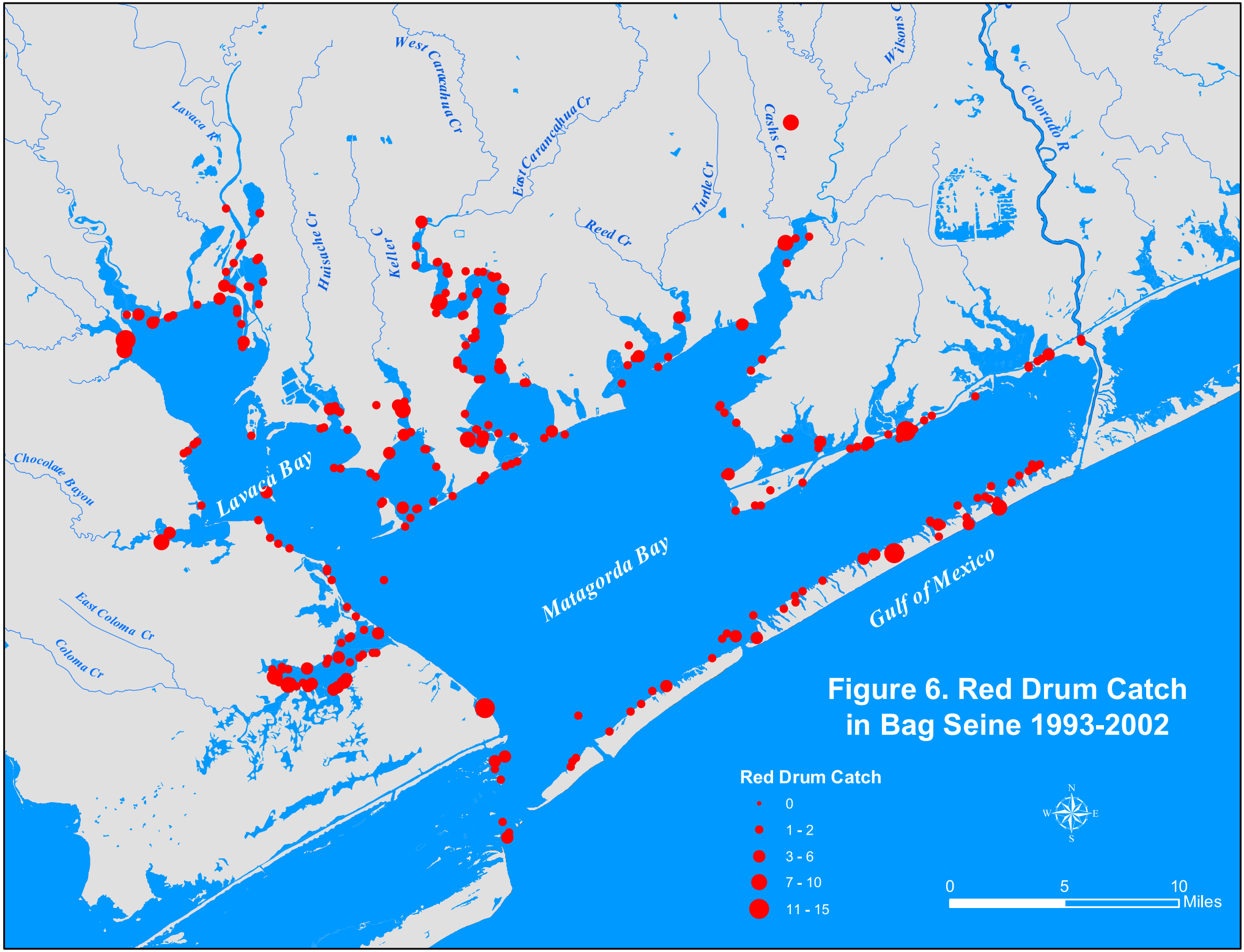


Figure 6. Red Drum Catch in Bag Seine 1993-2002

Appendix D
Salinity Regression Analysis

StatTools (Core Analysis Pack)

Analysis: Regression
Performed By: Ron Anderson
Date: Thursday, April 01, 2004
Updating: Static

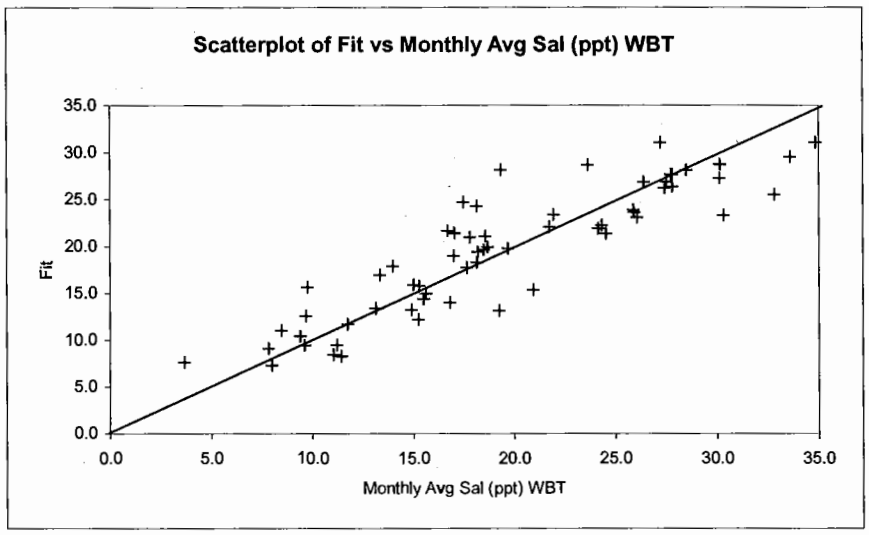
Summary	Multiple R	R-Square	Adjusted R-Square	StErr of Estimate	Durbin Watson
	0.891	0.794	0.7832	3.527	1.4500

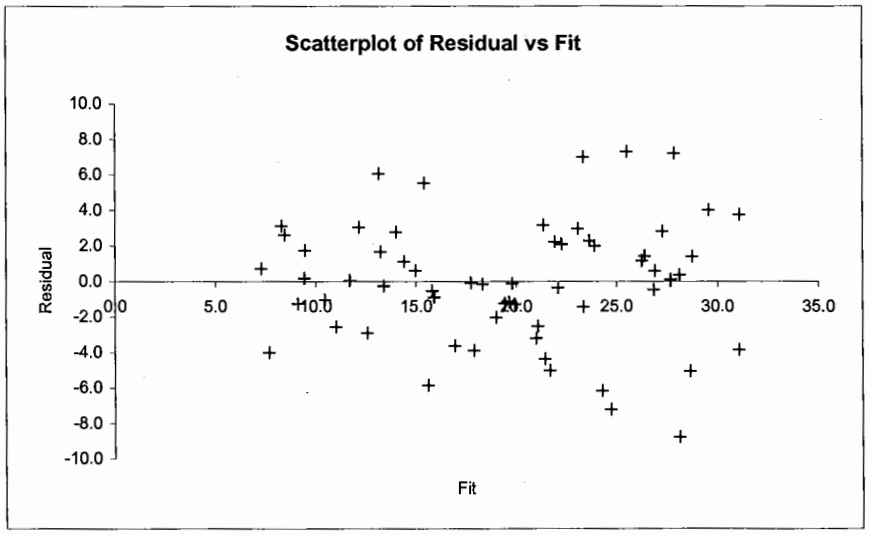
ANOVA Table	Degrees of Freedom	Sum of Squares	Mean of Squares	F-Ratio	p-Value
Explained	3	2778.2	926.1	74.434	< 0.0001
Unexplained	58	721.6	12.4		

Regression Table	Coefficient	Standard Error	t-Value	p-Value	Lower Limit	Upper Limit
Constant	106.618	6.128	17.399	< 0.0001	94.352	118.885
LN(Qm1)	-4.125	0.604	-6.827	< 0.0001	-5.335	-2.916
LN(Qm2)	-2.050	0.744	-2.753	0.0079	-3.540	-0.559
LN(Qm3)	-1.531	0.589	-2.598	0.0119	-2.711	-0.352

Step Information	Multiple R	R-Square	Adjusted R-Square	StErr of Estimate	Entry Number
LN(Qm1)	0.8204	0.6730	0.6676	4.367	1
LN(Qm2)	0.8774	0.7698	0.7620	3.695	2
LN(Qm3)	0.8910	0.7938	0.7832	3.527	3

LN(Qm4) had a t-value of less than .3





10:48 Thursday, April 22, 2004 16

The ARIMA Procedure

Maximum Likelihood Estimation

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	108.93249	8.64139	12.61	<.0001	0	SAL	0
AR1,1	0.43929	0.13146	3.34	0.0008	1	SAL	0
NUM1	-3.84131	0.53625	-7.16	<.0001	0	LQm	0
NUM2	-2.65652	0.53931	-4.93	<.0001	0	LQm_1	0
NUM3	-1.33709	0.53676	-2.49	0.0127	0	LQm_2	0

Constant Estimate	61.07972
Variance Estimate	9.316634
Std Error Estimate	3.052316
AIC	273.6555
SBC	283.507
Number of Residuals	53

Correlations of Parameter Estimates

Variable	Parameter	SAL MU	SAL AR1,1	LQm NUM1	LQm_1 NUM2	LQm_2 NUM3
SAL	MU	1.000	-0.093	-0.492	-0.436	-0.488
SAL	AR1,1	-0.093	1.000	0.100	0.010	0.018
LQm	NUM1	-0.492	0.100	1.000	-0.187	-0.111
LQm_1	NUM2	-0.436	0.010	-0.187	1.000	-0.193
LQm_2	NUM3	-0.488	0.018	-0.111	-0.193	1.000

Autocorrelation Check of Residuals

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	4.92	5	0.4254	-0.071	0.163	0.050	0.053	-0.211	0.039
12	13.38	11	0.2695	0.156	-0.102	0.140	-0.065	0.166	-0.196
18	14.83	17	0.6079	0.038	-0.044	-0.006	-0.072	0.059	-0.078
24	19.43	23	0.6762	-0.045	0.023	-0.056	0.075	-0.062	0.178

StatTools (Core Analysis Pack)

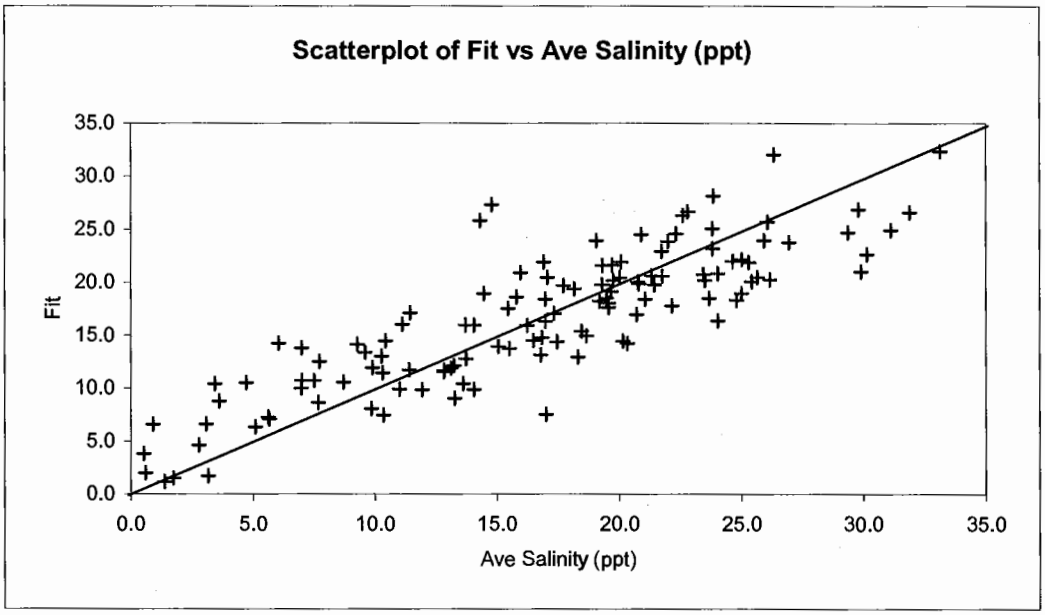
Analysis: Regression
Performed By: Ron Anderson
Date: Wednesday, March 24, 2004
Updating: Static

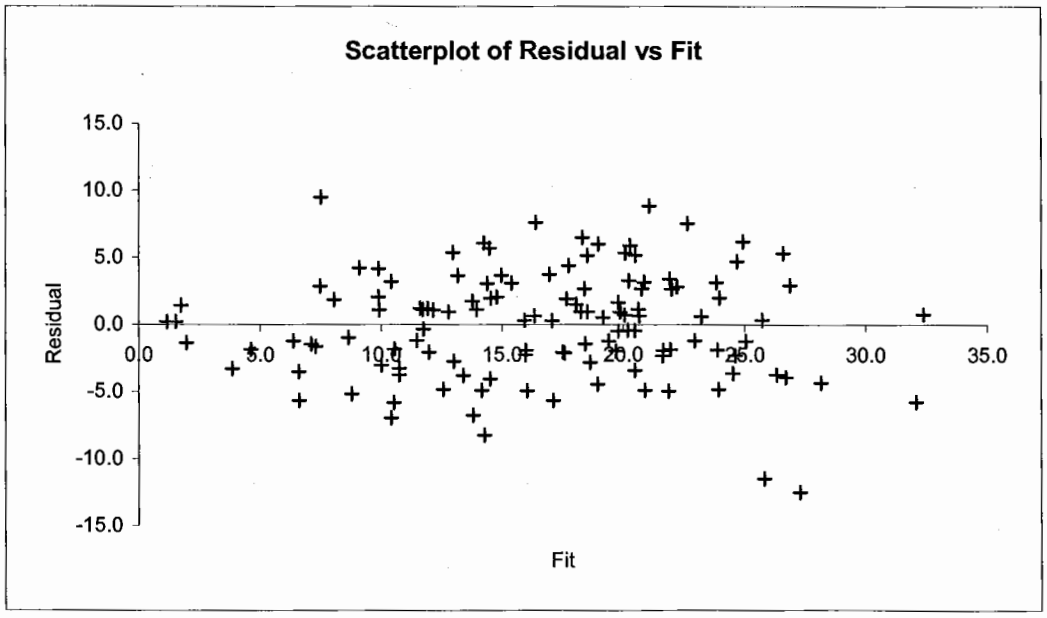
LAVACA SALINITY REGRESSION

Summary	Multiple R	R-Square	Adjusted R-Square	StErr of Estimate	Durbin Watson
	0.8551	0.7311	0.7222	4.0245	1.3342

ANOVA Table	Degrees of Freedom	Sum of Squares	Mean of Squares	F-Ratio	p-Value
Explained	4	5285.6324	1321.4081	81.5846	< 0.0001
Unexplained	120	1943.6131	16.1968		

Regression Table	Coefficient	Standard Error	t-Value	p-Value	Lower Limit	Upper Limit
Constant	64.7772	2.8358	22.8426	< 0.0001	59.162	70.392
LNQm2)	-1.7722	0.2526	-7.0166	< 0.0001	-2.272	-1.272
LN(Qm1)	-1.7431	0.2224	-7.8367	< 0.0001	-2.183	-1.303
LN(Qm4)	-0.7740	0.2187	-3.5385	0.0006	-1.207	-0.341
LN(Qm3)	-0.6386	0.2418	-2.6413	0.0094	-1.117	-0.160





The ARIMA Procedure

Maximum Likelihood Estimation

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag	Variable	Shift
MU	67.10222	4.26406	15.74	<.0001	0	Sal	0
AR1,1	0.48832	0.09932	4.92	<.0001	1	Sal	0
NUM1	-1.68509	0.23955	-7.03	<.0001	0	lnQ	0
NUM2	-2.02093	0.24659	-8.20	<.0001	0	lnQ_1	0
NUM3	-0.83264	0.24861	-3.35	0.0008	0	lnQ_2	0
NUM4	-0.59384	0.23855	-2.49	0.0128	0	lnQ_3	0

Constant Estimate	34.33486
Variance Estimate	10.1779
Std Error Estimate	3.190283
AIC	454.8098
SBC	469.6053
Number of Residuals	87

Correlations of Parameter Estimates

Variable		Sal	Sal	lnQ	lnQ_1	lnQ_2	lnQ_3
Parameter		MU	AR1,1	NUM1	NUM2	NUM3	NUM4
Sal	MU	1.000	0.033	-0.505	-0.396	-0.318	-0.465
Sal	AR1,1	0.033	1.000	-0.069	-0.068	-0.004	0.096
lnQ	NUM1	-0.505	-0.069	1.000	-0.176	-0.038	0.098
lnQ_1	NUM2	-0.396	-0.068	-0.176	1.000	-0.161	0.008
lnQ_2	NUM3	-0.318	-0.004	-0.038	-0.161	1.000	-0.277
lnQ_3	NUM4	-0.465	0.096	0.098	0.008	-0.277	1.000

Autocorrelation Check of Residuals

To Lag	Chi-Square	DF	Pr > ChiSq	Autocorrelations					
6	7.50	5	0.1859	-0.051	0.115	-0.043	-0.153	0.198	0.003
12	17.62	11	0.0909	0.185	-0.060	0.052	0.185	-0.114	0.116
18	27.16	17	0.0557	-0.148	0.045	0.167	-0.025	0.143	-0.123
24	36.41	23	0.0374	0.104	-0.066	0.174	-0.053	-0.054	0.163

Autocorrelation Plot of Residuals

Lag	Covariance	Correlation	-1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1	Std Error
0	10.177905	1.00000	| |********** |	0
1	-0.522065	-.05129	| . *| . |	0.107211
2	1.168725	0.11483	| . |** . |	0.107493
3	-0.442540	-.04348	| . *| . |	0.108894
4	-1.561171	-.15339	| .***| . |	0.109093
5	2.012918	0.19777	| . |**** |	0.111545
6	0.026665	0.00262	| . | . |	0.115505
7	1.884159	0.18512	| . |****. |	0.115506
8	-0.607411	-.05968	| . *| . |	0.118867
9	0.527871	0.05186	| . |* . |	0.119211
10	1.886428	0.18535	| . |****. |	0.119470
11	-1.162633	-.11423	| . **| . |	0.122731
12	1.184240	0.11635	| . |** . |	0.123947

Inverse Autocorrelations

Lag	Correlation	-1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
1	-0.00162	| . | . |
2	-0.18674	| ****| . |
3	0.07648	| . |** . |
4	0.21414	| . |**** |
5	-0.12082	| . **| . |
6	-0.17668	| ****| . |
7	-0.07258	| . *| . |
8	0.11685	| . |** . |
9	-0.09691	| . **| . |
10	-0.17790	| ****| . |
11	0.08613	| . |** . |
12	0.01018	| . | . |

Partial Autocorrelations

Lag	Correlation	-1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
1	-0.05129	| . *| . |
2	0.11249	| . |** . |
3	-0.03299	| . *| . |
4	-0.17246	| .***| . |

```
 5        0.20108    |                  .    |****                 |
 6        0.05732    |                  .    |*   .                |
 7        0.13009    |                  .    |***.                 |
 8       -0.07067    |                  .   *|    .                |
 9        0.08295    |                  .    |**  .                |
10        0.21370    |                  .    |****                 |
11       -0.10239    |                  .  **|    .                |
12       -0.01215    |                  .    |    .                |
```

Model for variable Sal

Estimated Intercept 67.10222

Autoregressive Factors

Factor 1: 1 - 0.48832 B**(1)

Input Number 1

Input Variable	lnQ
Overall Regression Factor	-1.68509

Input Number 2

Input Variable	lnQ_1
Overall Regression Factor	-2.02093

Input Number 3

Input Variable	lnQ_2
Overall Regression Factor	-0.83264

Input Number 4

Input Variable	lnQ_3
Overall Regression Factor	-0.59384

The AUTOREG Procedure

Maximum Likelihood Estimates

SSE	824.414799	DFE	81
MSE	10.17796	Root MSE	3.19029
SBC	469.605303	AIC	454.809854
Regress R-Square	0.6901	Total R-Square	0.8534
Durbin-Watson	2.0443		

Variable	DF	Estimate	Standard Error	t Value	Approx Pr > |t|
Intercept	1	67.1085	4.2694	15.72	<.0001
lnQ	1	-1.6851	0.2399	-7.02	<.0001
lnQ_1	1	-2.0211	0.2470	-8.18	<.0001
lnQ_2	1	-0.8329	0.2490	-3.34	0.0013
lnQ_3	1	-0.5940	0.2389	-2.49	0.0150
AR1	1	-0.4880	0.0995	-4.90	<.0001

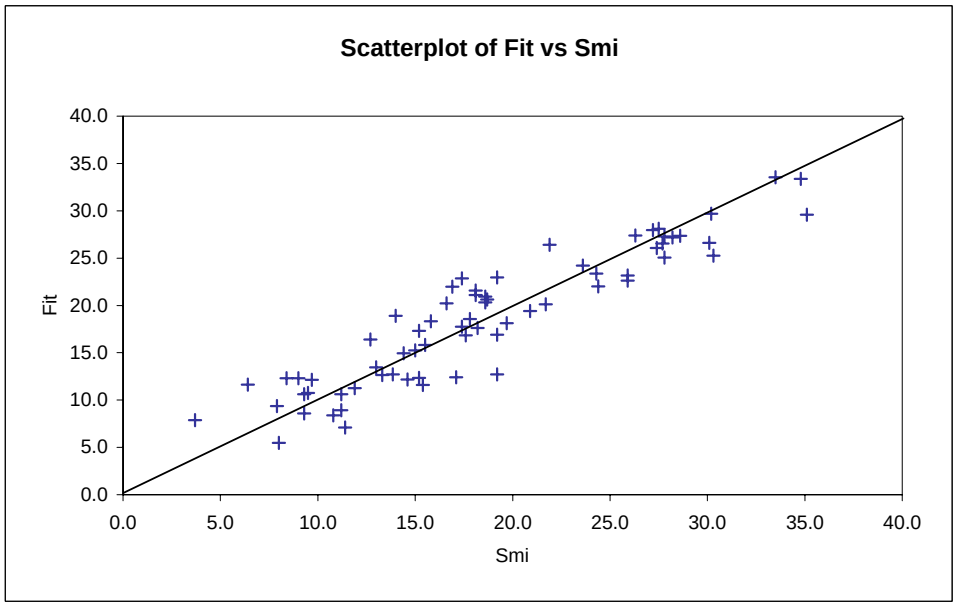
StatTools (Core Analysis Pack)

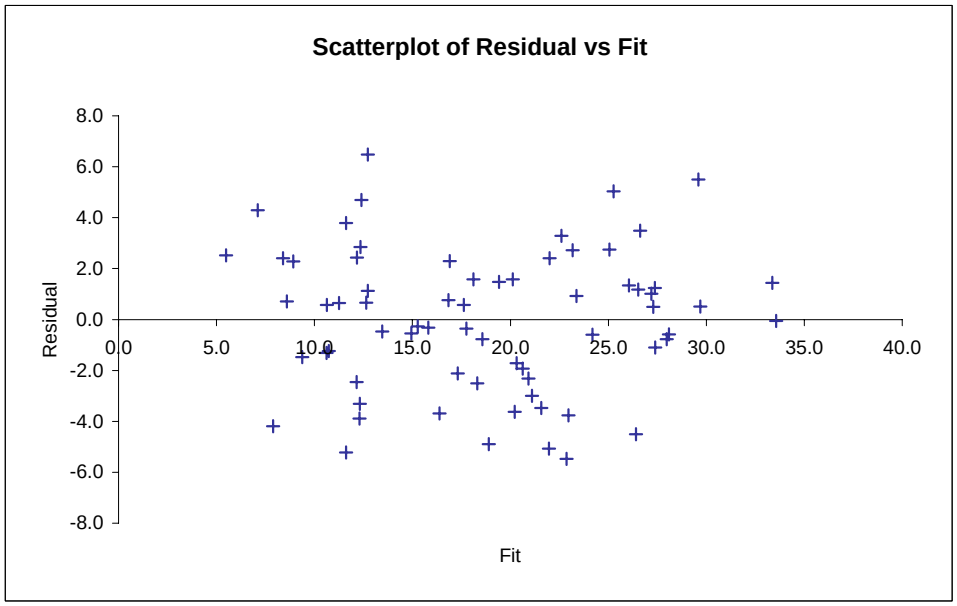
Analysis: Regression Equation 9.1 Monthly Salinity Inflow Relationship for West Tripod
Performed By: Ron Anderson
Date: Thursday, May 27, 2004
Updating: Static

Summary	Multiple R	R-Square	Adjusted R-Square	StErr of Estimate	Durbin Watson
	0.93	0.86	0.85	2.86	1.73

ANOVA Table	Degrees of Freedom	Sum of Squares	Mean of Squares	F-Ratio	p-Value
Explained	3	3241.97	1080.66	131.96	< 0.0001
Unexplained	64	524.12	8.19		

Regression Table	Coefficient	Standard Error	t-Value	p-Value	Lower Limit	Upper Limit
Constant	38.364	4.351	8.8175	< 0.0001	29.672	47.056
smi-1	0.436	0.061	7.1398	< 0.0001	0.314	0.558
LNQmi	-3.818	0.425	-8.9920	< 0.0001	-4.666	-2.970
Emi	20.605	8.496	2.4252	0.0181	3.632	37.579





StatTools (Core Analysis Pack)

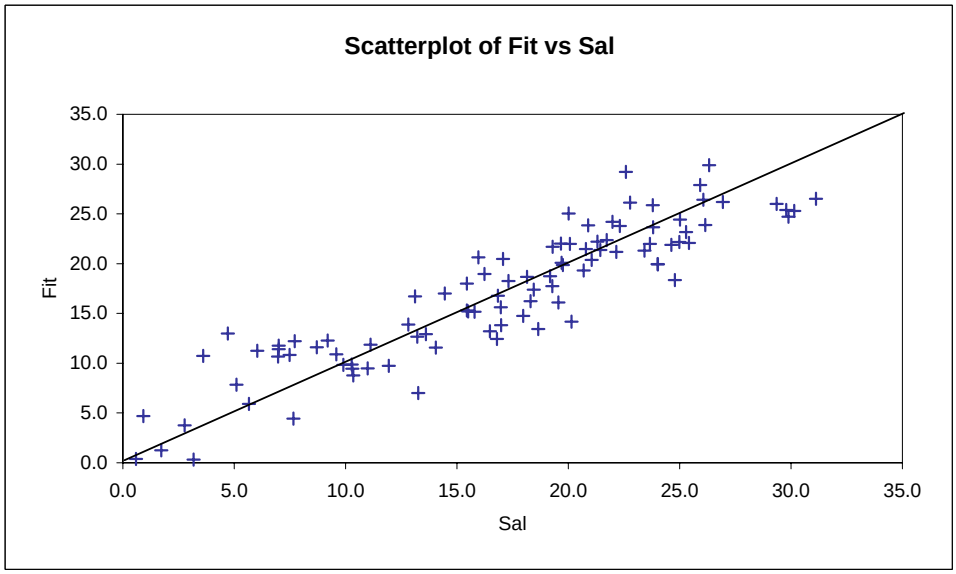
Analysis: Regression Equation 9.2 Lavaca Bay Critical Equation
Performed By: Ron Anderson
Date: Monday, June 28, 2004
Updating: Static

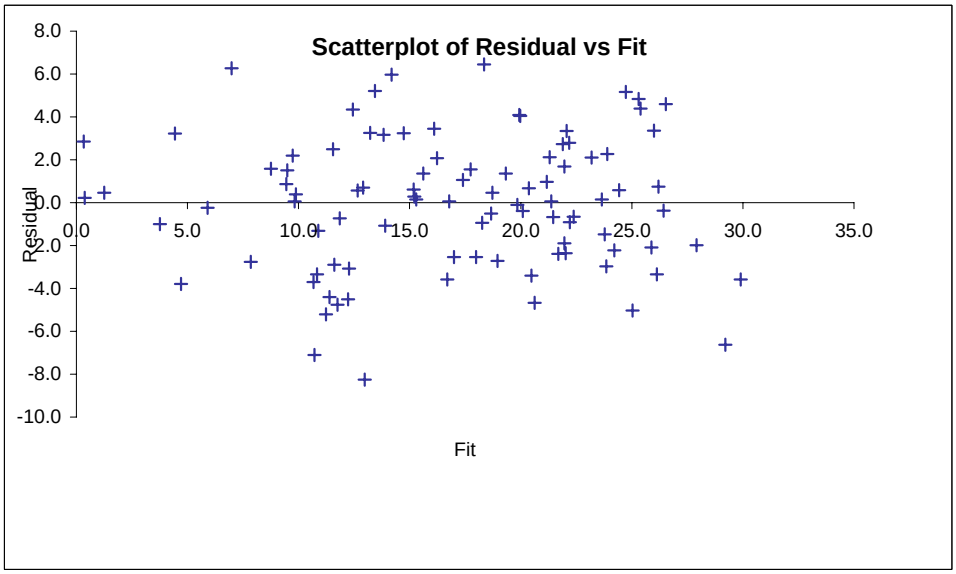
Summary	Multiple R	R-Square	Adjusted R-Square	StErr of Estimate	Durbin Watson
	0.9097	0.8275	0.8218	3.17	1.9430

ANOVA Table	Degrees of Freedom	Sum of Squares	Mean of Squares	F-Ratio	p-Value
Explained	3	4384.1	1461.4	145.5261	< 0.0001
Unexplained	91	913.8	10.0		

Regression Table	Coefficient	Standard Error	t-Value	p-Value	Lower Limit	Upper Limit
Constant	25.738	2.330	11.0447	< 0.0001	21.11	30.37
Sal-1	0.515	0.057	9.0604	< 0.0001	0.40	0.63
LN(Qm1)	-1.701	0.207	-8.2184	< 0.0001	-2.11	-1.29
LNQm2)	-1.040	0.260	-3.9991	0.0001	-1.56	-0.52

Step Information	Multiple R	R-Square	Adjusted R-Square	StErr of Estimate	Entry Number
Sal-1	0.7578	0.5742	0.5696	4.925	1
LN(Qm1)	0.8929	0.7972	0.7928	3.417	2
LNQm2)	0.9097	0.8275	0.8218	3.169	3





Appendix E
TXEMP Input Files

Appendix E – TXEMP Input Files

The three input files – input, inphvt.dat, and inpsal.dat - used by TXEMP in the Target Flow model run are listed below:

```
*************************
input
*************************
Matagorda Estuarine System***    using Colorado Gaged inflows, 70'th %ile
simple reg. eqns; tpwd data; SalP=50%%
RATUNG ratio of annual ungaged flow to sum of Lavaca & Colo.  (coastal/river basin ratio)
0.361  - 1941-2003 ratio
UGMFACT(i) i=1,12, monthly factors to distribute annual ungaged flow
.051, .061, .058, .070, .117, .110, .091, .043, .147, .138, .065, .049 - 1941-2003
RATIOLC(i) i=1,7, ratio of (ave. seasonal Lavaca)/(ave. seasonal Col.) gaged, 1941-2003
.377, .391, .469, .287, .670, .375, .434, six seasons + annual
RSEASLC(i) i=1,7, ratio of (std of seasonal Lav)/(std of seasonal Col.) gaged,1941-2003
.326, .508, .408, .290, 1.019, .503, .399, six seasons + annual
RATSPD, RATSPS ***  factors for spread of annual & seasonal lav.to col. inflows
0.5,.1, 2.0,.9, !Adj std dev for ratio of Lav to Col ann. seasonal flows
BLVARC(M), BUVARC(M), M=1,12, bounds on monthly flows in sal eqn., 1000 ac-ft, 1987-2003
0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, BLVARC
1043.,1043.,1043.,1043.,1043.,1043.,1043.,1043.,1043.,1043.,1043.,1043., BUVARC
2.2, 3.5, 3.3, 3.7, 5.9, 4.8, 4.6, 2.0, 4.9, 1.7, 1.5, 1.9 ! BLVAR(M),M= 1,12 Lav R Lwr Bnds on mo flows: LOWEST 10%, 1000 ac-ft, 1941-2003
77.0, 68.9, 43.7, 85.0, 139.4, 86.0, 29.2, 18.3, 50.6, 58.1, 53.4, 57.9 !BUVAR(M),M= 1,12 Lav R Upr Bnds on mo flws: 70'th %ile, , 1941-2003
30.6, 26.8, 22.3, 22.9, 28.4, 22.0, 20.0, 17.3, 25.3, 33.1, 26.2, 23.8!  BLVAR(M),M=14,25 Col R Lwr Bnds on mo flws: LWST 10%, 1941-2003
208.9, 197.6, 231.7, 221.7, 255.4, 210.5, 120.1, 68.7, 133.8, 154.2, 162.5, 166.2 !BUVAR(M),M=14,25 Col R Upr Bnds: 70'th %ile, 1941-2003
SFLWLB(K), SFLWUB(K), K=1,6 Seasonal (bi-monthly) Flow Bounds: 1000 acre-ft, 1941-2003
60.6, 50.8, 76.9, 47.1, 68.5, 56.8 !Lower Total Flow Bounds for productivity eqns
667.6, 2624.7, 2064.0, 1048.1, 2503.2, 1774.8 Upper Total Flow Bounds for productivity eqns
Productivity Target as % of mean productivity
0.8 ! (HARVSTM(I),I=1,9),TARHVFT  annual harvest means, target
Productivity Probability Levels
 .50, .50, .50, .50, .50, .50, .50, .50, .50 !  HARPRB(I),I=1,9  productivity reliability
Salinity Probability Levels
0.50, 0.50! SALPRB(L),L=1,NLOCS  salinity constraint probability for lavaca and eastern Matagord bay
```

```
** Nutrient LB and UB (annual inflow to estuary)
1710., 3600.    ! XLBNUT, XUBNUT    Lower and Upper Bounds on Nutrient (Nitrogen Remaining in million grams)
****GRG2 parameters  !
0.,0.0001           ! defaul( 1),FPNEWT
0.,0.0001           ! defaul( 2),FPINIT
0.,0.00001          ! defaul( 3),FPSTOP
0.,0.0001           ! defaul( 4),FPSPIV
0.,0.0              ! defaul( 5),PPH1EP
1.,10               ! defaul( 6),NNSTOP
0.,10               ! defaul( 7),IITLIM
1.,080              ! defaul( 8),LLMSER
1.,6                ! defaul( 9),IIPR
0.,0                ! defaul(10),IIPN4
0.,0                ! defaul(11),IIPN5
0.,0                ! defaul(12),IIPN6
0.,0                ! defaul(13),IIPER
0.,0                ! defaul(14),IIDUMP
1.,0                ! defaul(15),IIQUAD
1.,0                ! defaul(16),LDERIV
1.,0                ! defaul(17),MMODCG
1.                  ! defaul(18)
1, ! IOPTN problem specification 1=maxH;2=minH;3=maxQ;4=minQ;5=maxSalP;6=maxHarP
**SpeciesID:
1, 1, 1, 1, 1, 1, 1, 1, 1   ! IOBJCT(I),I=1,9  Set to 1 if species is to be included in the sum of hrvst eqn
3600                        !  SUMQLB Lower bound on annual inflow
3650                        !  SUMQUB Upper Bound on annual inflow
** initial solution and weighting scheme
0.  ! SOLN Set to 0. to generate initial montly flow soln; 1. to read in
131., 147., 280., 307., 272., 278., 215., 106., 178., 198., 152., 136., !  X(M),M=1,12  INITIAL MONTHLY INFLOWS
0.10                        !  WT1 initial weight
1.00                        !  WT9 limit of weight range
0.1                         !  WTINC increment to weighting factor
**  confidence interval
0.70                        !  SIGSAL significance level FOR SALINITY RANGE
0.80                        !  SIGFSH significance level FOR PRODUCTIVITY RANGE
```

**********End of Input*********

```
************************
inphvt.dat
************************
7 2004 RIVER
brownshrimp
6 2
 22.070 0.080
0 3
5.49432
    0.91154   -0.00383
   -0.00383    0.00002
whiteshrimp
8 2
 8.579 0.154
0 4
5.36046
    1.15420   -0.00775
   -0.00775    0.00006
menhaden
9 3
 -39.533 45.435 -28.331
0 11 35
22.42180
    4.86309   -0.73053   -0.13581
   -0.73053    0.20754   -0.06707
   -0.13581   -0.06707    0.08509
reddrum
10 4
 0.387 0.113 0.085 -0.168
0 14 15 16
0.14331
    5.10209   -0.49787    0.01034   -0.42248
   -0.49787    0.13679   -0.03857    0.00317
    0.01034   -0.03857    0.12343   -0.09269
   -0.42248    0.00317   -0.09269    0.16288
stripedmullet
9 3
 0.451 0.658 -0.484
0 11 35
```

```
0.41755
    4.86309   -0.73053   -0.13581
   -0.73053    0.20754   -0.06707
   -0.13581   -0.06707    0.08509
bluecrab
10 4
 -1.966 -0.378 0.666 0.380
0 12 13 15
0.52962
    7.22187    0.03950   -0.71561   -0.52707
    0.03950    0.13493   -0.09618   -0.04326
   -0.71561   -0.09618    0.16388    0.05201
   -0.52707   -0.04326    0.05201    0.07936
oyster
8 3
 18.367 -0.008 0.018
0 3 4
4.05893
    0.26254   -0.00016   -0.00007
   -0.00016    0.00000    0.00000
   -0.00007    0.00000    0.00000
****** End of regression eqns ******
HVSTLB(I) ,  HVSTUB(I) ,  HARVSTM(I),    COST(I)  ! NAME
25.72, 100.0, 37.57, 1.0, brownshrimp - increased upper constraint
11.78, 100.0, 29.02, 1.0, whiteshrimp - increased upper constraint
2.42, 141.38, 40.36, 1.0, menhaden
0.18, 0.85, 0.49, 1.0, reddrum
0.48, 2.72, 1.17, 1.0, stripedmullet
1.37, 3.77, 2.02, 1.0, bluecrab
5.28, 21.49, 15.90, 1.0, oyster

*************************
inpsal.dat
*************************
2 2004 TOTAL
W_Tripod
62 4
 53.375 -4.118 -2.056 -1.531
0 11 12 13
3.52333
    0.46828   -0.04846   -0.00243   -0.05231
   -0.04846    0.02935   -0.02300    0.00428
```

```
   -0.00243   -0.02300    0.04455   -0.02040
   -0.05231    0.00428   -0.02040    0.02792
UpperLav
126 5
 30.745 -1.760 -1.762 -0.628 -0.774
0 1 2 3 4
4.01425
    0.05064   -0.00497   -0.00227   -0.00259   -0.00488
   -0.00497    0.00301   -0.00151    0.00000    0.00016
   -0.00227   -0.00151    0.00392   -0.00135   -0.00014
   -0.00259    0.00000   -0.00135    0.00359   -0.00136
   -0.00488    0.00016   -0.00014   -0.00136    0.00295
c**end of input data
Eastern Matagorda Bay Salinity Lower Bounds
5., 5.,  5.,  5.,  1.,  1.,  1.,  1.,  5.,  5.,  5.,  5.
Eastern Matagorda Bay Salinity Upper Bounds - increase to 16-21
21., 21., 21., 21., 16., 16., 16., 21., 21., 21., 21., 21.
Upper Lavaca Bay Salinity Lower Bounds
5.,  5.,  5.,  5.,  1.,  1.,  1.,  1.,  5.,  5.,  5., 5.
Upper Lavaca Bay Salinity Upper Bounds  - increase to 16-21
21., 21., 21., 21., 16., 16., 16., 21., 21., 21., 21., 21.
```

Appendix F
TXEMP Sensitivity

Appendix F

Sensitivity of Productivity to Constraints in TXEMP

Introduction

This appendix describes four applications of the TXEMP optimization model for evaluating inflows to Matagorda Bay. The first is the solution of a constrained optimization problem that represents application of the State Methodology. The second is the solution of a loosely constrained optimization problem that looks at changes in productivity if flow and salinity constraints are simultaneously relaxed. The third is a sensitivity analysis in which salinity constraints are maintained while flow constraints are relaxed. The fourth is a sensitivity analysis in which flow constraints are maintained while salinity constraints are relaxed. A comparison of results is provided as a conclusion.

1) Constrained Optimization - Application of the State Methodology

The management objective of the State Methodology for determination of freshwater inflow needs is to maintain bay productivity near historical levels for certain key species found in the bay. These levels are maintained in the optimization model by enforcing productivity constraints on the solution. Additional management objectives call for constraining the solution to flows that are considered feasible from a water supply perspective. Finally, constraints on salinity are also applied to act as a safeguard to ensure that species salinity preferences are achieved. Application of the State Methodology answers the question of how best to provide (optimize) flows to the bay on a monthly basis so as to meet the productivity objectives while being constrained by flow and salinity requirements. This is referred to here as the constrained optimization problem.

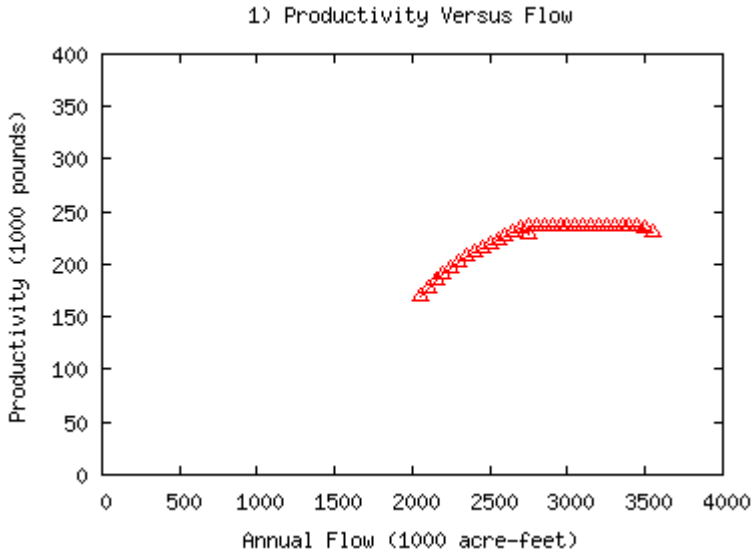


Figure F.1 Constrained productivity response curve.

The solution to the constrained optimization problem for Matagorda Bay is provided in Figure F.1. The curve shown represents bay productivity versus total inflow to the bay,

where total inflow is defined as the sum of Colorado River, Lavaca River, and coastal basin flows. Flow constraints in this run were set at the 70'th percentile monthly flow. Upper salinity constraints were set at 16 ppt during May, June, and July, and 21 ppt for all other months. Maximum productivity of 236 thousand pounds occurs for total inflows between 2.75 and 3.50 million acre-ft/year.

Each of the points on the productivity response curve represents a solution to the constrained optimization problem. The approach used to decide which flow to use as a management goal, or "Target Flow", in the 1997 study was to select the flow below which productivity began to rapidly decrease. Following that same approach, the "Target Flow" for the current solution occurs at an annual flow of 2.75 million acre-feet. The Colorado River contribution to this flow is 1.43 million acre-feet/year, and the Lavaca River contribution is 0.593 million acre-ft/year. Annual flow volumes are distributed on a monthly basis for the Colorado and Lavaca Rivers as shown in Figure F.2. In that figure, the optimal solution is shown in blue, and the upper and lower flow constraints are shown in red and green, respectively. Upper flow constraints limit the solution in January, February, May, June, July, and August. Flow peaks in January, February, and May through August (Figure F.2, Table F.1) reflect the model's attempt to maximize productivity for menhaden, brown shrimp, and white shrimp, which have large positive terms in their combined productivity equations for these months (Table F.2). The minimum in March-April flows is in response to the negative term in the blue crab equation for those months.

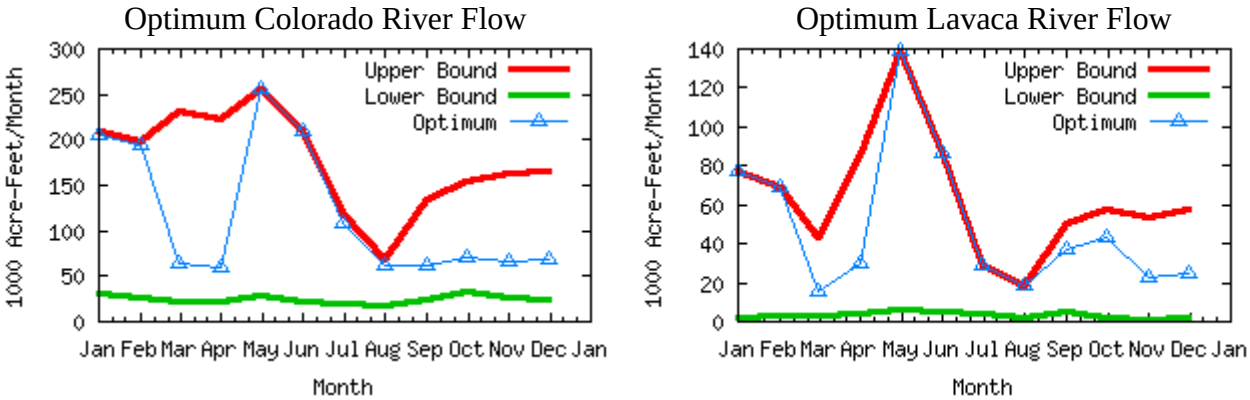


Figure F.2 Optimum monthly Colorado River and Lavaca River flows for the constrained optimization problem. Optimum solution is shown in blue, upper constraint is in red, and lower constraint is in green.

Salinities corresponding to the optimum monthly flows are shown in Figure F.3. Upper and lower constraints are shown in Figure F.3 in red and green, respectively. Salinity at the West Bay Tripod constrains the solution in April, May, and September through December. No salinity constraints are hit for the Lavaca Bay Causeway site.

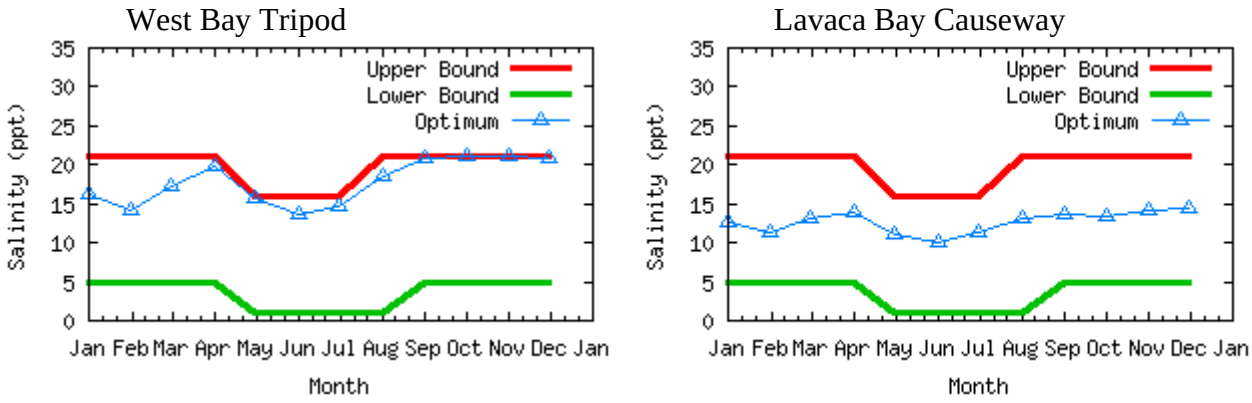


Figure F.3 Salinity corresponding to optimum flow solutions (Figure F.2) for the constrained optimization problem. Optimum salinity is shown in blue, upper constraint is in red, and lower constraint is in green.

Table F.1 Monthly optimal flows for Colorado River, Lavaca River, and coastal basins for the constrained optimization problem.

MONTHLY INFLOWS
(1000 ACRE-FEET)

MONTH	COLORADO	LAVACA	OTHER BASINS	TOTAL MONTHLY INFLOW
1	205.6	77.0	37.2	319.8
2	194.5	68.9	44.5	307.9
3	63.2	15.6	42.3	121.1
4	60.4	30.3	51.1	141.8
5	255.4	139.4	85.3	480.1
6	210.5	86.0	80.2	376.7
7	108.4	29.2	66.4	204.0
8	62.0	18.3	31.4	111.7
9	61.9	37.3	107.2	206.5
10	71.3	42.9	100.7	214.9
11	66.5	23.0	47.4	136.9
12	68.0	24.9	35.7	128.7
TOTAL	1427.8	592.8	729.4	2750.0
(PERCENT)	51.9	21.6	26.5	

Table F.2 Productivity equations for brown shrimp, white shrimp menhaden, red drum, striped mullet, blue crab, and oyster for the constrained optimization problem. Productivity is in thousands of pounds. Monthly flows are in thousands of acre-feet. LN is natural log of flow. Lag refers to prior year's flow.

```
Pbrownshr =  22.070 +  0.080 *    (Qmay+Qjun)

Pwhiteshr =   8.579 +  0.154 *    (Qjul+Qaug)

Pmenhaden = -39.533 + 45.435 *  LN(Qjan+Qfeb)
                    - 28.331 * {LN(Qsep+Qoct)}lag

Preddrum  =   0.387 +  0.113 *  LN(Qjul+Qaug)
                    +  0.085 *  LN(Qsep+Qoct)
                    -  0.168 *  LN(Qnov+Qdec)

Pstripedm =   0.451 +  0.658 *  LN(Qjan+Qfeb)
                    -  0.484 * {LN(Qsep+Qoct)}lag

Pbluecrab =  -1.966 -  0.378 *  LN(Qmar+Qapr)
                    +  0.666 *  LN(Qmay+Qjun)
                    +  0.380 *  LN(Qsep+Qoct)

Poyster   =  18.367 -  0.008 *    (Qmay+Qjun)
                    +  0.018 *    (Qjul+Qaug)
```

2) Loosely Constrained Optimization

The State Methodology provides "Target" flow recommendations based on the constrained optimization problem. That "optimum" set of monthly flows is distinct from optimal flows that would occur if the problem were more loosely constrained, i.e. by increasing upper flow and salinity constraints while maintaining other constraints related to productivity and flow. (The problem would be somewhat meaningless without a minimum set of constraints.) The loosely constrained optimum has generally not been investigated because it was considered infeasible from the perspective of water supply management (in the case of open flow constraints) or biologically undesirable (in the case of open salinity constraints). There has, however, been interest in investigating the loosely constrained problem since this provides a glimpse of potential, although from a management perspective unrealistic, optimum bay productivity. This problem is referred to here as the loosely constrained optimization problem.

The solution to the loosely constrained optimization problem is presented in Figure F.4. In this problem, upper flow constraints were set to the maximum observed monthly flow (100'th percentile), and salinity constraints were set to 17 ppt in May, June, July and to 22 ppt in the remaining months. Constraints were left in place for lower flow, lower salinity, Lavaca/Colorado flow ratios, and species productivity targets, and species

abundance ratios. Maximum productivity in this case is 331 thousand pounds for total annual flows of 3.60 million acre-feet/year.

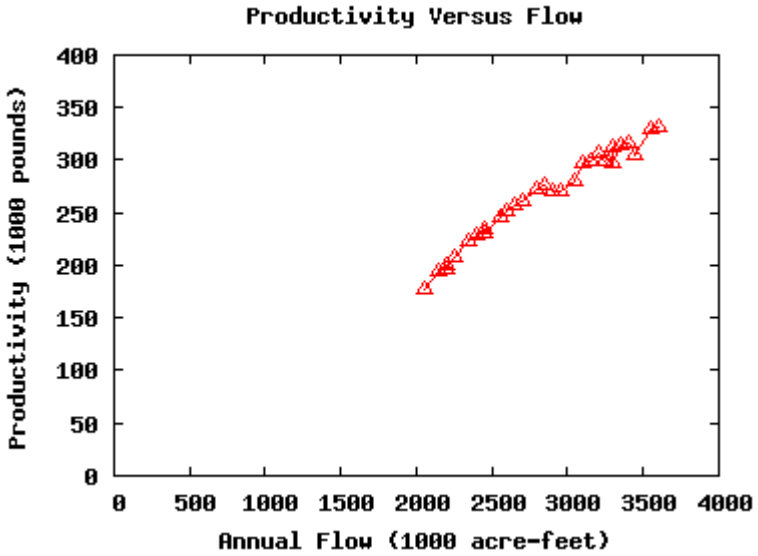


Figure F.4 Productivity response curve for the loosely constrained optimization problem. Upper flow constraint set to maximum monthly flow. Upper salinity constraint set to 17 ppt from May to July, 22 ppt in remaining months.

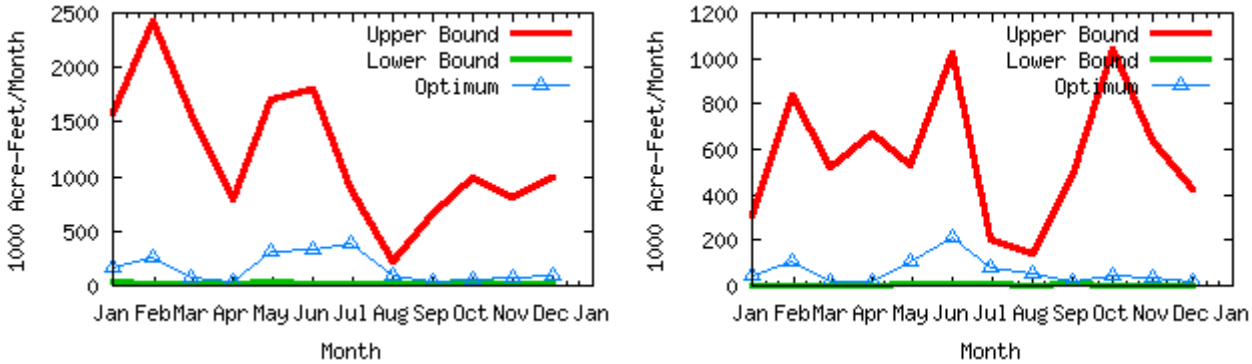


Figure F.5 Optimum monthly Colorado River (left) and Lavaca River (right) flows for the loosely constrained optimization problem. Optimum solution is shown in blue, upper constraint is in red, and lower constraint is in green.

The Colorado River contribution to the total annual flow is 1.893 million acre-feet/year, and the Lavaca River contribution is 0.752 million acre-feet/year. The monthly flow distributions corresponding to these annual flows are presented in Figure F.5. Upper flow constraints are well above the optimum solution and clearly play no role in restricting the solution. Peaks in January, February, and May through July are driven primarily by the significant positive terms in the productivity equations (Table F.2). Salinities corresponding to the monthly flows are shown in Figure 6. Only the April-May and October –November salinity constraints for the West Bay Tripod limit the solution. The April-May peak in salinity is driven by the negative coefficient for the March-April

term in the blue crab equation. The model tries to minimize flows for those months, leading to increased salinities in April-May. The October-November peak is drive by the negative September-October coefficient for menhaden following the same logic. The constraint on the ratio of monthly flows between the Lavaca River and the Colorado River prevents Lavaca River flows from decreasing any further during March-April and September-October.

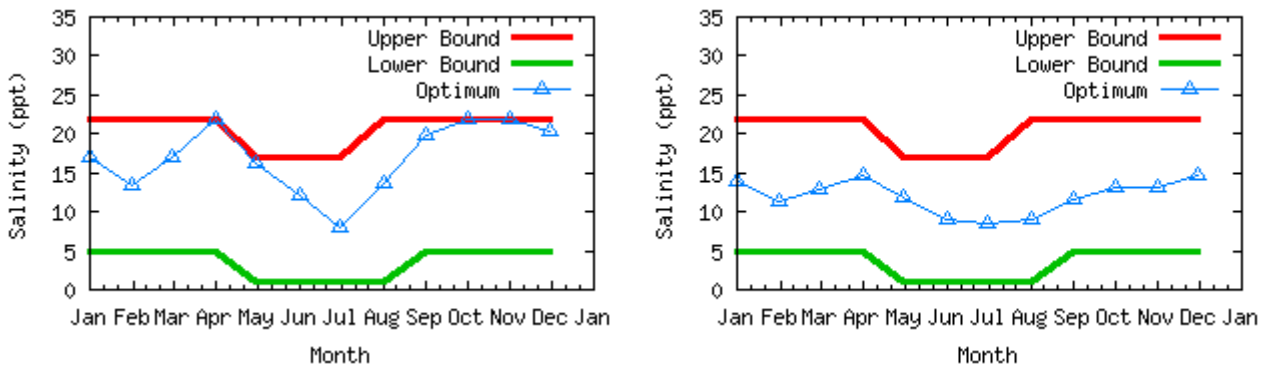


Figure F.6 Salinity corresponding to optimum flow solutions (Figure F.5) for the loosely constrained optimization problem. Optimum salinity is shown in blue, upper constraint is in red, and lower constraint is in green. West Bay Tripod (left), Lavaca Causeway (right).

Table F.3 Monthly optimal flows for Colorado River, Lavaca River, and coastal basins for the loosely constrained optimization problem.

MONTHLY INFLOWS
(1000 ACRE-FEET)

MONTH	COLORADO	LAVACA	OTHER BASINS	TOTAL MONTHLY INFLOW
1	162.3	40.5	48.7	251.5
2	248.5	109.3	58.2	416.1
3	64.8	15.8	55.4	136.0
4	32.6	20.3	66.8	119.8
5	318.3	108.4	111.7	538.5
6	337.0	210.3	105.0	652.4
7	385.5	78.5	86.9	550.9
8	93.8	55.1	41.1	190.0
9	40.0	19.1	140.4	199.4
10	59.7	40.9	131.8	232.4
11	67.1	32.1	62.1	161.3
12	83.4	21.5	46.8	151.7
TOTAL	1893.2	751.9	954.9	3600.0
(PERCENT)	52.6	20.9	26.5	

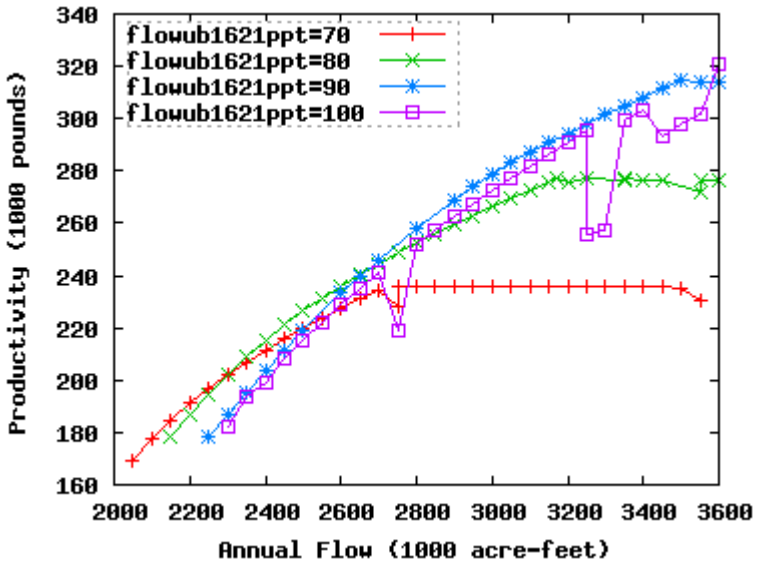


Figure F.7 Salinity-constrained sensitivity analysis. Upper monthly flow constraint range from 70'th percentile (red) flow to 100'th percentile (maximum observed) flow (purple).

3) Salinity-Constrained Sensitivity Analysis

The effect on productivity of varying the upper flow constraint was investigated in this series of runs. In this problem, the upper salinity constraint was set to 16 ppt in May, June, and July, and to 21 ppt in the remaining months. The upper flow constraint was set to the 70'th, 80'th, 90'th, and 100'th percentile (maximum observed) monthly flow in separate runs to generate a series of productivity response curves (Figure F.7).

Maximum productivity occurs for the 90'th and 100'th percentile curves at above 300 thousand pounds for total inflows of 3.50 million acre-feet/year. Significant reduction in productivity occurs as flows are reduced to the 80'th percentile constraint (276 thousand pounds, 3.15 million acre-feet/year) and the 70'th percentile constraint (236 thousand pounds, 2.75 million acre-feet/year). Increased productivity for ever larger upper flow constraints is accomplished in the optimization model by distributing larger flows to those months with positive coefficients in their productivity equations.

4) Flow-Constrained Sensitivity Analysis

The effect on productivity of varying upper salinity constraints was investigated in this series of runs. In this problem, the upper monthly flow constraints were fixed at the 70'th percentile flows. The upper salinity flow constraint was increased in 0.5 ppt increments from 15 ppt to 17 ppt in May, June, and July, and from 20 ppt to 22 ppt in the remaining months. Five curves representing these varying constraints are presented in Figure 8.

Maximum productivity increases slightly as the salinity constraints are increased. Using 15 ppt and 20 ppt constraints, productivity is 229 thousand pounds at a total flow of 2.850 million acre-ft/year. With the 17 ppt and 22 ppt constraints, productivity increases

slightly to 241 thousand pounds for a flow of 2.616 million acre-ft/year. A small increase in productivity is achieved with lesser amounts of water by allowing flow reductions for those months that have negative coefficients in the productivity equations (Table F.2).

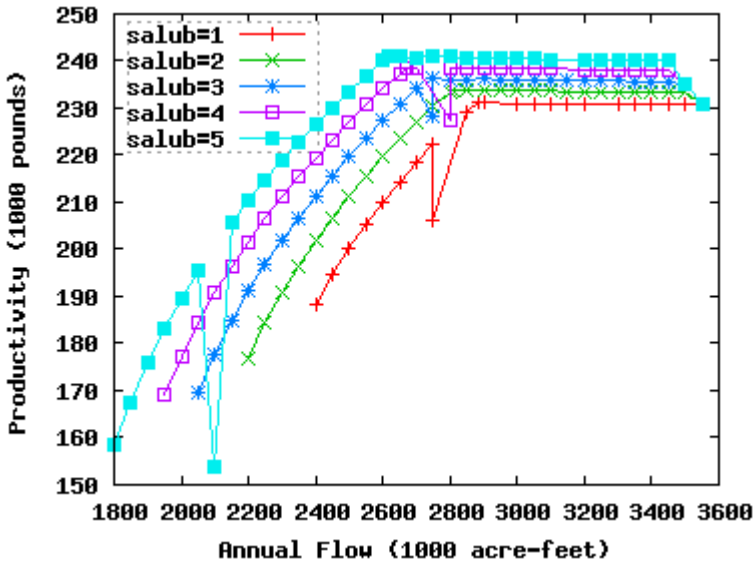


Figure F.8 Flow constrained sensitivity analysis. Salinity constraints for salub=1 – 15 ppt in May, June, and July, 20 ppt for all other months; salub=2 – 15.5 ppt and 20.5 ppt; salub=3 – 16.0 ppt and 21.0 ppt. salub=4 - 16.5 ppt and 21.5 ppt; salub=5 – 17 ppt and 22 ppt.

Comparison of Results

The above sensitivity analyses were extended to include more combinations of inflow and salinity constraints. Results from these runs are summarized in Table F.4 for productivity, Table F.5 for total flow, Table F.6 for Colorado River flow, and Table F.7 for Lavaca River flow. The productivity response to both relaxed flow and salinity constraints is displayed graphically in Figure F. 9. Changes in the salinity constraint (labeled delta (Upper Salinity Constraint)(ppt) on the figure) are represented as increases above the 15 ppt in May, June, and July and 21 ppt in other months. So, 0 ppt on this axis represents the 15 ppt-21 ppt constraint, 1 ppt on the axis represents the 16 ppt-22 ppt constraint, and so on. Figure F.9 shows that by relaxing upper flow and salinity constraints, the optimization model is provided a greater range of flexibility in distributing monthly flows, and productivity can be made to increase. Mild increases in productivity are indicated with relaxed salinity constraints, and even greater increases are indicated with relaxed flow constraints.

Although productivity is predicted to increase with relaxed salinity and flow constraints, these should be considered carefully. From the perspective of water availability, flows are limited and generally cannot be supplied in either volume or timing as is assumed by the optimization model. Flows that have historically occurred infrequently will not likely

be provided at higher frequencies in the future. From the ecological perspective, species are salinity tolerant within ranges represented by the salinity constraints. The bounds of these constraints are not sharp, but there are limits beyond which productivity will suffer. The productivity equations have no means of directly capturing the species response to salinity, so in a sense the salinity constraints act as a safeguard to ensure ecologically meaningful solutions. The constrained optimization problem described at the beginning of this section represents an example of moderately relaxed constraints and is suitable as a target flow recommendation.

Table F.4 Productivity with relaxed upper flow and upper salinity constraints.

	Productivity (thousand pounds) Flow Constraint %'ile			
Salinity Constraints (ppt)	70	80	90	100
15, 20	229	274	307	305
16, 21	236	277	315	321
17, 22	241	280	308	331
18, 23	246	283	324	336
19, 24	250	286	326	340
20, 25	255	289	327	345
21, 26	260	289	329	340
22, 27	262	289	329	329
23, 28	262	290	329	316

Table F.5 Total optimal inflow with relaxed upper flow and upper salinity constraints.

	Total Flow (million acre-feet) Flow Constraint %'ile			
Salinity Constraints (ppt)	70	80	90	100
15, 20	2.850	3.400	3.600	3.600
16, 21	2.750	3.173	3.500	3.600
17, 22	2.616	3.050	3.200	3.600
18, 23	2.533	3.000	3.300	3.500
19, 24	2.461	2.850	3.200	3.450
20, 25	2.399	2.750	3.150	3.400
21, 26	2.345	2.700	3.089	3.250
22, 27	2.307	2.700	3.066	3.300
23, 28	2.300	2.670	3.049	3.000

Table F.6 Optimal Colorado River inflow with relaxed upper flow and upper salinity constraints.

Salinity Constraints (ppt)	Colorado Flow (million acre-feet) Flow Constraint %'ile 70	80	90	100
15, 20	1.486	1.757	1.896	1.899
16, 21	1.428	1.665	1.837	1.884
17, 22	1.359	1.587	1.685	1.893
18, 23	1.317	1.564	1.725	1.841
19, 24	1.281	1.502	1.675	1.810
20, 25	1.250	1.437	1.647	1.802
21, 26	1.223	1.410	1.633	1.703
22, 27	1.203	1.420	1.597	1.729
23, 28	1.197	1.400	1.588	1.560

Table F.7 Optimal Lavaca River inflow with relaxed upper flow and upper salinity constraints.

Salinity Constraints (ppt)	Lavaca Flow (million acre-feet) Flow Constraint %'ile 70	80	90	100
15, 20	0.608	0.742	0.749	0.746
16, 21	0.593	0.666	0.735	0.761
17, 22	0.563	0.654	0.666	0.752
18, 23	0.544	0.640	0.700	0.731
19, 24	0.527	0.592	0.676	0.724
20, 25	0.513	0.584	0.668	0.696
21, 26	0.500	0.574	0.637	0.685
22, 27	0.492	0.564	0.656	0.696
23, 28	0.492	0.562	0.653	0.644

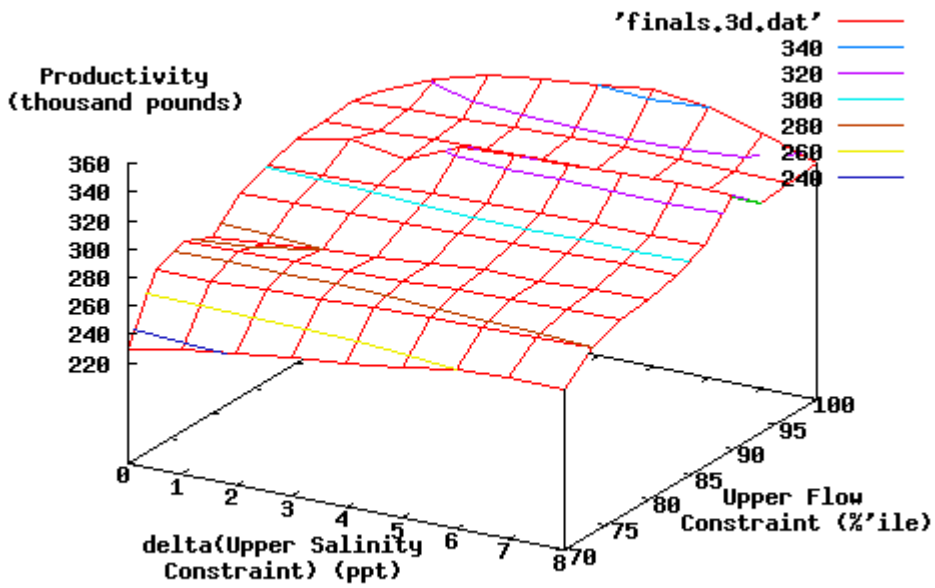


Figure F.9 Productivity for increased flow and salinity constraints. Salinity constraint change (delta(Upper Salinity Constraint)) represents as increment above 15 ppt for May, June, and July, and 20 ppt for all other months. Flow constraint represents monthly flow percentile. Constrained optimization problem represented by delta(Upper Salinity Constraint) = 0 ppt, Upper Flow Constraint = 70'th percentile

Appendix G
Statistical Comparisons of TXBLEND Output to Measured Data

Appendix G

Statistical Comparisons of TXBLEND Output to Measured Data

Statistical comparisons between salinities computed with the TXBLEND model and measured salinities are presented in this Appendix. Model outputs were provided for eleven sites in Matagorda Bay at which salinity was monitored (Figure 8.10). The comparisons below are for daily average salinity. Table 1 provides several statistical comparisons between the measured and model salinities, including the mean error, mean absolute error, root mean square error, and linear correlation coefficient. Cross plots showing modeled versus measured daily average salinity for each site are provided in Figure G.1 through Figure G.11, and correspond to the time series of the same data presented in Figure 8.11.a through Figure 8.11.k.

Table G.1 - Statistical Measures Comparing Modeled and Measured Daily Average Salinity.

Site	**Mean Error (ppt)**	**Mean Absolute Error (ppt)**	**RMS Error (ppt)**	**Linear Correlation Coefficient, r^2**
1492 - Matagorda Entrance Channel	-2.53	3.32	5.93	0.186
2449 - Sandy Point	0.02	2.98	4.36	0.641
4944 - Lavaca Causeway	-2.32	4.58	5.90	0.659
3022 - Carancahua Bay	-2.33	3.47	4.21	0.835
2791 - Tres Palacios Bay	-1.84	3.76	4.70	0.701
2235 - Channel Marker 4	-0.00	2.46	3.14	0.842
3445 - West Bay Tripod	-4.64	5.62	7.12	0.734
3672 - Shellfish Marker B	-3.96	6.12	8.04	0.441
4969 - East Bay Tripod	-4.00	4.80	5.90	0.750
2971 - East Bay Shellfish Marker	0.01	5.36	7.58	0.322
2491 - East Bay Eastern End	-0.07	3.78	4.97	0.434

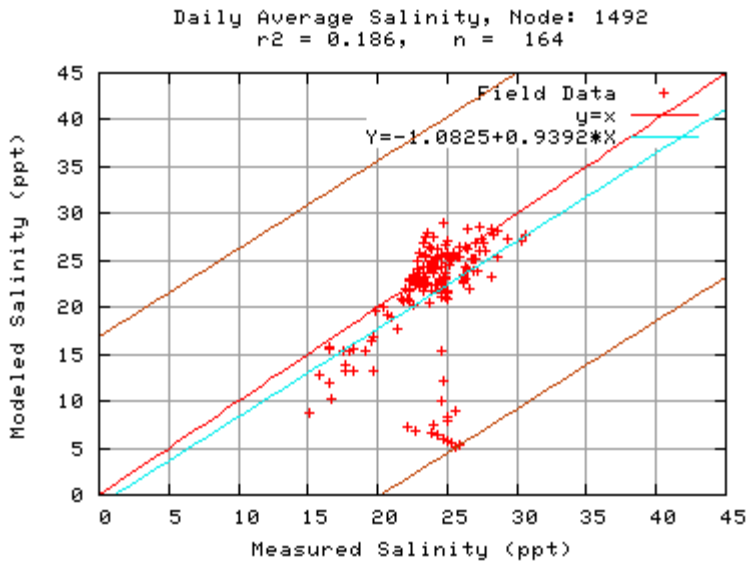


Figure G.1 Model Versus Measured Daily-Average Salinity at Matagorda Entrance Channel.

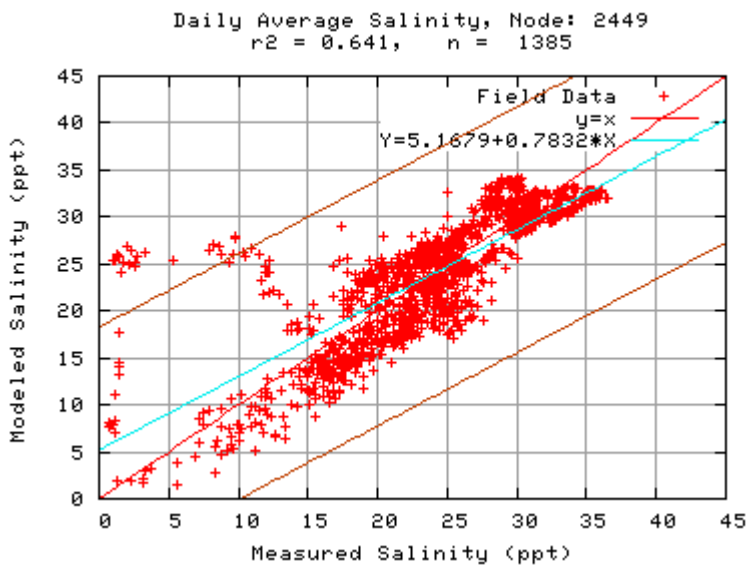


Figure G.2 Model Versus Measured Daily-Average Salinity at Sandy Point.

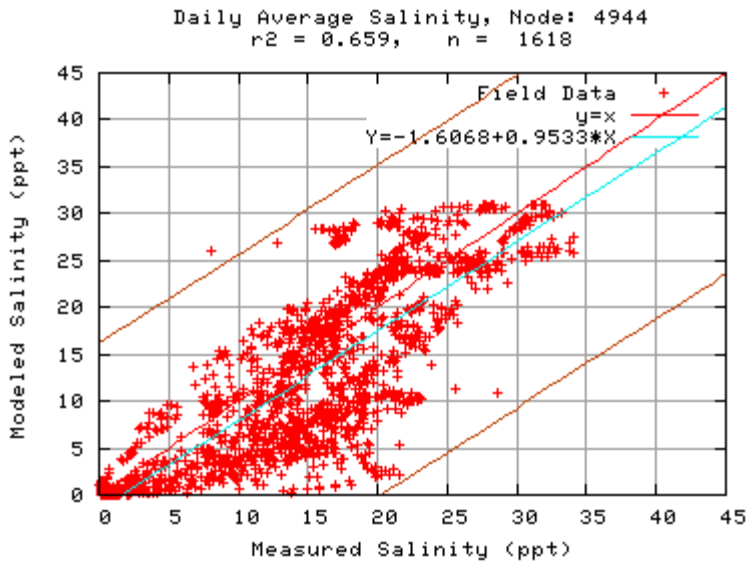


***Figure G.3 Model Versus Measured Daily-Average Salinity at Lavaca Causeway*.**

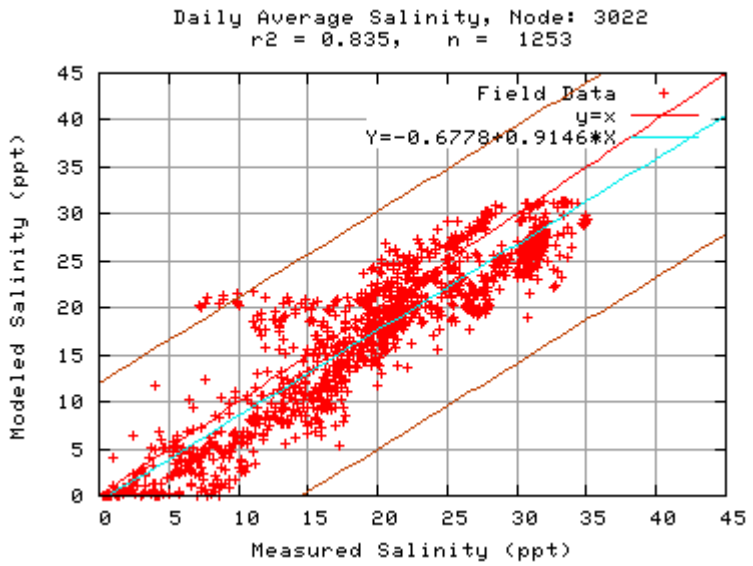


Figure G.4 Model Versus Measured Daily-Average Salinity at Carancahua Bay.

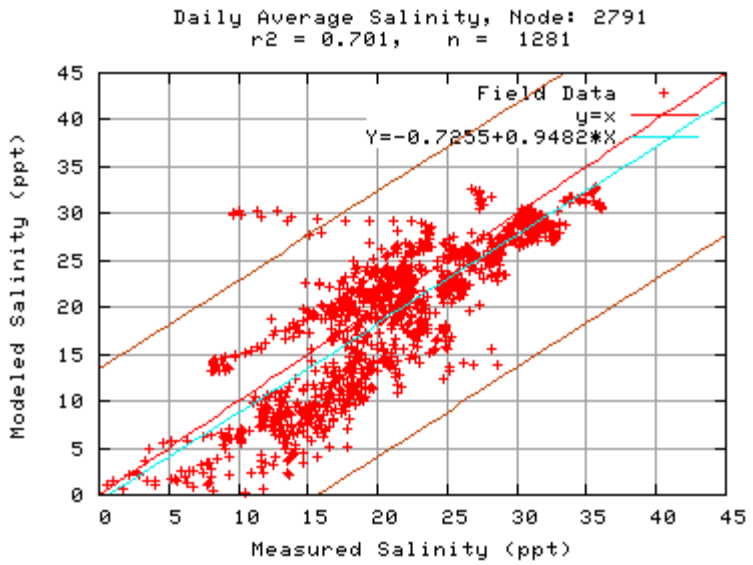


Figure G.5 Model Versus Measured Daily-Average Salinity at Tres Palacios Bay.

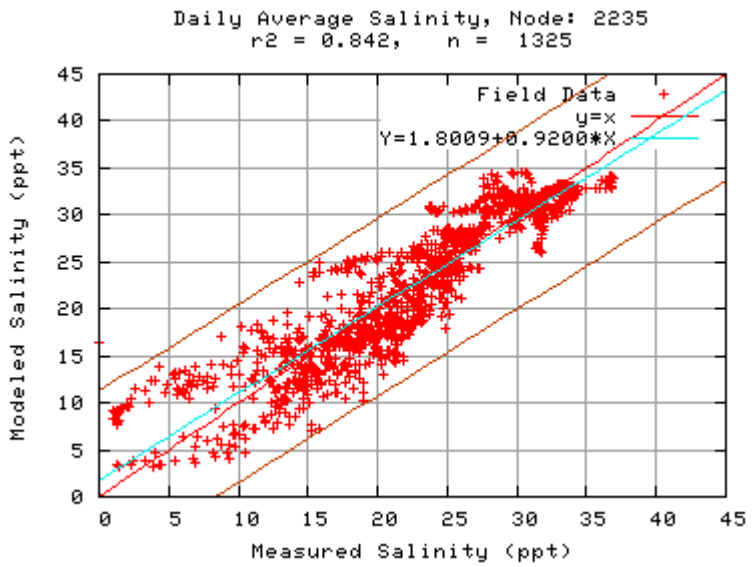


Figure G.6 Model Versus Measured Daily-Average Salinity at Channel Marker 4.

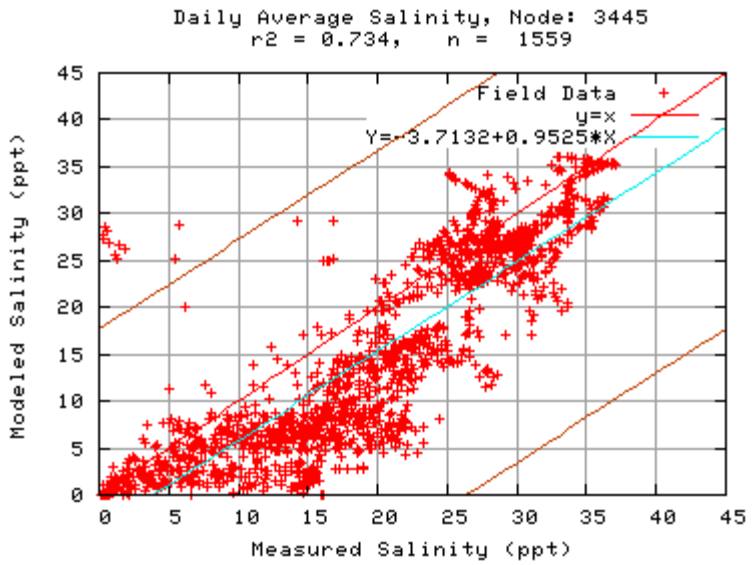


Figure G.7 Model Versus Measured Daily-Average Salinity at West Bay Tripod.

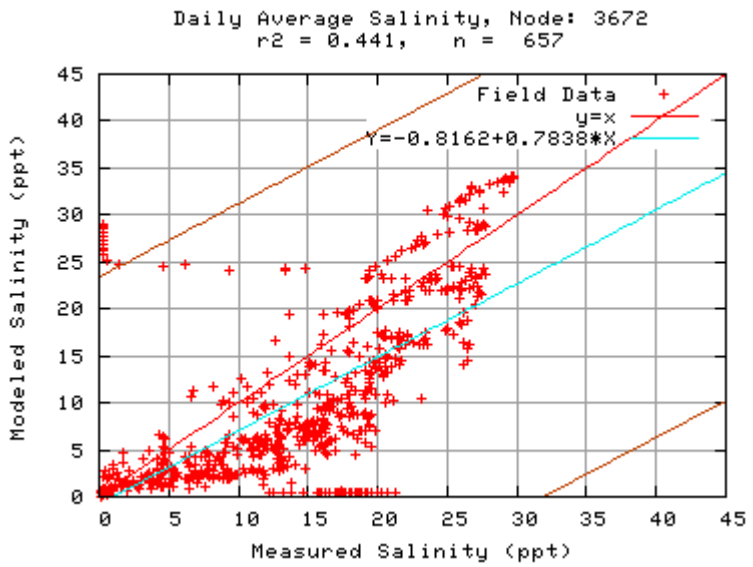


Figure G.8 Model Versus Measured Daily-Average Salinity at Shellfish Marker B.

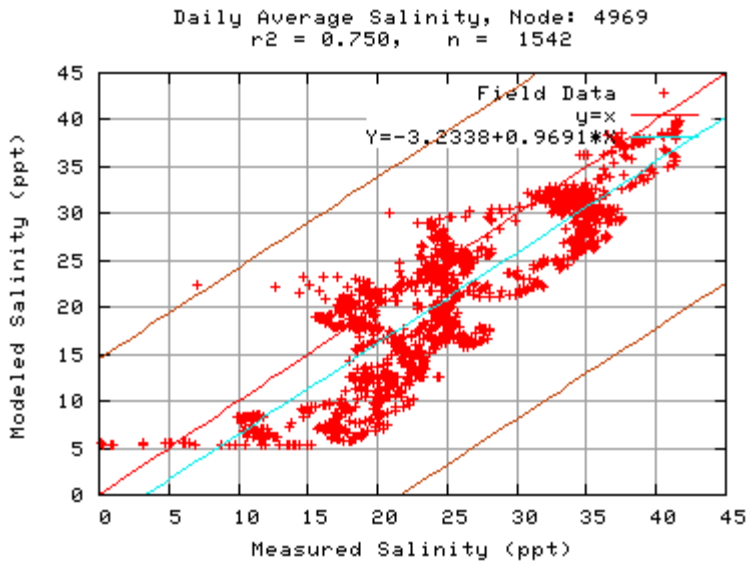


***Figure G.9 Model Versus Measured Daily-Average Salinity at East Bay Tripod*.**

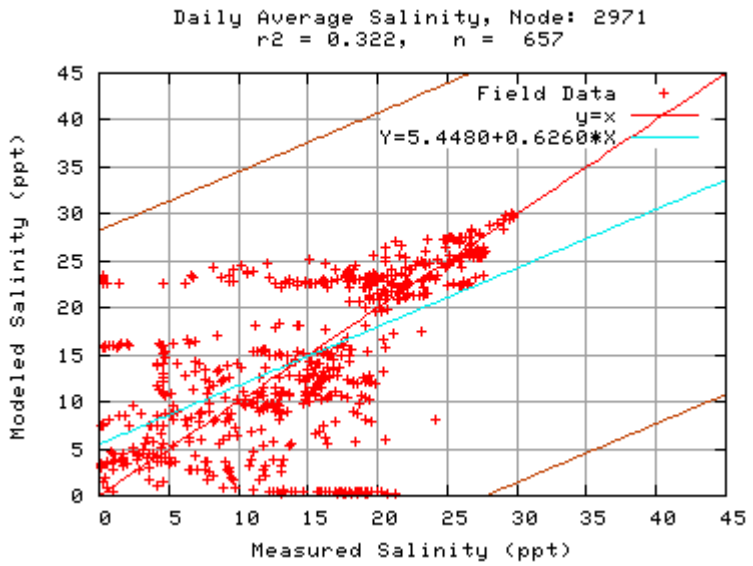


Figure G.10 Model Versus Measured Daily-Average Salinity at East Bay Shellfish Marker.

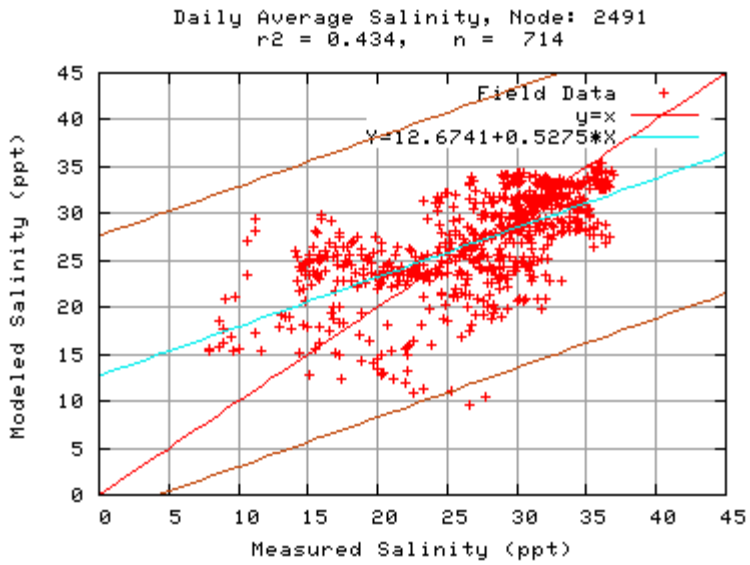


Figure G.11 Model Versus Measured Daily-Average Salinity at East Bay Eastern End.

ACRONYMS

ADCP -	Acoustic Doppler Current Profiler
DIN -	Dissolved Inorganic Nitrogen
ERDC -	Engineers Research and Development Center
FINS -	Freshwater Inflow Needs Study
GIS -	Geographical Information Systems
GIWW -	Gulf Intracoastal Waterway
LCRA -	Lower Colorado River Authority
LNRA -	Lavaca – Navidad River Authority
LWSP -	Lower Colorado River Authority/San Antonio Water System Water Project
MOA -	Memorandum of Understanding
NEXRAD -	Next Generation Weather Radar
NMFS -	National Marine Fisheries Service
NOAA -	National Oceanic and Atmospheric Administration
SAC -	Science Advisory Committee
SAWS -	San Antonio Water System
STP -	South Texas Project
TCEQ -	Texas Commission on Environmental Quality
TCOON -	Texas Coastal Ocean Observation Network
TDWR -	Texas Department of Water Resources
TKN -	Total Kjeldahl Nitrogen
TN -	Total Nitrogen
TNRCC -	Texas Natural Resources Conservation Commission

TP -	Total Phosphorus
TPWD -	Texas Parks and Wildlife Department
TWDB -	Texas Water Development Board
TXEMP -	Texas Estuarine Mathematical Programming Model
USACE -	United States Army Corps of Engineers
USFWS -	United States Fish and Wildlife Service
USGS -	United States Geological Survey
WES -	Waterways Experiment Station
WMP-	Water Management Plan

GLOSSARY

Acre-foot - An acre-foot of water equals 325,851 gallons of water or 43,560 cubic feet of water and is a common unit of measurement for larger volumes of water.

Beneficial inflows - Freshwater inflows providing for a salinity, nutrient, and sediment loading regime adequate to maintain an ecologically sound environment in the receiving bay and estuary that is necessary for the maintenance of productivity of economically important and ecologically characteristic sport or commercial fish and shellfish species and estuarine life upon which such fish and shellfish are dependent.

Coastal inflow - The difference between the total surface inflow and the river basin inflows in this study

Critical freshwater inflows needs - The amount of freshwater inflows needed to provide a fishery sanctuary habitat at specific locations in Matagorda Bay defined as 25 ppt or an annual average. This inflow level is used in water management during drier periods or drought from which finfish or shellfish species are expected to recover and repopulate the bay when more normal weather conditions return.

River basin inflows - The amount of surface water entering Matagorda Bay from the Lavaca River basin and Colorado River. For the Lavaca River basin, the amount is the sum of streamflow from the Lavaca River measured by a gage near Edna and streamflow from the Navidad River measured as outflow from Lake Texana but does not include any contribution from the portion of the Lavaca River basin downstream of these measurement locations. For the Colorado River basin for the period prior to June 1990, the amount is based on a method developed by TDWR in 1978. For the Colorado River basin for the period beginning in June 1990, the amount is streamflow measured at the Bay City gage minus diversions by the South Texas Project but does not include any contribution from the portion of the Colorado River basin downstream of the measurement location.

Streamflow - The amount of surface water passing a measurement location. For the Lavaca River basin the measurement locations are a gage near Edna and outlet from Lake Texana. For the Colorado River the measurement location

is a gage at the Bay City

Target freshwater inflow needs - The amount, timing, and location of freshwater inflows needed to optimize selected estuarine species productivity. This inflow level is used in water management for above average years where there are sufficient inflows to maximize biological productivity.

Target species - Economically important and ecologically characteristic sport or commercial fish and shellfish species and estuarine life upon which such fish and shellfish are dependent used in this study as indicator species of overall bay health and productivity. These species include gulf menhaden, striped mullet, red drum, blue crab, white shrimp, and oysters.

Total surface inflow - The estimated amount of surface water entering Matagorda Bay from all watersheds. It does not include either precipitation directly on Matagorda Bay or evaporation directly from Matagorda Bay

TXBLEND - A hydrodynamic and conservative transport model developed by the Texas Water Development Board specific to water bodies such as lakes or bays that seek to predict the movement of water quality characteristics such as salinity through the water body. The TXBLEND model is used in this study to verify that the freshwater inflow regime results identified by the TXEMP model and meeting all constraints will provide the desired salinity regime through the Matagorda Bay system.

TXEMP - The Texas Estuarine Mathematical Programming model is a general optimization model developed by the Texas Water Development Board designed to find a minimum and maximum function (e.g. biological productivity) that satisfies constraints that are imposed (hydrology, salinity, biological). TXEMP results are bounded by the constraints.

http://www.lcra.org/library/media/public/docs/water/firm_contracts.pdf

Customers with contracts for "firm" raw water supplies from LCRA

as of October 24, 2008

Total Number of Customers: 199 Total Acre-Feet Committed 425,276.13

CUSTOMER NAME	COUNTY	PURPOSE OF USE	ANNUAL AUTHORIZED AMOUNT (Acre Feet)
Bastrop Resort Partners, L.P. (Woodbine)	Bastrop	Recreational	700.00
C & D Turfgrass, Ltd.	Bastrop	Irrigation	850.00
Colovista Estates, Inc.	Bastrop	Irrigation	44.23
Gentex Power Corporation	Bastrop	Industrial	2,750.00
Potts Land Company, LC	Bastrop	Agricultural	70.00
Barton Creek Lakeside Irrigation Company	Burnet	Irrigation	196.41
Brightwell, Kim & Tery	Burnet	Domestic	0.70
Bryant, Kathie Ann	Burnet	Municipal	25.00
Burnet, City of	Burnet	Municipal	4,100.00
Camp Champions	Burnet	Irrigation	6.00
Camp Longhorn	Burnet	Irrigation	50.00
Cottonwood Shores, City of	Burnet	Municipal	138.00
Eagle Mountain Reserve, LLC	Burnet	Municipal	123.00
Granite Shoals, City of	Burnet	Municipal	830.00
Highland Lakes Golf Club, Inc.	Burnet	Irrigation	40.00
Lake LBJ MUD	Burnet	Municipal	1,789.16
Legends on Lake LBJ	Burnet	Irrigation	125.00
Mahon, Darrell E.	Burnet	Domestic	1.2745
Marble Falls, City of	Burnet	Mun/Ind	2,000.00
Marble Falls, City of	Burnet	Municipal	1,000.00
McClain, Brad	Burnet	Irrigation	29.00
Meadowlakes Municipal Utility District	Burnet	Municipal	75.00
Morris, Don	Burnet	Domestic	0.70
Pecan Utilities Co., Inc.	Burnet	Municipal	30.00
Pecos Land Development	Burnet	Municipal	60.00
RiverView RV Park, Ltd.	Burnet	Irrigation	5.00
Schneider, Irwin & Sally	Burnet	Domestic	0.48
Southwestern Graphite Company	Burnet	Industrial	400.00
Spicewood Beach POA	Burnet	Irrigation	8.00
US Fish & Wildlife Service	Burnet	Industrial	100.00
Windemere Oaks WCS	Burnet	Municipal	55.00
Crakes, Rick	Burnet	Domestic	0.48
Ehler, Gene	Burnet	Domestic	1.00
Ligon, Frank	Burnet	Domestic	2.20
McCann, Terrance	Burnet	Domestic	1.10
Palmie, Mark	Burnet	Domestic	0.48
Romney, William S.	Burnet	Domestic	0.48
Wood, Gary W.	Burnet	Domestic	0.65
Wright, Joan	Burnet	Domestic	0.67
Blanco San Miguel, Ltd	Burnet/Blanco	Municipal	2,500.00
Austin, City of	Fayette	Industrial	3,500.00
Frisch Auf! Valley Country Club	Fayette	Irrigation	90.00
La Grange ISD	Fayette	Irrigation	12.00
Boot Ranch Development	Gillespie	Upstream Rec	56.00
Dripping Springs, City of	Hays	Municipal	506.00

Dripping Springs WSC	Hays	Municipal	560.00
Hays County WCID #1	Hays	Municipal	656.50
Hays County WCID #2	Hays	Municipal	143.50
Hays Reunion Ranch	Hays	Municipal	240.00
N. Hays Investors I, L.P.	Hays	Municipal	625.00
Waters Condominium Association, the	LBJ	Recreational	16.00
Babin, Jeanette	Llano	Domestic	1.06
Blue Lake Golf Club, Inc.	Llano	Irrigation	29.14
Chaison, Elizabeth	Llano	Domestic	0.85
Clark, Walter R.	Llano	Domestic	0.85
Escondido Partnership, Ltd.	Llano	Recreational	480.00
Horseshoe Bay Applehead POA, Inc.	Llano	Irrigation	27.00
Horseshoe Bay POA	Llano	Irrigation	27.00
Hydro Offices	Llano	Irrigation	3.00
Kingsland WSC	Llano	Municipal	500.00
Lake LBJ Investment Corporation	Llano	Irrigation	900.00
Llano County MUD #1	Llano	Municipal	87.00
The Trails POA, Inc.	Llano	Recreational	45.00
Calicott, Travis L.	Llano	Domestic	1.00
Croom, John & Cindy	Llano	Domestic	0.72
Thompson, Robert I.	Llano	Domestic	0.48
Withers MD, Edward H.	Llano	Domestic	0.48
Star S Ranch, Inc.	Mason	Ag, Livestock, Domestic, Rec	110.00
Terry Jackson, Inc.	Mason	Mining	1.50
Bay City Country Club	Matagorda	Recreational	35.00
Celanese Ltd.	Matagorda	Industrial	3,222.33
Equistar Chemicals, L.P.	Matagorda	Industrial	2,800.00
Texas Brine Company, LLC	Matagorda	Industrial	8,200.00
South Texas Nuclear Operating Company	Matagorda	Industrial	40,000.00
Fleming Springs Ranch	San Saba	Irrigation	20.00
Alexander, William C.	Travis	Domestic	0.95
Armstrong, Reed	Travis	Domestic	0.48
Atlas, Brian	Travis	Recreational	450.00
Austin American Statesman	Travis	Irrigation	30.00
Austin, City of	Travis	Municipal	138,560.00
Austin Golf Club, Inc.	Travis	Irrigation	200.00
BAE Systems Integrated Defense Solutions, Inc.	Travis	Recreational	2.00
Baldwin III, Robert B.	Travis	Municipal	199.00
Barton Creek Resort & Clubs, Inc.	Travis	Irrigation	500.00
Bastrop Energy Partners, L.P.	Travis	Industrial	3,220.00
Bluebonnet Hill, Ltd.	Travis	Irrigation	199.00
Briarcliff, Village of	Travis	Municipal	300.00
Bull Creek Management	Travis	Domestic	65.00
Capital Commercial Development	Travis	Municipal	7.70
Cedar Park, City of	Travis	Irrigation	441.00
Cedar Park, City of	Travis	Municipal	18,000.00
Centex Destination Properties, Inc.	Travis	Recreational	499.00
Club Corp of Texas (formerly Lakeway Golf Clubs)	Travis	Irrigation	230.00
Cypress Ranch WCID No. 1	Travis	Municipal	436.00
the Golf Club at Circle C, LP	Travis	Irrigation	54.00
Davenport Ranch MUD #1	Travis	Mun/Irr	1,700.00
Deer Creek Ranch WSC	Travis	Municipal	250.00
Eanes ISD	Travis	Municipal	37.00
Finley III, Arley D.	Travis	Domestic	1.52

General Office Complex	Travis	Irrigation	1,470.00
GP Golf, LLLP	Travis	Recreational	270.00
H2 Interests, LLC	Travis	Municipal	924.40
Hermosa Office Park PUD Owner's Assoc., Inc.	Travis	Irrigation	15.00
Hidden Valley Subdivision Cooperative	Travis	Municipal	10.00
Hurst Creek MUD	Travis	Mun/Irr	1,600.00
Hyatt Regency - Austin	Travis	Industrial	15.34
Hyatt Regency - Austin	Travis	Irrigation	15.34
Inverness Utility Co., Inc.	Travis	Municipal	150.00
Island on Lake Travis, Ltd.	Travis	Industrial	3.00
Island on Lake Travis, Ltd.	Travis	Irrigation	11.00
Jonestown WSC	Travis	Municipal	460.00
Jordan, Len	Travis	Municipal	7.00
Lago Vista, City of	Travis	Mun/Irr	6,500.00
Lake Travis Ranch LLC	Travis	Recreational	840.00
Lake Travis Ranch LLLC	Travis	Municipal	495.00
Lakecliff on Lake Travis	Travis	Irrigation	475.00
Lakeside Utilities, Inc.	Travis	Municipal	25.00
Lakeway MUD	Travis	Municipal	3,069.00
Lakeway Rough Hollow South Community	Travis	Irrigation	90.00
Lazy Nine MUD	Travis	Municipal	1,615.00
LCRA Water & Wasterwater Utilities	Travis	Recreational	700.00
Leih, Thomas J.	Travis	Domestic	0.48
Lone Star Infrastructure	Travis	Industrial	150.00
Loop 360 WSC	Travis	Municipal	1,250.00
Pedernales Country Club	Travis	Irrigation	52.00
Pflugerville, City of	Travis	Municipal	12,000.00
Point Venture POA, Inc.	Travis	Irrigation	75.00
Resort Ranch of Lake Travis, Inc.	Travis	Mun/Irr	150.00
RGK Rentals, Ltd.	Travis	Municipal	499.00
River Place Golf Group, L.P.	Travis	Irrigation	92.07
River Place MUD	Travis	Municipal	900.00
Rivercrest Water Systems, Inc.	Travis	Municipal	185.00
Senna Hills MUD #1	Travis	Municipal	170.00
Shumaker Enterprises	Travis	Industrial	300.00
South Central Water Company	Travis	Municipal	1,300.00
St. Stephen's Episcopal School	Travis	Irrigation	43.00
Straus, Jocelyn Levi	Travis	Mun/Irr	630.00
the Club at Waterford	Travis	Municipal	300.00
the Club at Waterford, LP	Travis	Recreational	300.00
Transit Mix Concrete and Materials, Inc.	Travis	Industrial	75.76
Travis County MUD #10	Travis	Municipal	55.00
Travis County MUD #12	Travis	Municipal	1,680.00
Travis County MUD #4	Travis	Irrigation	804.00
Travis County MUD #4	Travis	Municipal	2,104.00
Travis County WCID #17	Travis	Recreational	554.00
Travis County WCID #17	Travis	Municipal	8,800.00
Travis County WCID #18	Travis	Municipal	1,400.00
Travis County WCID #20	Travis	Mun/Irr	1,135.00
Travis County WCID Point Venture	Travis	Municipal	210.00
Travis County, Texas	Travis	Recreational	108.00
Travis Meadows, Inc.	Travis	Recreational	35.00
USAA Stratum Executive Center	Travis	Municipal	18.50
Volente Beach, Inc.	Travis	Recreational	1.00
West Cypress Hills WCID #1	Travis	Municipal	491.00

Abell, G. Hughes	Travis	Domestic	1.10
Affuso, Anthony J.	Travis	Domestic	0.50
Ashmun, Cliff	Travis	Domestic	0.54
Awalt, James & Susan	Travis	Domestic	1.01
#REF!	Travis	Domestic	0.87
Blake, Kelly	Travis	Domestic	0.48
Borders, Thomas & Mary	Travis	Domestic	2.23
Brinkmeyer, Todd	Travis	Domestic	0.97
Broussard, Harvey C.	Travis	Domestic	2.54
Cohoon, James L.	Travis	Domestic	0.89
Cooper, Jerry L.	Travis	Domestic	0.93
Counts M.D., Donald R.	Travis	Domestic	1.00
Counts M.D., Donald R.	Travis	Domestic	2.00
Crowther, Sam & Jackie	Travis	Domestic	1.76
Demond, Kari	Travis	Domestic	0.98
Dertien, Paul	Travis	Domestic	0.48
Eppright, Russell	Travis	Domestic	0.48
Hutton, Rob	Travis	Domestic	2.00
Johnson, J. Burton	Travis	Domestic	0.68
Lambert, Charles W.	Travis	Domestic	0.97
Lasater, Marceline	Travis	Domestic	0.54
MacMurtrie, Sandra & Charlie Davis	Travis	Domestic	0.48
Martinez, Janie	Travis	Domestic	0.92
McIngvale, Linda	Travis	Domestic	0.48
Moore, Roy F.	Travis	Domestic	0.48
Nichols, William E.	Travis	Domestic	0.48
Philips, Renee	Travis	Domestic	0.58
Redwine, Mickey	Travis	Domestic	1.00
Shaffer, Eric & Susan	Travis	Domestic	0.76
Stewart, Jeff & Anna	Travis	Domestic	0.48
Taylor, Terry	Travis	Domestic	0.48
Taylor, Terry	Travis	Domestic	0.48
Wasinger, Bruce	Travis	Domestic	0.60
Brazos River Authority	Williamson	Municipal	25,000.00
Leander, City of	Williamson	Municipal	24,000.00
LCRA Water & Wastewater Utilities		Municipal	11,378.00
LCRA Power Plants		Industrial	63,851.00
Subtotal			**425,276.13**
Environmental flows in current and pending Water Management Plan			33,440
Reserved by LCRA Board in Water Management Plan for future use			50,000
Colorado River Municipal Water District Owen Ivie Reservoir			90,546
Total of commitments and reserved			**599,262.13**

http://www.lcra.org/library/media/public/docs/water/WSRPDecember2008report.pdf

Water Supply Resource Plan
Water demand projections for municipal and industrial needs

Executive Summary

Since the last census and development of the 2006 Region K Regional Water Plan we have seen growth in our basin increase at a rate higher than what was predicted in the regional water planning process. Recent projections by the Texas Water Development Board illustrate that their estimates of population shown in Region K projections for Bastrop, Burnet, Colorado, Gillespie, Llano, Travis were significantly less than current population estimates for those counties. Several other counties are also showing a slight increase in population as well. In addition, LCRA has seen a recent large application for industrial supply in Matagorda County.

Staff has evaluated available resources, including data provided by some of the counties in our service area. Utilizing this new information, staff has revised population projections for all the counties within the lower Colorado River watershed and LCRA's service area in the Region K planning area. With these new population projections, staff has calculated new municipal, industrial and other firm water demands for this planning area over the decades from 2010-2100. These new projections, shown as Scenario II in this memorandum, indicate that LCRA could expect demands that it may be called upon to supply in future years to be about 14-25% greater than are currently shown in Region K's Regional Water Plan. Estimates show that some of these increased demands could occur as soon as the 2010-2020 timeframe.

The next step in the Water Supply Resource Planning process is to develop estimates of irrigation water demands and to evaluate all of LCRA's existing water supplies and the list of potential new supplies that we shared with the Board in October. Staff will share this information with the Board in future updates.

Project Overview

As part of the long-term water supply planning process it is important for LCRA to evaluate and substantiate if and when projected water demands will exceed available supplies. This is particularly important because of changing conditions such as: increased population growth in the Region K and LCRA Water Service Area; recurring drought cycles; potential industrial and power plant growth in the region; possible impacts associated with climate change; and the upcoming need to evaluate future contractual obligations that may extend beyond the current 50-year planning horizon of Region K. Further, if such evaluation indicates that projected water demands would exceed available supplies, LCRA as a regional water supplier would be in a position to plan for the types of new water supplies that may be needed to meet future demands during the planning timeframe. The Water Supply Resource Plan will be LCRA's roadmap for how it will meet water needs for our basin in the future. This plan will show how much water LCRA can make available, when and where it can be provided in the future and the potential cost.

Public meetings were held in July and August of this year and the results were provided to the Board at its October 2008 Board meeting. The public meetings identified potential water supply approaches and the public's values and concerns relating to water supply planning.

The next step in developing the Water Supply Resource Plan is projecting water demands for needs that will be met with LCRA water supplies.

Planning Scenarios
Staff has developed for the Board's consideration two alternative planning scenarios which extend to the year 2100.

Scenario I is based on the following:

- Municipal demands developed using the Region K population projections to 2060 and then using the State Demographer's recommended methodology to develop population projected from 2060 to 2100, and
- Industrial demands based on Region K information.

Scenario I generally reflects the water demand projections in the approved Region K plan and projects them to 2100.

Scenario II is based on the following:

- Municipal demands developed using substantiated revised population estimates based on recent growth patterns to estimate growth through 2040 or 2060, then using the State Demographer's recommended methodology to develop population projected to 2100. Municipal demands for each decade were calculated based on the population projections using the same per capita water use approach as used in Region K;
- New and pending contracts for municipal demand;
- Region K industrial demand and new and pending contracts for industrial use;
- Domestic use on the Highland Lakes, and
- Conveyance losses from the point of release of water from the Highland Lakes to the point of delivery.

Scenario 2 builds on the water demand projections in the approved Region K plan by including updated population growth estimates, based on current growth patterns, current and pending contracts and other water uses not accounted for in the current Region K plan.

Municipal use includes water for cities and towns. Industrial use includes water for manufacturing, commercial, industrial and electric generation.

Population Projection Methodology
To estimate population changes out to the year 2100, staff reviewed data from the Region K Water Plan, the Texas State Data Center, United States Census Bureau, Capital Area Planning Council of Governments (CAPCOG), Houston-Galveston Area Council (H-GAC), and data that was provided by several counties. A number of counties showed growth rates higher than projected in Region K. While there has been rapid population growth in central Texas over the recent past, the State Demographer has indicated in recent discussions that: 1) history has shown that growth can not be sustained at the recent rapid rates, and 2) the land has a certain carrying capacity, i.e. only so much land can be developed due to slopes, floodplains, parkland, and other limitations in high growth areas. Additionally staff visited with LCRA Community and Economic Development staff to discuss what approaches they take in projecting population growth over a long-term planning period.

Therefore, for the rapidly developing metropolitan area near Austin, staff used on a near-term basis the population projections that best correlated with data from the U. S. Census Bureau and/or substantiated county data and for the latter part of the planning period used the Texas State Data Center's 1990-2000 Half Migration Rate extrapolated to 2100.

Water Demand Projections
As noted above, two planning scenarios were developed to evaluate long-term water demands to be met by LCRA in the planning area. *Key assumptions* in projecting water demands for both planning scenarios are:

- **Planning area** The planning area that staff used to determine population projections and future water demands for the plan is limited to that portion of the Colorado River watershed and LCRA's service area within the fourteen county Region K planning area. (See Attachment 1 for a map of this area.) Note that in counties like Blanco and Burnet, the portion of the counties that are not in the Colorado River watershed are not included in the planning area for the plan.

- **Firm water demands** The water demand estimates provided in this memo are for municipal, industrial and other firm water demands, including categories where customers purchase firm water supplies for use (i.e. golf course irrigation, recreation, etc.). These water demand estimates do not include any water that LCRA currently provides for environmental purposes or increases in such amounts that may be required as a result of water rights permitting processes. Nor do these estimated demands include water demands for LCRA's interruptible customers within the four irrigation operations that we serve. Discussion of future irrigation demands will take place at a future Board meeting.

- **Supplies provided from LCRA** The estimates of future water demands that are included in this memo reflect those demands that staff believes LCRA may be asked to provide at some point in the future. For example, cities that currently rely on groundwater to meet municipal demands are expected to meet future demands with groundwater to the extent available. However staff has assumed that, where

water demands are projected to exceed available groundwater, those cities will look to LCRA to provide the balance of needed water.

- **Development of municipal demands** In determining municipal demands based on population projections, staff used the same basic approach that water planners use in the state and regional water planning processes by computing demand based on population data.

- **Uncertainty in projecting industrial demands** Projecting future needs for industrial growth is among the most difficult projections in water supply planning because there is seldom certainty about when a large industrial user will locate in an area. Staff used the projections from Region K in Scenario I. For Scenario II staff increased Region K projections by the amount of the contracts that have been issued or are pending since 2005 when Region K numbers were developed. For example, the White Stallion Energy Center demand for water was not included in Scenario I but is included in Matagorda County demand projections in Scenario II. As a result of this uncertainty in the overall water planning process, staff will update the Water Supply Resource Plan periodically to capture population and industrial changes that can affect demand supply.

- **Domestic use and water losses included** Staff has included demands and losses not currently being accounted for in the Region K Water Plan, including domestic use from the Highland Lakes and conveyance losses incurred when water is delivered to downstream customers.

- **Williamson County** Staff capped the amount of water provided to customers in Williamson County equal to the amount of the existing contracts.

- **LCRA-SAWS Water Project** The plan will assess future water demands both with and without the LCRA-SAWS Water Project (Project). The projections included in this memo do not contain any demands for the project. Once the Board has provided staff guidance on the Project policy related issues, staff will work with its consultants to determine the amount of water that could be available for the project and include that amount in the demand projections.

A graph of Scenario I and Scenario II water demand projections is presented in Attachment 2. The graph reflects the composite municipal and industrial water demand projected to the year 2100 for both scenarios.

Summary of Population and Water Demand Projections for Each County
Tables summarizing the population and water demand projections for both Scenarios I and II for each of LCRA's statutory counties are included behind Attachment 2. The summary for each county describes how Scenario II information was derived. Following the individual county information is a table presenting the total anticipated LCRA water demand for both scenarios.

Water Supply Resource Plan
Water Supply Planning Area

N
W E
S

0 30 60
Miles

Area of Detail

Region K Planning Area

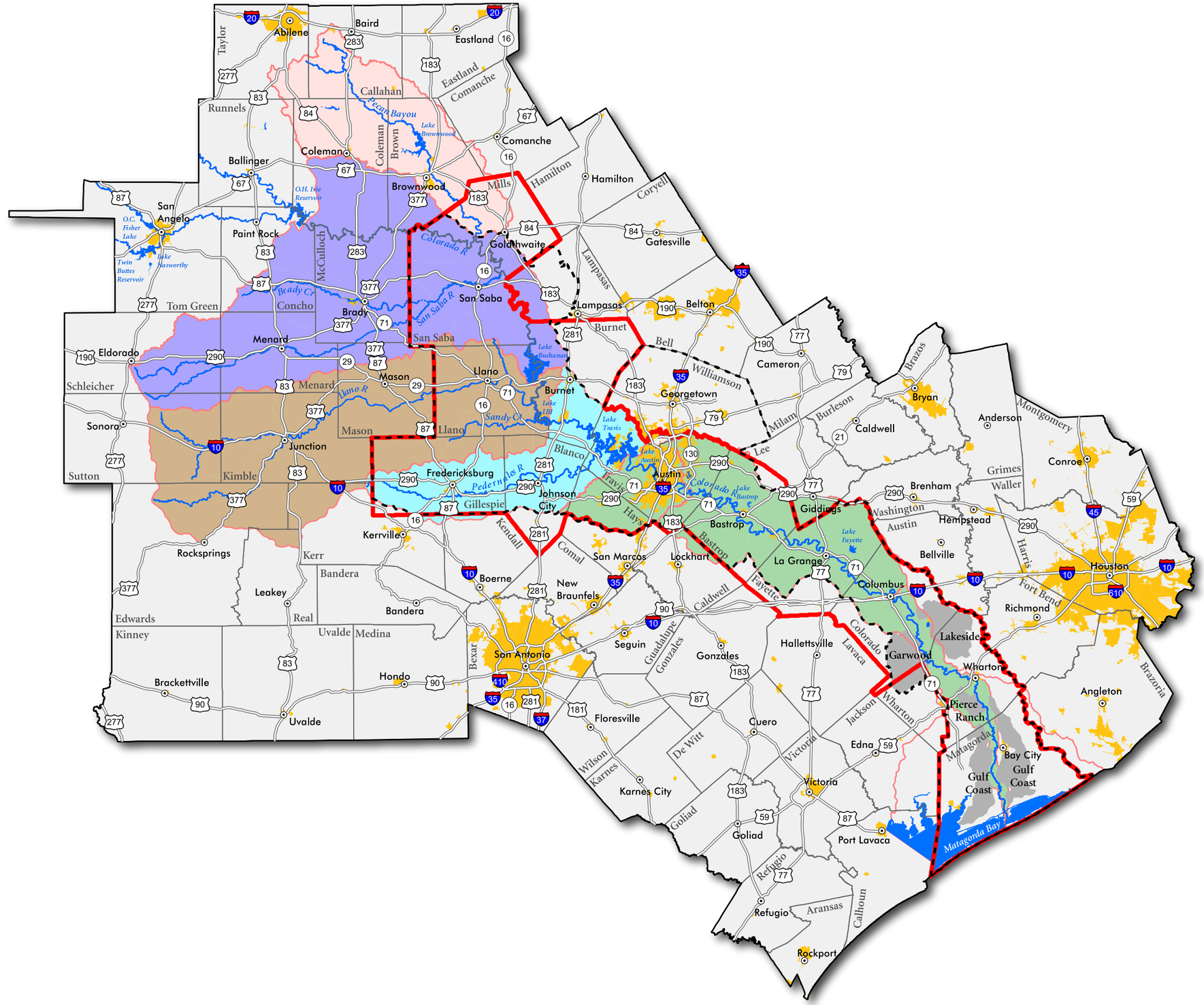
WSRP Planning Area

Irrigation Divisions

LCRA
ENERGY • WATER • COMMUNITY SERVICES

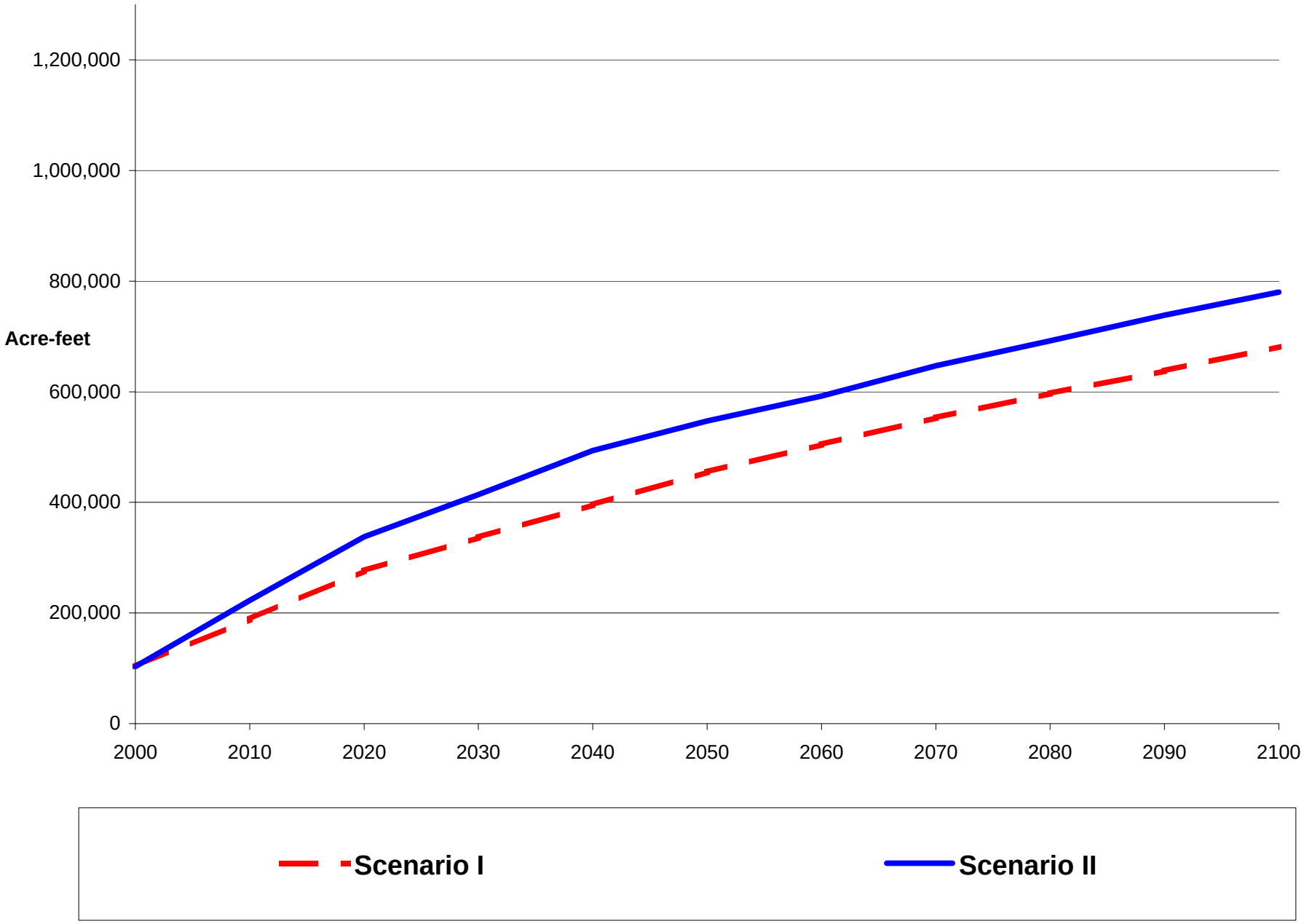
This map has been produced by the Lower Colorado River Authority for its own use. Accordingly, certain information, features, or details may have been emphasized over others or may have been left out. LCRA does not warrant the accuracy of this map, either as to scale, accuracy or completeness.

December 1, 2008



Attachment 1

LCRA Water Supply Resource Plan
Projected Water Demands (Municipal and Industrial without SAWS)



Attachment 2

LCRA Water Supply Resource Plan **Bastrop County**
County Population and Water Demand Summary
December 2008

Population Assumptions and Projections – Data was available from the Texas State Data Center (TSDC), State Water Plan, U.S. Census Bureau, and CAPCOG. For Scenario II, correlating this information with the 2005 and 2007 U.S. Census estimates, the CAPCOG projection was selected for the period from 2010 to 2040. Then, based on input from the State Demographer and LCRA Community and Economic Development, the TSDC 1990-2000 Half Migration Rate was applied from 2040 to 2100.

*Population Summary**

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	57,733	75,386	97,601	123,734	153,392	190,949	237,958	252,060	281,600	311,200	340,700
Scenario II	57,733	84,600	123,700	179,500	258,700	284,000	312,000	338,000	366,000	393,000	420,000

* Summary above reflects the projected population for the entire county for the two scenarios. The water demand projections shown below reflect the population not being served from another source of supply and therefore it is anticipated to be served by LCRA.

Water Demand Assumptions and Projections – Using gallons per person per day from Region K for Bastrop County and combining with the Scenario I and Scenario II population projections, municipal demand was computed for the LCRA water planning area. Industrial demands were added to the municipal demand to estimate total water demand. Due to anticipated population growth exceeding the current available groundwater supplies in Bastrop County, the WSRP presumes that a portion of the county will receive water from LCRA to meet some municipal demands.

Total Projected LCRA Water Demand (acre-feet)

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	8,798	12,841	17,865	24,560	28,080	31,517	34,119	35,851	37,444	40,051	41,660
Scenario II	8,798	12,850	18,724	28,167	34,665	37,172	38,563	40,984	42,450	44,874	46,315

LCRA Water Supply Resource Plan **Blanco County**
County Population and Water Demand Summary
December 2008

Population Assumptions and Projections – Data was available from the Texas State Data Center (TSDC), State Water Plan, U.S. Census Bureau, and CAPCOG. For Scenario II, correlating this information with the 2005 and 2007 U.S. Census estimates, the CAPCOG projection was selected for the period from 2010 to 2040. Then, based on input from the State Demographer and LCRA Community and Economic Development, the TSCD 1990-2000 Half Migration Rate was applied from 2040 to 2100.

*Population Summary**

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	8,418	9,946	11,756	13,487	15,002	16,641	18,544	20,100	21,800	23,500	25,200
Scenario II	8,418	11,000	14,100	17,000	19,200	20,900	22,900	24,500	26,300	28,000	30,000

* Summary above reflects the projected population for the entire county for the two scenarios. The water demand projections shown below reflect the population not being served from another source of supply and therefore it is anticipated to be served by LCRA.

Water Demand Assumptions and Projections – Using gallons per person per day from Region K for Blanco County and combining with the Scenario I and Scenario II population projections, municipal demand was computed for the LCRA water planning area. There are no anticipated industrial water demands in Blanco County. A primary difference between the scenarios is that Scenario II includes the Blanco-San Miguel water contract.

Total Projected LCRA Water Demand (acre-feet)

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	14	14	384	424	457	497	547	612	656	706	749
Scenario II	14	115	1,460	2,534	3,085	3,124	3,175	3,246	3,292	3,341	3,393

LCRA Water Supply Resource Plan **Burnet County**
County Population and Water Demand Summary
December 2008

Population Assumptions and Projections – Data was available from the Texas State Data Center (TSDC), State Water Plan, U.S. Census Bureau, County, and CAPCOG sources. For Scenario II, correlating this information with the 2005 and 2007 U.S. Census estimates, the CAPCOG projection was selected for the period from 2010 to 2040. Then, based on input from the State Demographer and LCRA Community and Economic Development, the TSCD 1990-2000 Half Migration Rate was applied from 2040 to 2100.

*Population Summary**

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	34,147	41,924	51,044	60,382	69,271	78,981	90,263	98,100	107,400	116,700	126,000
Scenario II	34,147	47,300	64,700	84,500	104,000	114,000	125,000	136,000	146,000	157,000	168,000

* Summary above reflects the projected population for the entire county for the two scenarios. The water demand projections shown below reflect the population not being served from another source of supply and therefore it is anticipated to be served by LCRA.

Water Demand Assumptions and Projections – Using gallons per person per day from Region K for Burnet County and combining with the Scenario I and Scenario II population projections, municipal demand was computed for the LCRA water planning area. There are no anticipated industrial water demands in Blanco County. The difference in water demands between the scenarios is the anticipated larger population growth in Scenario II.

Total Projected LCRA Water Demand (acre-feet)

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	4,154	4,779	5,529	6,284	7,017	7,830	8,808	10,274	12,013	13,730	15,469
Scenario II	4,154	5,332	6,880	8,601	10,292	11,089	12,015	14,061	16,164	18,313	20,475

LCRA Water Supply Resource Plan **Colorado County**
County Population and Water Demand Summary
December 2008

Population Assumptions and Projections – Data was available from the Texas State Data Center, State Water Plan, U.S. Census Bureau, and the Houston Galveston Area Council (HGAC). For Scenario II, correlating this information with the 2005 and 2007 U.S. Census estimates and the HGAC data, the Texas State Data Center 1990-2000 Migration Rate was selected for the planning period. The 1990-2000 Migration Rate is nearly the same as the 1990-2000 Half Migration Rate and appropriate for long-term planning in rural areas.

*Population Summary**

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	20,390	21,101	22,032	22,550	22,760	22,801	22,561	23,540	23,920	24,301	24,681
Scenario II	20,390	22,655	24,589	25,592	25,599	27,800	29,100	30,400	31,800	33,100	34,400

* Summary above reflects the projected population for the entire county for the two scenarios. The water demand projections shown below reflect the population not being served from another source of supply and therefore it is anticipated to be served by LCRA.

Water Demand Assumptions and Projections – Using gallons per person per day from Region K for Colorado County and combining with the Scenario I and Scenario II population projections, municipal demand was computed for the LCRA water planning area. Communities presently rely on groundwater for their municipal supplies and groundwater is anticipated to be available over the planning period to continue to meet this need. There are no anticipated industrial water demands in Colorado County.

Total Projected LCRA Water Demand (acre-feet)

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	16	16	16	16	16	16	16	16	16	16	16
Scenario II	16	17	18	18	18	20	21	21	21	22	22

LCRA Water Supply Resource Plan **Fayette County**
County Population and Water Demand Summary
December 2008

Population Assumptions and Projections – Data was available from the Texas State Data Center (TSDC), State Water Plan, U.S. Census Bureau, and CAPCOG. In discussions with Fayette County, the County supported the use of the State Water Plan projections for their county. For Scenario II, correlating the county recommendation with the above data indicated that use of the State Water Plan data was appropriate for the planning period.

*Population Summary**

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	21,804	24,826	28,808	32,363	35,259	38,933	44,120	46,800	49,300	52,900	54,300
Scenario II	21,804	24,826	28,808	32,363	35,259	38,933	44,120	46,800	49,300	52,900	54,300

* Summary above reflects the projected population for the entire county for the two scenarios. The water demand projections shown below reflect the population not being served from another source of supply and therefore it is anticipated to be served by LCRA.

Water Demand Assumptions and Projections – Using gallons per person per day from Region K for Fayette County and combining with the population projections, municipal demand was computed for the LCRA water planning area. Primary water demand in Fayette County is for steam electric generation.

Total Projected LCRA Water Demand (acre-feet)

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	21,371	41,691	41,716	41,736	41,751	41,769	41,795	41,817	41,839	41,860	41,882
Scenario II	21,371	41,691	41,716	41,736	41,751	41,769	41,795	41,817	41,839	41,860	41,882

LCRA Water Supply Resource Plan **Gillespie County**
County Population and Water Demand Summary
December 2008

Population Assumptions and Projections – Data was available from the Texas State Data Center (TSDC), State Water Plan, U.S. Census Bureau, and County sources. For Scenario II, correlating this information with the 2005 and 2007 U.S. Census estimates, the TSDC 1990-2000 Migration Rate was selected for the period from 2010 to 2040. Then, based on input from the State Demographer and LCRA Community and Economic Development, the TSCD 1990-2000 Half Migration Rate was applied from 2040 to 2100.

*Population Summary**

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	20,814	24,089	27,510	28,845	28,845	28,845	28,845	30,000	31,000	32,200	33,500
Scenario II	20,814	24,727	28,826	30,936	29,818	31,200	32,700	33,900	35,000	36,300	37,700

* Summary above reflects the projected population for the entire county for the two scenarios. The water demand projections shown below reflect the population not being served from another source of supply and therefore it is anticipated to be served by LCRA.

Water Demand Assumptions and Projections – Using gallons per person per day from Region K for Gillespie County and combining with the Scenario I and Scenario II population projections, municipal demand was computed for the LCRA water planning area. There are no anticipated industrial water demands in Gillespie County. Presently, the communities rely on groundwater for their municipal supplies and groundwater is anticipated to be available until later in the planning cycle when a portion of the population is expected to require another source of water.

Total Projected LCRA Water Demand (acre-feet)

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	38	38	37	36	35	34	34	1,000	1,034	1,074	1,119
Scenario II	38	39	39	39	36	37	39	1,130	1,168	1,212	1,260

LCRA Water Supply Resource Plan **Hays County**
County Population and Water Demand Summary
December 2008

Population Assumptions and Projections – Data was available from the Texas State Data Center (TSDC), State Water Plan, U.S. Census Bureau, and CAPCOG. Only the northwestern portion of Hays County is included in the Region K Water Plan, thus to facilitate and be consistent with the regional water planning process, the State Water Plan projections were used for both planning scenarios. Reviewing the State Water Plan data with the above sources indicated that use of these projections was appropriate for the planning period.

*Population Summary**

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	97,589	166,342	242,051	302,795	363,678	436,388	493,320	553,000	618,000	684,000	751,000
Scenario II	97,589	166,342	242,051	302,795	363,678	436,388	493,320	553,000	618,000	684,000	751,000

* Summary above reflects the projected population for the entire county for the two scenarios. The water demand projections shown below reflect the population not being served from another source of supply and therefore it is anticipated to be served by LCRA.

Water Demand Assumptions and Projections – Using gallons per person per day from Region K for Hays County and combining with the population projections, municipal demand was computed for the LCRA water planning area. There are no anticipated industrial water demands in Hays County, thus the entire water demand is for municipal purposes.

Total Projected LCRA Water Demand (acre-feet)

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	3,154	5,419	7,923	10,145	12,387	15,172	17,361	19,772	22,191	24,595	27,015
Scenario II	3,154	5,419	7,923	10,145	12,387	15,172	17,361	19,772	22,191	24,595	27,015

LCRA Water Supply Resource Plan **Llano County**
County Population and Water Demand Summary
December 2008

Population Assumptions and Projections – Data was available from the Texas State Data Center (TSDC), State Water Plan, U.S. Census Bureau, County, and CAPCOG sources. For Scenario II, correlating this information with the 2005 and 2007 U.S. Census estimates, the County data was selected for the period from 2010 to 2020. Then, based on input from LCRA Community and Economic Development, the TSCD 2000-2004 Migration Rate was applied from 2020 to 2100.

*Population Summary**

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	17,044	17,360	17,360	17,360	17,360	17,360	17,360	17,360	17,360	17,360	17,360
Scenario II	17,044	24,514	31,984	34,000	36,000	38,000	40,000	41,900	43,800	45,800	48,000

* Summary above reflects the projected population for the entire county for the two scenarios. The water demand projections shown below reflect the population not being served from another source of supply and therefore it is anticipated to be served by LCRA.

Water Demand Assumptions and Projections – Using gallons per person per day from Region K for Llano County and combining with the Scenario I and Scenario II population projections, municipal demand was computed for the LCRA water planning area. The difference in water demands between the scenarios is the anticipated larger population growth in Scenario II.

Total Projected LCRA Water Demand (acre-feet)

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	3,339	3,123	2,889	3,000	3,144	3,345	3,603	3,774	3,874	3,974	4,074
Scenario II	3,339	3,977	4,616	4,935	5,279	5,696	6,181	6,568	6,885	7,212	7,563

LCRA Water Supply Resource Plan **Matagorda County**
County Population and Water Demand Summary
December 2008

Population Assumptions and Projections – Data was available from the Texas State Data Center, State Water Plan, U.S. Census Bureau, and the Houston Galveston Area Council (HGAC). For Scenario II, correlating this information with the 2005 and 2007 U.S. Census estimates and the HGAC data, the Texas State Data Center 1990-2000 Migration Rate was selected for the planning period. The 1990-2000 Migration Rate is nearly the same as the 1990-2000 Half Migration Rate and appropriate for long-term planning in rural areas.

*Population Summary**

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	37,957	40,506	43,295	44,991	45,925	45,793	45,377	48,500	50,700	53,700	56,400
Scenario II	37,957	41,924	45,431	47,701	48,365	52,300	54,900	57,600	60,200	62,900	65,600

* Summary above reflects the projected population for the entire county for the two scenarios. The water demand projections shown below reflect the population not being served from another source of supply and therefore it is anticipated to be served by LCRA.

Water Demand Assumptions and Projections – Using gallons per person per day from Region K for Matagorda County and combining with the Scenario I and Scenario II population projections, municipal demand was computed for the LCRA water planning area. Communities presently rely on groundwater for their municipal supplies and groundwater is anticipated to be available over the planning period to continue to meet this need. The majority of water necessary for Matagorda County is to serve industrial and steam electric generation. The difference in water demands between the scenarios is the inclusion of the White Stallion Power Generation water requirements in Scenario II.

Total Projected LCRA Water Demand (acre-feet)

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	37,468	44,579	48,542	50,120	50,144	51,499	51,525	54,530	54,530	54,530	54,530
Scenario II	37,468	44,580	73,544	80,128	80,151	81,509	81,537	84,542	84,542	84,541	84,541

LCRA Water Supply Resource Plan **Mills County**
County Population and Water Demand Summary
December 2008

Population Assumptions and Projections – Data was available from the Texas State Data Center, State Water Plan, and U.S. Census Bureau. For Scenario II, correlating this information with the 2005 and 2007 U.S. Census estimates, the Texas State Data Center 1990-2000 Migration Rate was selected for the planning period. The 1990-2000 Migration Rate is nearly the same as the 1990-2000 Half Migration Rate and appropriate for long-term planning for rural areas.

*Population Summary**

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	5,151	5,137	5,414	5,476	5,537	5,497	5,397	5,600	5,700	5,700	5,800
Scenario II	5,151	5,773	6,380	6,521	6,132	6,800	7,100	7,350	7,600	7,900	8,200

* Summary above reflects the projected population for the entire county for the two scenarios. The water demand projections shown below reflect the population not being served from another source of supply and therefore it is anticipated to be served by LCRA.

Water Demand Assumptions and Projections – Using gallons per person per day from Region K for Mills County and combining with the Scenario I and Scenario II population projections, municipal demand was computed for the LCRA water planning area. Presently, the communities rely on groundwater for their municipal supplies and groundwater is anticipated to be available until later in the planning cycle when a portion of the population is expected to require another source of water. There are no anticipated industrial demands in Mills County.

Total Projected LCRA Water Demand (acre-feet)

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	21	21	21	21	21	21	21	190	190	190	190
Scenario II	21	24	25	25	23	26	28	276	280	291	297

LCRA Water Supply Resource Plan **San Saba County**
County Population and Water Demand Summary
December 2008

Population Assumptions and Projections – Data was available from the Texas State Data Center, State Water Plan, and U.S. Census Bureau. For Scenario II, correlating this information with the 2005 and 2007 U.S. Census estimates and the HGAC data, the Texas State Data Center 1990-2000 Migration Rate was selected for the planning period. The 1990-2000 Migration Rate is nearly the same as the 1990-2000 Half Migration Rate and appropriate for long-term planning for rural areas.

*Population Summary**

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	6,186	6,387	6,746	7,059	7,332	7,365	7,409	7,800	8,000	8,200	8,500
Scenario II	6,186	6,935	7,775	8,265	8,390	9,200	9,800	10,400	11,000	11,500	12,100

* Summary above reflects the projected population for the entire county for the two scenarios. The water demand projections shown below reflect the population not being served from another source of supply and therefore it is anticipated to be served by LCRA.

Water Demand Assumptions and Projections – Using gallons per person per day from Region K for San Saba County and combining with the Scenario I and Scenario II population projections, municipal demand was computed for the LCRA water planning area. Presently, the communities rely on groundwater for their municipal supplies and groundwater is anticipated to be available throughout the planning period. There are no anticipated industrial demands in San Saba County.

Total Projected LCRA Water Demand (acre-feet)

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	22	22	22	22	22	22	22	22	22	22	22
Scenario II	22	22	22	22	22	23	23	23	23	23	23

LCRA Water Supply Resource Plan **Travis County**
County Population and Water Demand Summary
December 2008

Population Assumptions and Projections – Data was available from the Texas State Data Center (TSDC), State Water Plan, U.S. Census Bureau, and CAPCOG. For Scenario II, correlating this information with the 2005 and 2007 U.S. Census estimates, the CAPCOG projection was selected for the period from 2010 to 2040. Then, based on input from the State Demographer and LCRA Community and Economic Development, the TSDC 1990-2000 Half Migration Rate was applied from 2040 to 2100.

*Population Summary**

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	812,280	969,955	1,185,499	1,385,236	1,550,538	1,722,737	1,888,543	2,030,000	2,180,000	2,310,000	2,460,000
Scenario II	812,280	1,003,600	1,208,900	1,434,100	1,680,200	1,820,000	1,960,000	2,120,000	2,270,000	2,420,000	2,550,000

* Summary above reflects the projected population for the entire county for the two scenarios. The water demand projections shown below reflect the population not being served from another source of supply and therefore it is anticipated to be served by LCRA.

Water Demand Assumptions and Projections – Using gallons per person per day from Region K for Travis County and combining with the Scenario I and Scenario II population projections, municipal demand was computed for the LCRA water planning area. Industrial demands were added to the municipal demand to estimate total water demand. Since the City of Austin owns several water rights and is the primary water provider in Travis County, the total below does not include the amount of water Austin will provide through their existing rights.

Total Projected LCRA Water Demand (acre-feet)

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	17,505	61,797	109,263	150,544	194,664	239,620	280,020	316,855	354,490	388,428	426,173
Scenario II	17,505	68,300	113,883	160,017	219,450	258,276	293,757	334,110	371,769	409,491	443,496

LCRA Water Supply Resource Plan **Wharton County**
County Population and Water Demand Summary
December 2008

Population Assumptions and Projections – Data was available from the Texas State Data Center (TSDC), State Water Plan, U.S. Census Bureau, and Houston Galveston Area Council. Only the eastern portion of Wharton County is included in the Region K Water Plan with the remainder of the County in Region P. Thus to facilitate and be consistent with the regional water planning process, the Region K projections were used for both scenarios.

*Population Summary**

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	41,188	43,560	46,045	47,647	48,567	48,590	48,074	51,100	53,500	55,900	58,300
Scenario II	41,188	43,560	46,045	47,647	48,567	48,590	48,074	51,100	53,500	55,900	58,300

* Summary above reflects the projected population for the entire county for the two scenarios. The water demand projections shown below reflect the population not being served from another source of supply and therefore it is anticipated to be served by LCRA.

Water Demand Assumptions and Projections – Using gallons per person per day from Region K for Wharton County and combining with the population projections, municipal demand was computed for the LCRA water planning area. Communities presently rely on groundwater for their municipal supplies and groundwater is anticipated to be available over the planning period to continue to meet this need. There is a limited amount of industrial demands to be met in Wharton County which represents the majority of the water requirements.

Total Projected LCRA Water Demand (acre-feet)

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	294	586	722	805	901	1,010	1,149	1,268	1,398	1,528	1,738
Scenario II	294	586	722	805	901	1,010	1,149	1,268	1,398	1,528	1,738

LCRA Water Supply Resource Plan **Williamson County**
County Population and Water Demand Summary
December 2008

Population Assumptions and Projections – Data was available from the Texas State Data Center (TSDC), State Water Plan, U.S. Census Bureau, and CAPCOG. Only the a small portion of southern Williamson County is included in the Region K Water Plan, however, this County is in the LCRA service area via existing water contracts. Thus to facilitate and be consistent with the regional water planning process, the Region K projections were used for both scenarios. Region K projections were used from 2010 to 2060, then, the TSDC 1990-2000 Half Migration Rate was applied from 2060 to 2100.

*Population Summary**

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	249,967	352,811	476,833	625,189	787,039	963,542	1,153,166	1,280,000	1,400,000	1,250,000	1,650,000
Scenario II	249,967	352,811	476,833	625,189	787,039	963,542	1,153,166	1,280,000	1,400,000	1,250,000	1,650,000

* Summary above reflects the projected population for the entire county for the two scenarios. The water demand projections shown below reflect the population not being served from another source of supply and therefore it is anticipated to be served by LCRA.

Water Demand Assumptions and Projections – Using gallons per person per day from Region K for Williamson County and combining with the population projections, municipal demand was computed for the LCRA water planning area. There are no anticipated industrial water demands in Williamson County, thus the entire water demand is for municipal purposes. With existing water contracts totaling 67,000 acre-feet, this was determined to be the maximum amount provided to Williamson County over the planning period

Total Projected LCRA Water Demand (acre-feet)

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	6,949	13,841	41,095	48,761	56,625	62,343	65,682	67,000	67,000	67,000	67,000
Scenario II	6,949	13,841	41,095	48,761	56,625	62,343	65,682	67,000	67,000	67,000	67,000

LCRA Water Supply Resource Plan
LCRA Water Demand Summary

*Total Projected LCRA Water Demand (acre-feet)**

Planning Scenario	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario I	103,143	188,897	276,164	336,621	395,415	454,850	504,860	553,140	596,856	637,864	681,798
Scenario II	103,143	222,924	337,806	414,080	493,838	547,419	592,484	646,979	692,181	738,464	780,180

* The contract to provide water to Lometa is included in the above total projected LCRA water demand. Lometa is not in the Region K Planning Area, however, by contract LCRA provides water to this area in Lampasas County.

*Scenario II Projected LCRA Water Demand by County (acre-feet)***

County	2010 Projected Demand	2100 Projected Demand	Demand Increase
Bastrop	12,850	46,315	33,465
Blanco	115	3,393	3,278
Burnet	5,332	20,475	15,143
Colorado	17	22	5
Fayette	41,691	41,882	191
Gillespie	39	1,260	1,221
Hays	5,419	27,015	21,596
Llano	3,977	7,563	3,586
Matagorda	44,580	84,541	39,961
Mills	24	297	273
San Saba	22	23	1
Travis	68,300	443,496	375,196
Wharton	586	1,738	1,152
Williamson	13,841	67,000	53,159

** Excludes Lometa, domestic water use and conveyance loss

LCRA-SAWS Water Project

- Proposed Project
- About the Study Period
- Questions and Answers
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- How to Participate
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LCRA-SAWS Water Project

Welcome to the LCRA-SAWS Water Project Web site, where you can find information on the proposed project, an ongoing study of the project's feasibility, and how to get involved in the study process.

About the project

The LCRA-SAWS Water Project is a water sharing proposal to develop alternative supplies that could help meet long-term needs in the lower Colorado River basin and the San Antonio area. The plan was developed during the statewide regional water supply planning process required under Senate Bill 1, passed in 1997. It is an important water supply strategy for both regions and the state. LCRA and San Antonio Water System (SAWS) are in the sixth year of a six-year in-depth study of the proposal's technical, environmental and financial feasibility. The study period also will determine if the project can meet legislative requirements and obtain federal, state and local permits.

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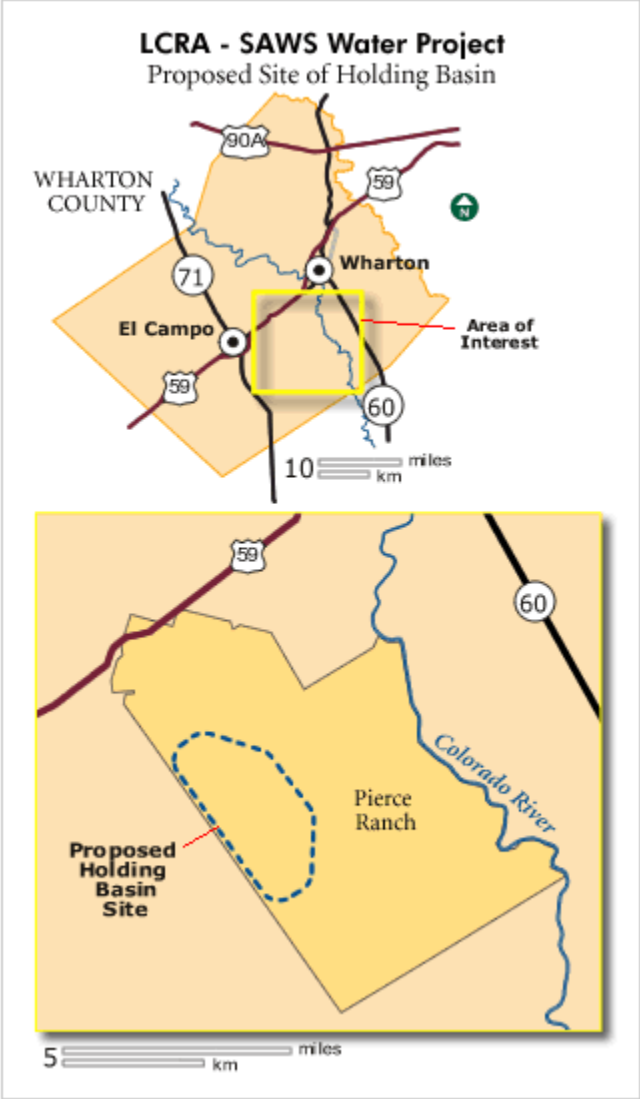
LCRA selects Wharton County site for proposed water storage facility

For Immediate Release: September 06, 2007 08:50 AM

Sidebar: How sites were evaluated
Media contacts: Robert Cullick, 1-800-776-5272, Ext. 4086, or Merrell Foote, Ext. 3234



AUSTIN – LCRA announced today (Sept. 6) that it has identified a portion of Pierce Ranch in Wharton County as its preferred site for a holding basin to capture and store excess and unused water for the proposed LCRA-SAWS Water Project.

The owners of the ranch have signed a preliminary agreement that provides LCRA an option to purchase about 4,200 acres of the ranch for the holding basin. The purchase price will be determined at the time LCRA exercises the option to purchase the land. The agreement is subject to approval by the LCRA Board of Directors.

In May 2006 LCRA identified six other sites in Colorado, Wharton and Matagorda counties as potential locations for the holding basin. Landowners of these sites have been notified that LCRA no longer will consider their property as a preferred holding basin site for the project.

The LCRA Board adopted a resolution in September 2006 directing staff on key issues related to the project, including land acquisition. The Board emphasized the need to respect property owners' rights, seek willing sellers and offer fair compensation for land. The owners' willingness to sell was one of several key factors considered by LCRA in selecting the site.

"The LCRA Board instructed staff to respect the rights of private landowners and to use eminent domain as a last resort for this project. This agreement is a great example of how LCRA's land acquisition process is intended to work," said LCRA Board Chair Ray Wilkerson.

Site a good choice because of several factors

"From the beginning of this project, LCRA's goal has been to buy property from willing sellers," said LCRA General Manager Joe Beal. "This is a key reason for choosing the ranch site, but it is not the only reason. The site also is a good choice because it appears to have similar or less environmental and socioeconomic impacts compared to other sites we considered."

LCRA and the ranch have worked cooperatively for many years to serve agricultural irrigation customers. In 2000 LCRA purchased water rights from the ranch and acquired an option to buy a specific portion of the ranch for future water development. LCRA considered building the holding basin on that site but decided against it because the site is too small and is located in the 100-year floodplain.

The landowners recently agreed to transfer LCRA's option to a more suitable location on the ranch. LCRA chose this site only after evaluating the project's potential environmental, technical, socioeconomic and financial impact at all the sites being studied.

"We are pleased to be participating in a project which may well set the standard for future interbasin cooperation in the challenge of providing water from surplus to deficit areas in the state of Texas," said Laurance Armour III, ranch manager and trustee.

An intake structure, pumps and pipelines to convert and convey water from the river to the holding basin also would be located at the ranch if LCRA builds the holding basin. In the coming months LCRA will conduct site-specific technical studies and will study potential pipeline routes to transport water from the holding basin to SAWS facilities at the Wharton County line. The actual size and design of the holding basin will be developed after the site-specific studies and other project studies are completed.

The LCRA Board also directed staff to develop recommendations to mitigate, or offset, impacts of the project, such as tax revenue loss. LCRA will develop a mitigation plan for the holding basin and related facilities when more is known about their actual size and design.

The proposed LCRA-SAWS Water Project would help meet long-term water needs in the lower Colorado River basin and the San Antonio area by conserving water used for agriculture, storing excess and unused surface water supplies in the holding basin for future use, and using groundwater to help meet agricultural irrigation needs when surface water is lacking.

In-depth study
LCRA and SAWS are in the fourth year of an in-depth study of the project's technical, environmental and financial feasibility. After the study period, scheduled to end no later than 2015, the LCRA Board will determine if the project protects and benefits the river basin as required by House Bill 1629, passed by the Texas Legislature in 2001. The SAWS Board will decide if the project's cost and water supply are acceptable.

During the study period, LCRA and SAWS also will determine if the project can obtain federal, state and local permits. LCRA and SAWS plan to file an application in 2009 with the U.S. Army Corps of Engineers for a federal permit for the entire project, including the holding basin and related facilities. The application must describe all the potential sites studied and the evaluation process and criteria used to assess them.

The Corps will review the application, the analysis of the potential sites, and the proposed project and facilities. The Corps also will seek public input during the review. The final location of the holding basin will not be determined until the Corps completes the federal review process and determines whether to issue a permit. This process will take time.

"This is the site we are putting forth in the permit application we plan to file with the U.S. Army Corps of Engineers, but ultimately it is the Corps' decision on whether to approve the site and issue the permit," Beal said.

LCRA plans to hold a project update meeting in Wharton County later this fall to discuss project studies and developments with stakeholders, residents and the public. To receive meeting notices and to learn more about the project, subscribe to a free e-mail newsletter at www.lcra.org/lswp/. To receive the newsletter by mail, call 1-800-776-5272, Ext. 7208.

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Applications received by LCRA for water supply contracts

Applications scheduled for Board approval

Applicant	Date application received	Diversion Point	County	Use	Supply	Acre-feet Requested	Current contract amount (acre-feet)	Total (acre-feet)	Notes
Hays County WCID #2	4/11/2008	Lake Austin	Hays	Municipal	Firm	532	0	532	scheduled for August Board meeting
Underground Services Markham (formerly Texas Brine Co.)	3/24/2008	Colorado River	Wharton	Industrial	Firm	9,868	8,200	9,868	not scheduled
White Stallion Energy Center, LLC	10/13/2008	Colorado River	Matagorda	Industrial	Firm	22,000	0	22,000*	not scheduled
* they have requested 22,000 AFY to be provided at the point of delivery near the plant site with an additional amount for delivery losses calculated by the applicant the MAQ would be 29,750 AFY.									
Lazy Nine Municipal Utility District IE	4/17/2009	Lake Austin	Travis	Municipal	Firm	534	0	534	not scheduled

NOTE: Board agenda schedules are subject to change; please see the Board agenda posted at 'http://www.lcra.org/about/board_agenda.html' for the latest agenda information.

Applications to go thru the Administrative Process

Fleming Springs Ranch	2/25/2009	Fleming Springs	San Saba	Irrigation	Firm	20	20	20	The current contract will expire soon and this application is to replace the existing contract
Austin YMBL Sunshine Camps	3/4/2009	Lake Travis	Travis	Municipal	Firm	2.5	0	2.5	
City of Austin: Public Works: Waller Creek Tunnel Project,	3/17/2009	Lady Bird Lake	Travis	Irrigation-Recreational		165	0	165	
6D Ranch, Ltd.	3/23/2009	Lake Austin	Travis	Irrigation	Firm	45	0	45	

DEFINITIONS:

Firm water: The amount of water lakes Buchanan and Travis could supply during a repeat of the most severe drought on record. Most of this water is committed for use by cities, industries, power plants and protection of aquatic life.

Interruptible water: Water that is available for use on a year-to-year basis, depending on how much water is stored in lakes Travis and Buchanan. Interruptible water is subject to curtailment during water shortages.

Matagorda Bay and estuaries

LCRA, state agencies to conduct new study of freshwater inflow

Fresh water from the Colorado River into West Matagorda Bay greatly influences estuarine biological productivity by lowering salinity, increasing nutrients and providing sediment. Knowing what the bay needs for ecological health is vital to LCRA's proper management of water supply.

Although Texas law does not mandate specific freshwater inflow needs, state policy calls for "the maintenance of a proper ecological environment of the bays and estuaries of Texas and the health of related living marine resources."

What is a proper ecological environment, and what does it take to maintain it? To shed light on the matter, LCRA and the Texas Parks and Wildlife Department, Texas Water Development Board and Texas Commission on Environmental Quality agreed to update the 1997 Matagorda Bay Freshwater Inflow Needs Study. This study along with another, more comprehensive look at Matagorda Bay health criteria being conducted as a part of the LCRA-SAWS Water Project studies will be used in future planning and permitting activities. See the final 2006 Matagorda Bay Freshwater Inflow Needs Study.

— Updated May 23, 2008 01:17 PM

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QUICK LINKS

- Final Matagorda Bay Freshwater Inflow Needs Study
- Frequently asked questions about the study

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http://www.lcra.org/library/media/public/docs/lswp/findings/MBHE_2006_Habitat_Progress_Report.pdf

Progress Report

Matagorda Bay Health Evaluation

Habitat Assessment

Prepared for

Lower Colorado River Authority

and San Antonio Water System

DECEMBER 2006

Water Project

LCRA ENERGY • WATER • COMMUNITY SERVICES

San Antonio Water System

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APPENDIX A Development of Oyster Reef Condition Indices and Oyster Suitability Criterion Models for the Matagorda Bay Health Evaluation

Acronyms and Abbreviations

CSI	Composite Suitability Index
DCI	Dermo Condition Index
EAMB	East Arm of Matagorda Bay
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
EMB	East Matagorda Bay
FINS	Freshwater Inflow Needs Study
FKF	Frequency of Killing Floods
GIS	Geographic Information System
GIWW	Gulf Intracoastal Waterway
GLO	General Land Office (Texas)
GPS	Global Positioning System
H-GAC	Houston-Galveston Area Council
HEM	High Estuarine Marsh
HIM	High Intermediate Marsh
HSI	Habitat Suitability Index
LCRA	Lower Colorado River Authority
LEM	Low Estuarine Marsh
LIM	Low Intermediate Marsh
LSWP	LCRA-SAWS Water Project
MIMP	Mad Island Marsh Preserve, operated by the Nature Conservancy
MBHE	Matagorda Bay Health Evaluation
ME	Marsh Edge
MI	Marsh Interior
NCRD	New Colorado River Delta
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OCI	Oyster Condition Index
ODCI	Oyster Dermo Condition Index
ppt	Parts per thousand (salinity unit)
SAWS	San Antonio Water System
SRP	Science Review Panel

TCEQ	Texas Commission on Environmental Quality
TPWD	Texas Parks and Wildlife Department
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WMA	Mad Island Marsh Wildlife Management Area, operated by TPWD

Executive Summary

This document presents a 2006 (Task Order 4) progress update including characterization, linkages, model development, fieldwork, and preliminary results associated with the habitat component of the Matagorda Bay Health Evaluation (MBHE). As described in the Matagorda Bay Health Framework Document, the habitat component is only one piece of the multi-faceted approach to describe bay health, and evaluate potential impacts/benefits from the LCRA-SAWS Water Project (LSWP) so as to meet the project objective to maintain bay health and productivity. The habitat assessment involves providing baseline environmental conditions within Matagorda Bay and relationship development between key aquatic species and habitat or condition based on biological, chemical and physical variables. These variables include but are not limited to freshwater inflow, salinity, temperature, inundation regime, physical habitat features, and organism abundance.

Fieldwork conducted in 2006 proved valuable in supporting many of the parameters and relationships selected for use in the habitat models. Preliminary results described in this progress report include baseline habitat conditions for juvenile brown shrimp, white shrimp, and marsh function. These results are preliminary and used in this progress report for illustration purposes only. Only three of the five marsh complexes are included in this preliminary evaluation. As additional salinity model output for the remaining marshes becomes available and overall quality assurance review of salinity output is conducted, these analyses will be revised.

The progress report concludes with a forecast of activities scheduled for 2007. The focus of the 2007 habitat assessment will be using the GIS habitat models and Oyster Reef statistical models to assess existing conditions, aid the development of freshwater inflow criteria, evaluate potential enhancement opportunities during extreme drought conditions, and conduct project alternatives analysis. Additional 2007 activities will include model validation, limited habitat characterization fieldwork, and development of recommendations for the habitat component of the MBHE long-term monitoring program.

1.0 INTRODUCTION

The focus of the habitat assessment is to evaluate effects of freshwater inflow alterations to Matagorda Bay as part of the LCRA-SAWS Water Project (LSWP). The most notable freshwater input potentially affected by the LSWP is the Colorado River. Additionally, since the LSWP has the potential to alter the irrigation return flows via conservation, reduction of the second rice crop, etc., the marsh areas north of the Gulf Intracoastal Waterway (GIWW) may also directly experience changes in freshwater inflow. Thus, the habitat analysis addresses how inflow changes affect the biology of the system both within the immediately adjacent areas (marshes) and the open bay environments. The defined project area for the habitat assessment comprises the area from Tres Palacios Bay on the west to Lake Austin on the east.

Matagorda Bay is characterized by large changes in salinity over a broad range of temporal and spatial scales. One of the primary techniques being used by the habitat team to evaluate the health and productivity of Matagorda Bay is linking the MBHE hydrodynamic/salinity model to key species biological responses or suitability indices. As part of the MBHE Habitat component, these linkages have been developed for key Matagorda Bay shellfish and finfish. Using these biological linkages, the suite of habitat "models" can provide an assessment of existing habitat conditions within the project area and allow for the comparison between different freshwater inflow scenarios. The three main areas of focus involve oyster reef condition, habitat availability for key juvenile organisms, and marsh function.

To conduct the habitat assessment, statistical models of oyster reef condition and GIS based habitat models were generated. The statistical model framework is described in Section 3 and Appendix A. The GIS model framework includes a series of inputs, relationships, analyses and outputs relating environmental conditions with the habitat availability for key juvenile species and marsh function. The process included an initial habitat characterization (MBHE 2005a, MBHE 2005b) of the project area which described the current biological, chemical and physical habitat conditions. In 2006, the focus shifted to habitat model development and incorporation of output from the hydrodynamic/salinity model. In the fourth quarter of 2006, use of the habitat model to simulate habitat conditions under provided freshwater inflow scenarios was initiated.

2.0 PROJECT COMMUNICATION

As in previous years, communication of the progress of this study was maintained with LCRA/SAWS and the Project Management Team. This involved several in-person meetings as well as phone conversations and email correspondence. The monthly Project Management meetings conducted at LCRA provided another opportunity for interaction with the project sponsors, management team, and other study groups. Multiple internal LSWP MBHE team meetings and conference calls were conducted to maintain communication within the team by addressing progress, methodologies, concerns, and scheduling.

In addition to the communications described above, the project team also interacted with resource agency scientists, the Science Review Panel (SRP) and LSWP Advisory Group on multiple occasions during 2006. During the 2005 initial habitat assessment phase, a series of meetings and workshops with academic professionals, members of the SRP and resource agency professionals were conducted. Details about these meetings are provided in the 2005 Habitat Assessment Progress Report (MBHE 2005b). On December 8, 2005 a comprehensive resource agency workshop was conducted to provide an outline of the habitat component of the MBHE to several resource agencies and professionals involved in the project (MBHE 2005b).

Additional meetings were conducted in 2006 to follow-up with several resource agencies and to incorporate more recent information on key project species and habitat within the Matagorda Bay system. A habitat team meeting with Texas Parks and Wildlife Department (TPWD) Austin office personnel was conducted in January 2006 to discuss the overall habitat model approach and a TPWD habitat utilization study within Texas bays. A meeting with the MBHE benthic study team was also conducted in January to coordinate additional benthic invertebrate sampling within areas that may be important to or related to the habitat analysis. Two meetings with SRP members were conducted in February to review the habitat model approach, and several key recommendations were provided: (1) a limited fieldwork effort be conducted to gather drop-trap information from within the project area to support use of National Marine Fisheries Service (NMFS) drop trap data, (2) obtain additional information on the primary productivity of dominant wetland plants within the project area, and (3) pursue an additional resource agency workshop to outline information used in the model and all model outputs.

Following further evaluation of key organism suitability criteria and development of a preliminary habitat model, a follow-up resource agency workshop was conducted on March 10, 2006. This workshop addressed basic model questions raised during the first workshop and provided detailed technical information on ecological relationships used in the model. Several resource agencies also expressed interest in acquiring data on habitat use and plant productivity from within the project area to verify relationships developed from NMFS data. A seasonal fieldwork effort was designed in collaboration with the SRP and resource agencies to address these concerns, and seasonal sampling

was conducted at two locations within the project area to collect additional information on habitat use and seasonal plant productivity (Section 5).

3.0 OYSTER REEF CONDITION INDICES AND OYSTER SUITABILITY CRITERION MODELS

The American (also called eastern) oyster, *Crassostrea virginica* is one of the key species being evaluated by the project team. As a popular seafood, oysters are of vital economic and cultural importance to the Gulf of Mexico region. Additionally, oysters provide a number of key ecosystem functions: oyster spawn and larvae comprise a large proportion of the planktonic biomass in Texas bays, providing a vital food source for many planktivores; oyster reefs provide an important physical habitat for a diverse group of benthic organisms; and oyster filter feeding plays a key role in maintaining water clarity (Kennedy and Newell 1996). Consequently, maintaining the health of the Matagorda Bay oyster population is consistent with the objectives of the LSWP.

In 2006, the project team developed condition indices and suitability criterion models to describe the biological linkage between oyster condition, salinity and temperature. Additional factors such as food availability and contaminants were not considered as predictors of oyster condition at this time, and interactions with other species (predators) will only be incorporated indirectly via how their impact on oysters is dependent on salinity and temperature. Although, interactions with other species are not specifically considered as predictors of oyster reef condition; infestation by the parasite *Perkinsus marinus*, commonly called dermo (the term "dermo" describes both the infection and the organism, formerly classified as *Dermocystidium marinum*), were included in the description of oyster condition. This is because high levels of dermo infestation can severely reduce oyster reproduction and survival rates and also decrease the market value of oysters by degrading their meat. While regions within the bay that do not currently contain reefs may develop new reefs, there are many other factors besides salinity, temperature, and dermo that will determine reef placement and these factors are beyond the scope of the current modeling effort. Hence, the suitability criterion model focuses on predicting oyster condition on existing reefs and does not consider data from non-reef areas or attempt to predict areas where new reef formation might occur.

A detailed technical report documenting the development of an index of oyster reef condition and an oyster suitability criterion model for the Matagorda Bay system is presented in Appendix A. The technical report includes a review of existing research and data associated with direct and indirect effects on oyster growth and survival in relation to temperature and salinity. An assessment of the available data is also included and was used to determine the data that best suited the development of an oyster condition index and related suitability criterion model. The report highlights the existing data collection activities from multiple sources and locations and how aggregation of that data was performed to provide better oyster population information and to improve data coverage spatially and temporally. These steps were all conducted prior to the construction and development of the condition index and suitability criterion model.

A summary of the technical report findings is as follows. Four different oyster condition indices were created based on available data, such as oyster abundance, size, and/or dermo infestation.

Regression models for condition as a function of salinity and temperature parameters were developed and evaluated in order to determine the best predictive regression model for each condition index. The best models were designated as suitability criterion models for oyster reef condition in Matagorda Bay. All four oyster condition indices were more strongly driven by salinity parameters than by temperature parameters. The oyster abundance indices had intermediate salinity optima, while the condition indices that incorporated dermo intensity had negative relationships with salinity– dermo intensity increased (hence condition decreased) with salinity. In 2007, these suitability criterion models will be linked with output from the hydrodynamic/salinity model to simulate the effects of inflow patterns on oyster reef condition throughout Matagorda and East Matagorda Bays.

4.0 HABITAT EVALUATION

4.1 Habitat Characterization

Physical and chemical habitats are considered two major habitat components which influence the selected Matagorda Bay species and have a response to variation in freshwater inflow. The 2006 habitat characterization task involved continuing the collaborative work of several individual components from 2005. In 2006, characterization of marsh habitats, seagrasses, and shallow non-vegetated bay bottom (SNB) within the project area were finalized. Oyster reef distribution in and around the project area (EAMB and East Matagorda Bay [EMB]) were previously mapped by TPWD and the Texas General Land Office (GLO) through various sources. The MBHE project team conducted a field ground-truthing effort in October 2005 to verify and update the distribution maps. The updated oyster reef maps along with previous TPWD sample locations were shown in the 2005 Habitat Assessment Progress Report (MBHE 2005b). During 2006 field activities, large areas of previously undocumented oyster reefs were identified in the immediate area of the new Colorado River delta (NRCD). Therefore, a preliminary reconnaissance of the area was conducted by airboat in fall 2006 to delineate the extent of the reefs and make the determination of significance. From that trip, it was determined that the nature and extent of the oyster reefs in this area warranted mapping. As such, mapping of oysters in the NCRD area is scheduled for the winter of 2007, with the data to be included in the existing habitat condition for the model.

Only shallow-water habitats (<2m in depth) that are potentially available to the key project species are currently evaluated in the habitat model and in this assessment. These physical habitats include high intermediate marsh (HIM), low intermediate marsh (LIM), high estuarine marsh (HEM), low estuarine marsh (LEM), submerged aquatic vegetation (both freshwater and saltwater; SAV), oyster reef (OR), and SNB. A comprehensive map of existing physical habitat within the project area was developed (Figure 4.1) and serves as the physical habitat input to the GIS based habitat model. A limited field effort was conducted to collect additional information within LEM and HEM habitats and is presented in Section 5.

The key chemical components of habitat relative to this assessment include salinity and temperature. MBHE (2005b) described the salinity, water temperature, and dissolved oxygen characterization for the project area. However, it is not anticipated that the project will significantly affect water temperatures or dissolved oxygen within the project area, and therefore, these parameters were not included in modeling efforts. Temperatures will be included in the form of monthly and seasonal averages, but are considered constant between years. As summarized in Section 3 and described in Appendix A, salinity and temperature interactions are considered in the oyster reef condition evaluation.

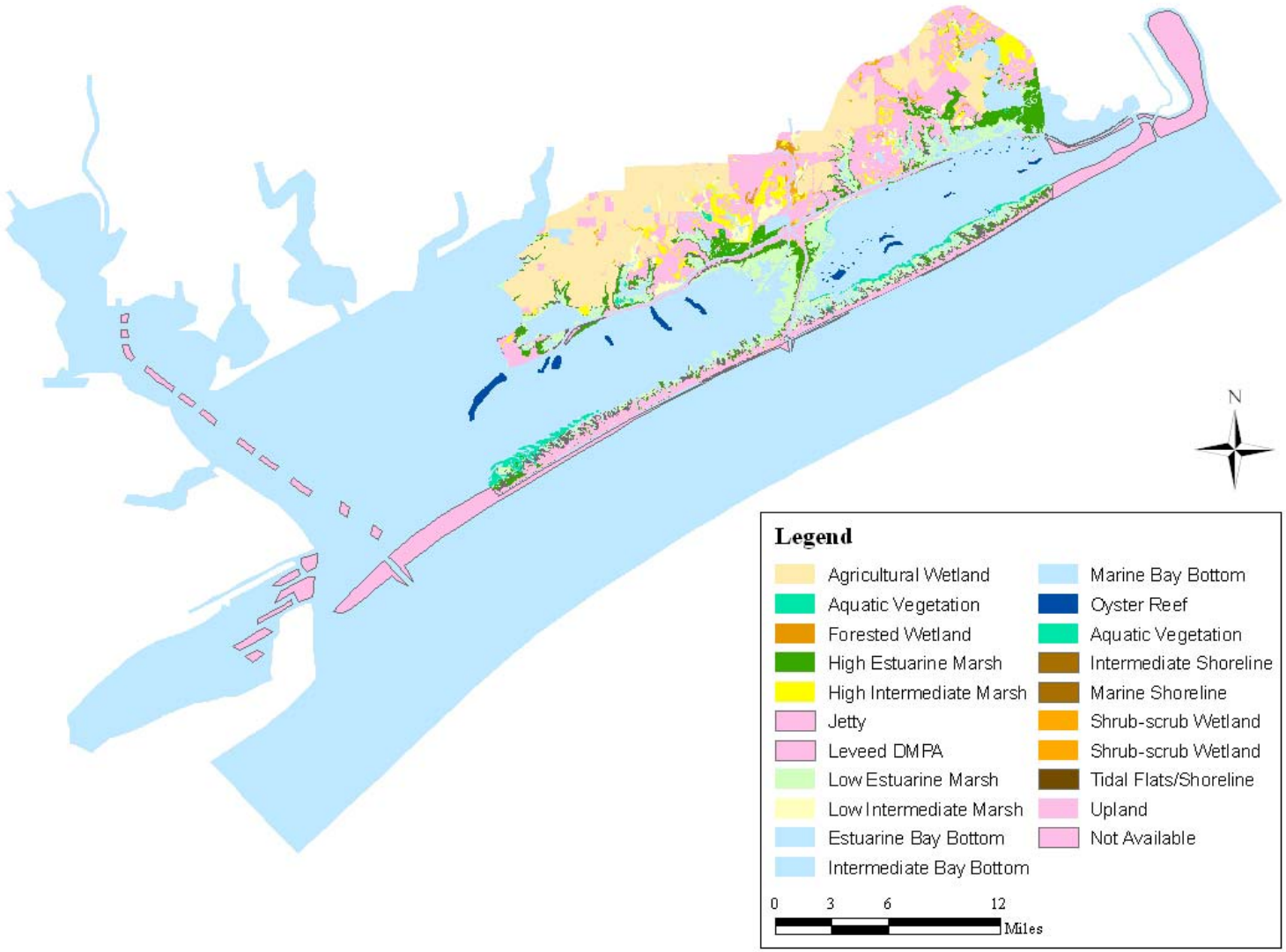

Figure 4.1 - Map of physical habitats within the project area extending from Tres Palacios Bay to Lake Austin, Texas and including Matagorda Bay and East Matagorda Bay.

4.2 Biological Linkage

Defining and describing the biological linkages present in the project area first requires a description of the habitat condition of the project area. This existing habitat condition serves as a measure of the suitability of habitat for Matagorda Bay plant and animal species. Eight key species of organisms were originally selected for the habitat assessment within the project area: brown shrimp, white shrimp, blue crab, Atlantic croaker, gulf menhaden, spotted seatrout, red drum, and Eastern oyster (MBHE 20005b). These species were selected because they represent a wide spectrum of trophic levels in the estuarine food web, in addition to being recreationally or commercially important, either directly or indirectly, in Matagorda Bay.

The project team used organism abundance data from both the TPWD coastal fisheries database and the NMFS drop trap sampling efforts to assess the extent that coastal bays in Texas and Matagorda Bay specifically serve as habitat for the key species. The TPWD maintains the coastal fisheries database through their monitoring program and provides information regarding their sampling locations (i.e. date, time, etc.), organisms sampled (i.e. species, abundance, sampling gear type) and water quality measurements (i.e. temperature, salinity, etc). NMFS (in particular, the Fisheries Ecology Branch of the NMFS Galveston Laboratory) has published multiple journal articles and reports on their drop trap sampling efforts in several bays on the Texas coast. These studies provided information on species abundance within both shallow open bay habitat (non-vegetated) and shallow vegetated marsh habitat. The NMFS studies emphasized the importance that marsh habitats serve in providing shelter or nursery habitat for aquatic organisms.

Several of the key species of interest have multiple life-stages in which the organisms migrate between the sheltered waters of Matagorda Bay and the deep open waters of the Gulf of Mexico. Evaluation of both the TPWD and NMFS datasets has guided the project team to two key decisions in the assessment. The first decision is to focus on habitat for juvenile life-stages of the key shellfish and finfish species. The prime reasons are the availability of data in marsh habitats and the fact that juvenile organisms are smaller and less mobile than adults, and are therefore less able to escape unfavorable conditions. The second decision is to exclude red drum and spotted seatrout from this analysis. There is simply not enough literature-based data collected in marsh areas for these two species to support the development of physical habitat suitability criteria. Additionally, the habitat field collection activities conducted in 2006 yielded only a handful of spotted seatrout and no red drum. Therefore, the key species included in GIS habitat model analysis reflect the lower trophic levels (shellfish [blue crab, brown shrimp and white shrimp] and forage fish [Gulf menhaden and Atlantic croaker]). Although excluded from the habitat analysis, both of these sport fish are included in the MBHE bio-statistics work.

In order to focus the habitat assessment within the project area, we analyzed the TPWD coastal fisheries database to determine the period of time each of the key organisms are most abundant within the project area (Table 4.1). We calculated the average annual mean abundance for each species and then selected the months in which equal or greater abundances were observed. We chose to use information collected in bag seines to define this period for two reasons. First, the bag seine technique samples smaller, less mobile organisms and is therefore less likely to include large samples of adult organisms than the otter trawl gear type. Secondly, bag seine samples are collected in shallow-water areas, which tend to be more sheltered and often adjacent to marsh habitat, both of which serve as nursery habitat for juvenile organisms. This

information is used in the GIS habitat model to define the time period for which salinity conditions within the project area are analyzed for each individual key species.

Table 4.1 - Time period for which each key species is most abundant in Matagorda Bay (based on TPWD bag seine data, 1977-2004).

Species	**TPWD Coastal Fisheries Database Bag Seine**
Blue crab	February-June, October-November
Brown shrimp	April-July
White shrimp	July-November
Atlantic croaker	January-June
Gulf menhaden	April-August

4.3 Habitat Suitability Development

In order to simulate habitat quantity and quality as it relates to a specific organism, relationships were developed between each of the five key project species and chemical and physical habitat parameters for which they select in the natural environment. A habitat suitability index (HSI) was assigned to each shallow-water physical habitat included in the analysis and for salinity relative to each of the five key species.

Relative HSI values for both salinity and physical habitat range from zero (0) to one (1) and are considered unitless. A selection value of 1 is the highest value assigned and indicates juvenile organisms of that species are found in the highest abundance within this habitat. Lower selection values are assigned to other habitats with proportionally lower populations of juveniles. Any habitat that is not suitable for a juvenile species receives a ranking of zero and is consequently designated as area that is not available for the organism. As the physical habitat suitability criteria were developed for juvenile organisms, and data used to generate these criteria were generally collected in shallow water habitat (function of gear type), a depth limitation of two meters was applied to the entire project area.

4.3.1 Physical Habitat

As previously described, there are two major biological data sources for the Texas Gulf coast: the TPWD coastal fisheries database and the NMFS drop trap sampling data. However, the two databases differ in regards to their ability to define organism density relationships as a function of physical habitat and salinity. The NMFS drop trap data provides an advantage over the TPWD coastal fisheries database because NMFS drop trap sampling was conducted in many different physical habitat types including coastal marshes (edge and interior), submerged aquatic vegetation, oyster reefs and shallow non-vegetated bottom. The TPWD gear types are primarily used to sample open bay bottom and are not used within coastal marsh areas. Additionally, TPWD recorded biological sample data (in most instances) do not include

information on vegetation adjacent to TPWD bag seine pulls. Therefore, we used the NMFS drop trap sample data to develop physical habitat suitability criteria for each of the key project species. As limited samples were available from the immediate project area, the project team expanded the data set to include Galveston, Lavaca, and San Antonio bays. The suitability criteria for physical habitat were fitted using normalized frequencies from the combined data set. Figures 4.2 and 4.3 show the physical habitat suitability developed for the key shellfish and forage fish species, respectively.

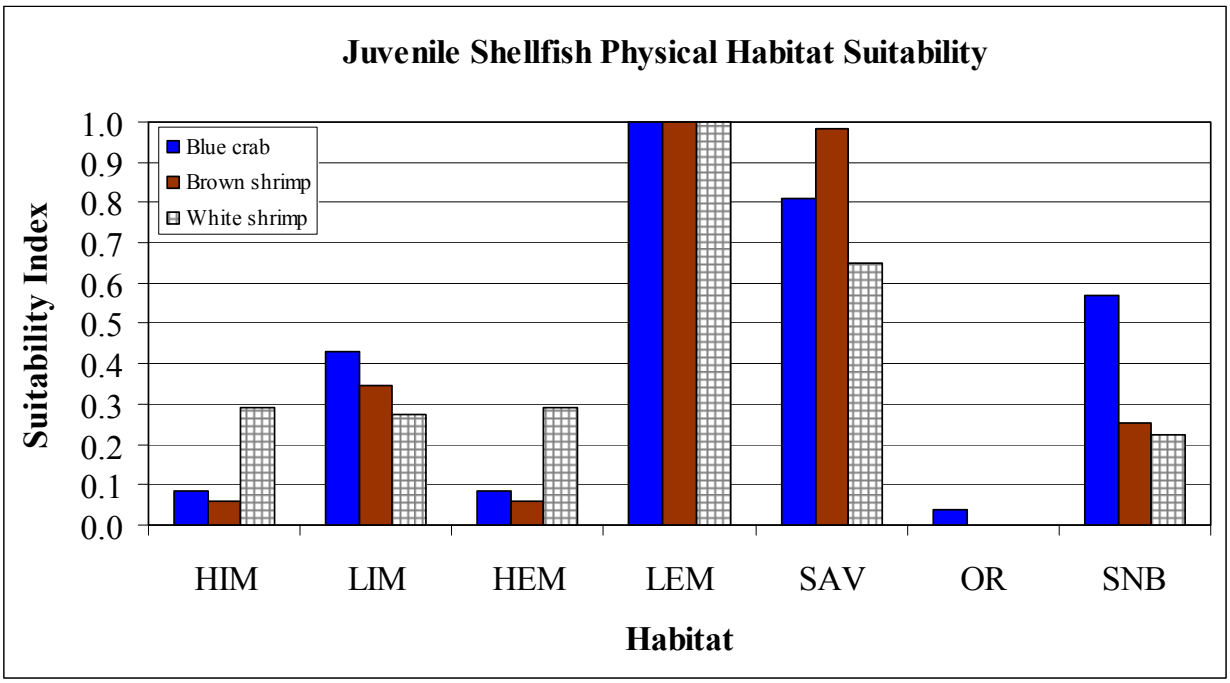

Figure 4.2 - Physical habitat suitability indices (HSI) for the juvenile life-stage of the three key shellfish species included in the habitat analysis.

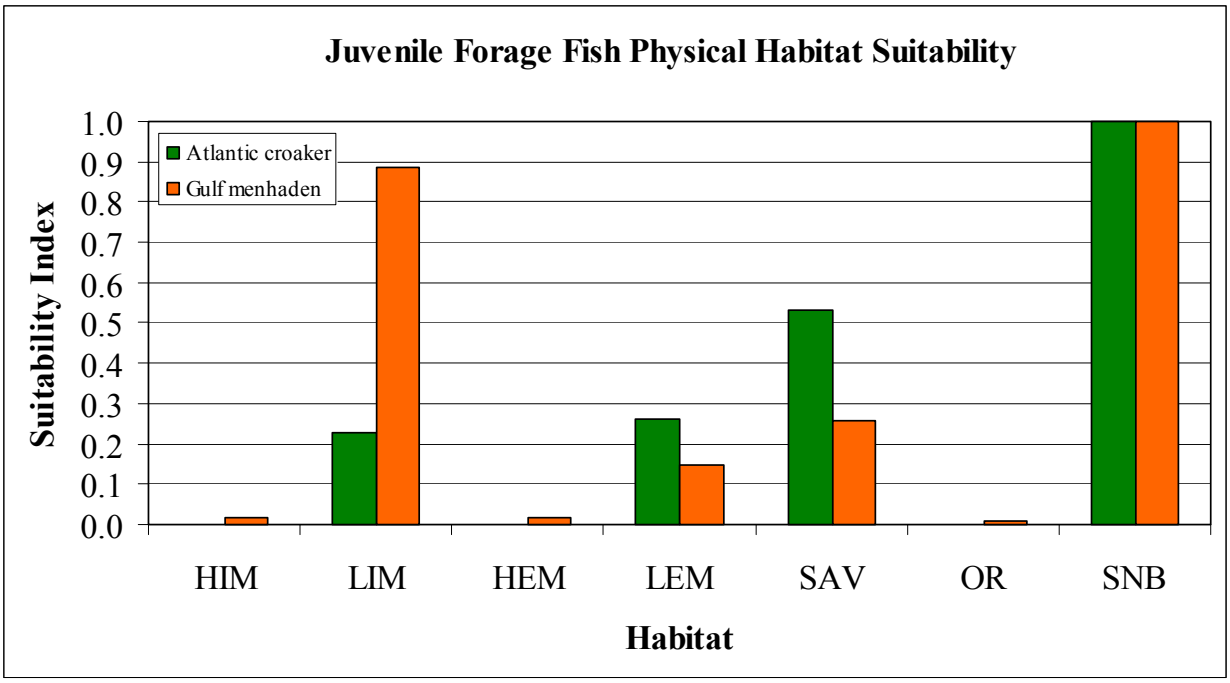

Figure 4.3 - Physical habitat suitability indices (HSI) for the juvenile life-stage of the two key forage fish species included in the habitat analysis.

Oyster reef suitability criteria as shown in Figures 4.2 and 4.3 appears anomolously low or absent entirely. This is because limited samples have been conducted over the years in this type of habitat. However, Dr. Greg Stunz of Texas A&M University in Corpus Christi (also on the LSWP Science Review Panel) has been conducting research on oyster reef utilization by juvenile shellfish and finfish and has indicated to the project team that he will be making this data available in the near future. Therefore, upon receipt of the oyster reef data from Dr. Stunz, the project team will evaluate and update suitability criteria where applicable.

4.3.2 Chemical Habitat

Within this analysis, the chemical habitat selection is associated with an organism's affinity to certain salinities or a salinity range. Within the project area, a wealth of salinity and organism data is available from TPWD routine monitoring collections, but that data was collected for purposes other than the development of suitability criteria for juvenile organisms within marsh habitats. Therefore, using the TPWD coastal fisheries database was not applicable for exclusive use in suitability curve development. Suitability indices for salinity were instead developed from the literature using a modified envelope approach. Enveloped suitability criteria are often used when site-specific suitability criteria are not available or inherent concerns with bias exist (Jowett et al. 1991, Dunbar and Ibbotson 2001). In the context of the MBHE study, enveloped suitability criteria for salinity were derived by superimposing a composite suitability curve over the majority of literature-based observation data and existing species-specific selection criteria, then reconciling that composite curve with recent studies and physiological results when available.

Initially, salinity ranges tolerated by each of the key species were compiled from NOAA's Estuarine Living Marine Resources (ELMR) Program information (Patillo et al. 1997). The U.S. Fish and Wildlife Service (FWS) series on Species Profiles: Life Histories and Environmental Requirements (Gulf of Mexico) was then reviewed for the same key species (Blue crab [1986], brown shrimp [1983], white shrimp [1984], Atlantic croaker [1983], and Gulf menhaden [1983]). FWS Habitat Suitability Index models are available for four of the key species (Northern Gulf of Mexico brown and white shrimp [1983], juvenile Atlantic croaker [1985], Gulf menhaden [1982]) and were reviewed in detail. Salinity selection was then refined for each of the key project species using data collected from studies conducted by the Fisheries Ecology Branch of the NMFS Galveston Laboratory (see http://galveston.ssp.nmfs.gov/research/fisheryecology/publications/). This collection of studies (previously referenced as the NMFS dataset) provided substantial information for juvenile organisms collected within shallow non-vegetated bottom and marsh habitats, however, limited samples from the immediate project area were available. Therefore, the NMFS data was again expanded to include Galveston, Lavaca, and San Antonio bays for the salinity suitability development.

The peak density zones for the key species in neighboring bays as described by the TPWD freshwater inflow recommendation studies (Lee et al. 2001, Pulich et al. 1998) were also evaluated for the suitability criteria development. Additionally, many species-specific studies relative to salinity selection have been performed as well as laboratory studies evaluating salinity effects on survival, growth, and metabolic rates of juveniles. A few examples of laboratory studies evaluated include Chazaro-Olvera and Peterson (2004) "Effects of Salinity of Growth and Molting of Sympatric Callinectes spp. from Camaronera Lagoon, Veracruz, Mexico" from the Bulletin of Marine Science and Peterson et al. (1999) "Does salinity affect somatic growth in juvenile Atlantic croaker, *Micropogonias undulatus* (Linnaeus)?" [J. Exp. Mar. Biol. Ecol.]. Evaluating components of growth and metabolic rate at various salinity levels also provides insight as to the suitability of a prescribed range. Therefore, physiological information was also incorporated into suitability curve development. A detailed list of references evaluated will be presented in the final Habitat Technical Report in 2007.

Ultimately, professional judgment was used during the reconciling phase and further input from the LSWP project team, SRP, resource agencies, and others is welcomed. However, regardless of final adjustments or modifications of the curves, suitability indices per species will be held consistent among alternatives for the project analysis thus providing a fair relative comparison. Figures 4.4 and 4.5 display the literature based suitability index for salinity for the juvenile life stage of the key project species.

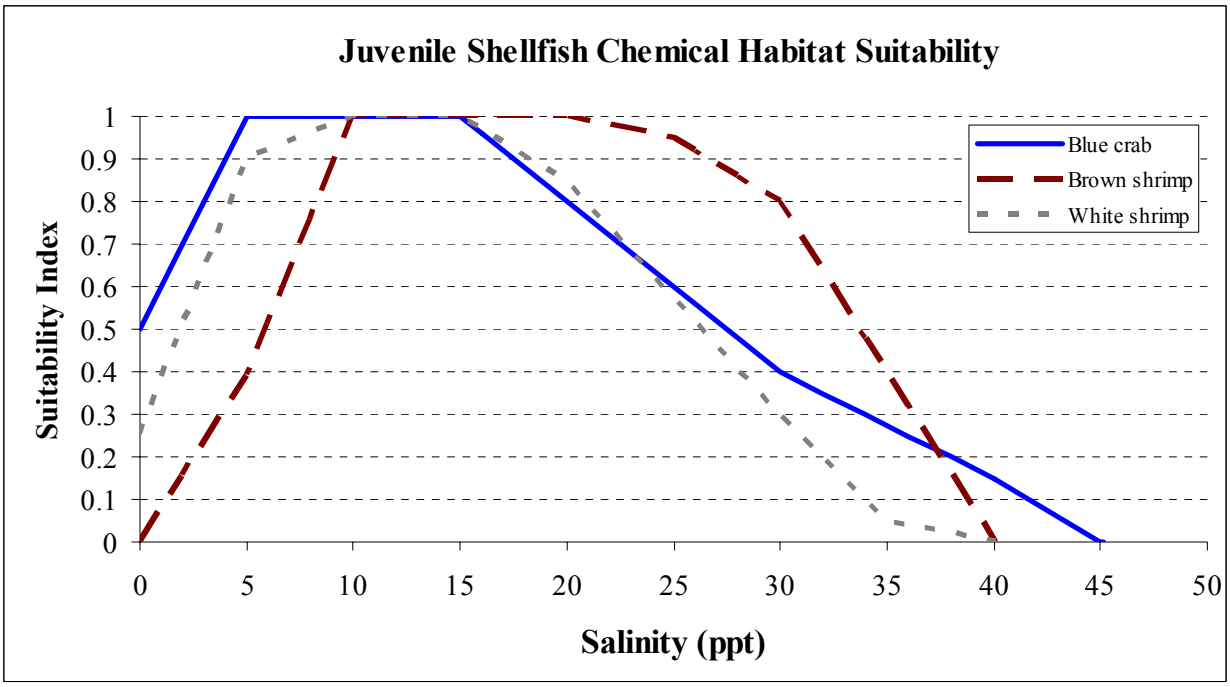

Figure 4.4 - Literature based suitability index for salinity for juvenile shellfish within the MBHE study area.

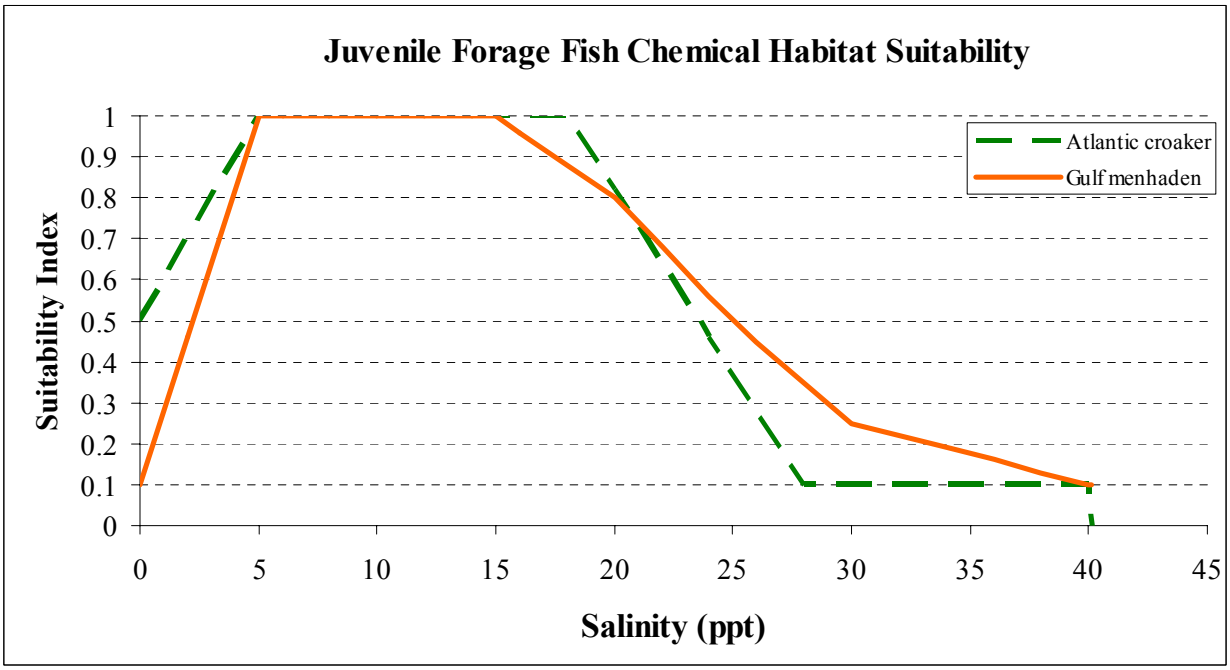

Figure 4.5 - Literature based suitability index for salinity for juvenile forage fish within the MBHE study area.

4.3.3 Marsh Productivity Relationship Development

Freshwater flow into coastal marshes brings necessary sediment to help offset submergence, provides essential nutrients to the marsh and reduces salinity levels in wetlands, allowing for enhanced growth of vegetation (DeLaune et al. 2005). The supply of plant detritus from wetlands via tidal export also provides an important potential carbon and nutrient food source to local benthic communities. Diversion of freshwater away from these marshes could result in impacts to each of these functions. As evident in coastal Louisiana, vertical marsh accretion rates have not been sufficient to keep pace with rising sea-level and subsidence, resulting in a deterioration of approximately 65.6 square kilometers per year (Dunbar et al. 1992). Therefore, an analysis of the function of the marshes themselves is warranted, and potential enhancement opportunities exist through the supplement of freshwater to coastal marshes within the Matagorda Bay project area.

The main marsh function that is analyzed in this habitat assessment is plant primary productivity. Plant productivity is measured by the amount of biomass produced, which can be significantly influenced by the amount of freshwater inflow to the system. This marsh function component assumes that there are direct relationships between both wetland plant productivity and salinity conditions, as well as between plant productivity and inundation regime. Visser et al. (2003) provides a series of algorithms for plant primary productivity based on the combined influence of salinity and inundation. These plant productivity relationships were based on extensive literature reviews, greenhouse experiments and professional judgment for marsh habitats with the same dominant plant species present in each of the LSWP delineated wetland types (i.e., freshwater marshes, intermediate marshes, brackish marshes and saline marshes). A more detailed discussion of the development of these algorithms was provided in the 2005 Habitat Assessment Progress Report (MBHE 2005b).

The initial habitat characterization task provided marsh habitat delineation based on vegetation communities with freshwater marshes and intermediate marshes mapped together as intermediate marsh, as well as with brackish and saline marshes mapped together as estuarine marsh. However, high and low marsh habitats (indicative of inundation frequency) for both intermediate and estuarine marshes were mapped separately. Low intermediate marshes (LIM) in the project area are generally seasonally flooded for a period of time, while low estuarine marshes (LEM) are regularly flooded by diurnal tides. High intermediate marshes (HIM) are infrequently seasonally flooded, while high estuarine marshes (HEM) are infrequently flooded by high tides and storm events. We utilized the algorithm for intermediate marsh production (Table 4.2) to determine productivity for HIM (based on 10% inundation frequency) and LIM (based on 50% inundation frequency). The algorithm for saline marsh production (Table 4.3) was utilized to determine productivity in HEM (based on 10% inundation frequency) and LEM (based on 50% inundation frequency) habitats. These four relationships for marsh productivity based on salinity and inundation are shown in Figure 4.6.

It is evident in the literature that large inter-annual and intra-annual changes in plant primary productivity can occur. Therefore, the project team is evaluating the annual plant primary productivity by habitat type and season. The project team is proposing to use marsh function as an independent output from the habitat model. As with the drop-trap sampling validation, marsh productivity data were gathered during the 2006 MBHE limited field effort to assist in project site-specific analysis. One drawback to the marsh function analysis overall is that a large portion of freshwater marshes are located behind water control structures, and are

therefore only included in a limited fashion in the salinity model and subsequently in the habitat model.

Table 4.2 - Intermediate marsh production at varying levels of inundation and average annual salinity, expressed as a percentage of the maximum potential production.

Intermediate Marsh Production

Percentage of Maximum

	Salinity (ppt)								
Inundation	**0**	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**
0	70	70	57.2	50.4	43.8	37	30.2	25.6	24.4
10	80	80	65.4	57.6	50	42.2	34.5	29.3	27.9
20	90	90	73.5	64.8	56.3	47.5	38.8	32.9	31.4
30	95	95	77.6	68.4	59.4	50.2	40.9	34.8	33.2
40	100	100	81.7	72	62.5	52.8	43.1	36.6	34.9
50	100	100	81.7	72	62.5	52.8	43.1	36.6	34.9
60	100	100	81.7	72	62.5	52.8	43.1	36.6	34.9
70	95	95	77.6	68.4	59.4	50.2	40.9	34.8	33.2
80	90	90	73.5	64.8	56.3	47.5	38.8	32.9	31.4
90	80	80	65.4	57.6	50	42.2	34.5	29.3	27.9
100	70	70	57.2	50.4	43.8	37	30.2	25.6	24.4

Table 4.3 - Saline marsh production at varying levels of inundation and average annual salinity, expressed as a percentage of the maximum potential production.

Saline Marsh Production

Percentage of Maximum

	Salinity (ppt)								
Inundation	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
0	40	40	40	34.9	31.2	27.5	23.9	20.1	16.5
10	60	60	60	52.4	46.9	41.3	35.8	30.2	24.7
20	80	80	80	69.8	62.5	55	47.8	40.2	33
30	90	90	90	78.6	70.3	61.9	53.7	45.3	37.1
40	95	95	95	82.9	74.2	65.4	56.7	47.8	39.1
50	100	100	100	87.3	78.1	68.8	59.7	50.3	41.2
60	95	95	95	82.9	74.2	65.4	56.7	47.8	39.1
70	85	85	85	74.2	66.4	58.5	50.7	42.8	35
80	72	72	72	62.9	56.2	49.5	43	36.2	29.7
90	60	60	60	52.4	46.9	41.3	35.8	30.2	24.7
100	30	30	30	26.2	23.4	20.6	17.9	15.1	12.4

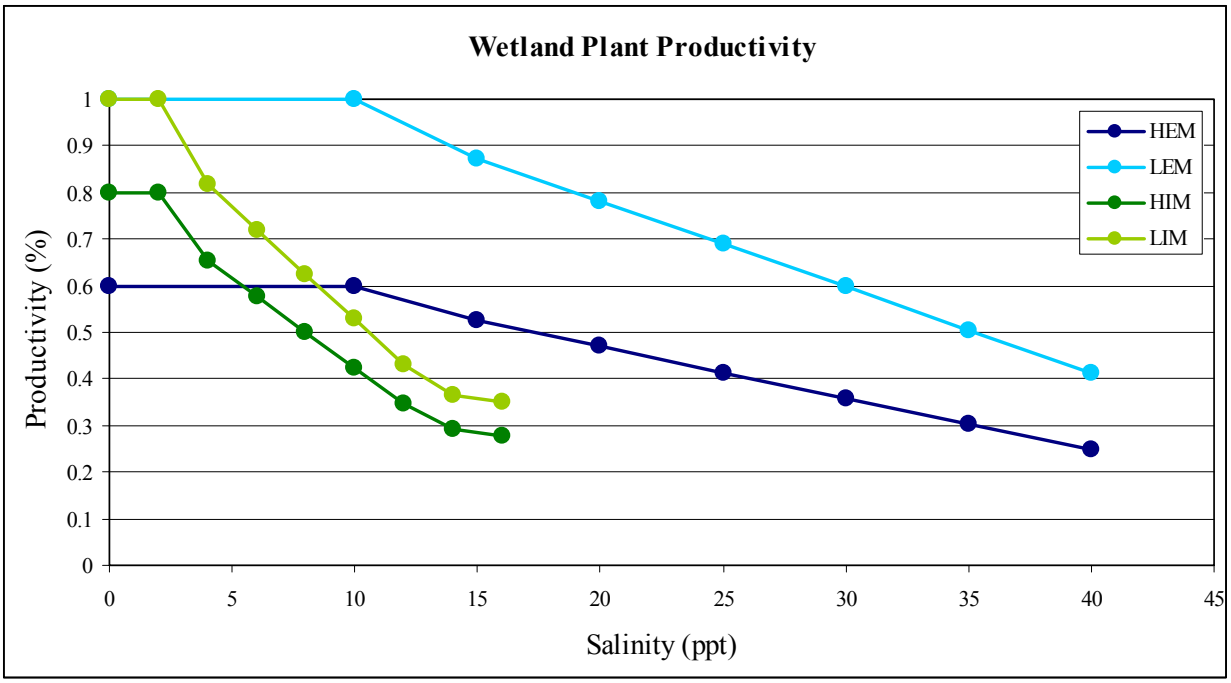

Figure 4.6 - Wetland plant productivity (expressed as the percent of maximum potential production) at a range of salinity conditions. HEM and HIM are based on 10% inundation frequency. LEM and LIM are based on 50% inundation frequency.

4.3.4 Habitat Model Concerns

During the resource agency habitat workshop conducted in March 2006, three major concerns were expressed relative to the habitat modeling approach. A universal concern was the inclusion of data from other Texas bays in the development of physical habitat suitability criteria. A second item was the lack of marsh productivity data within the immediate project area, the concern being that there would be no way to evaluate whether the proposed marsh-salinity literature based relationships are appropriate and applicable to marsh vegetation in Matagorda Bay. Finally, there was considerable concern regarding the inclusion of a habitat switching component within the physical habitat component of the model.

To address the first two concerns, a detailed, yet limited field investigation was designed and implemented, as described in Section 5 of this report. Upon detailed discussions with the SRP, there was a consensus that currently, data limitations prohibit the use of a habitat switching component in the habitat model, and thus that component was removed from the analysis.

5.0 2006 HABITAT FIELDWORK

The overall intent of the seasonal field sampling effort was to collect habitat utilization, wetland plant productivity and wetland soil and water quality data from within the project area during periods when each of the key organisms were abundant in the bay. The ultimate goal was to validate the literature based relationships developed for the key species and plants used in the habitat model. Specific objectives of this study were to:

- quantify fish and invertebrate species abundance and community composition within shallow habitats in the Matagorda Bay study area in relation to physical habitat and salinity,
- correlate species abundance in relation to physical habitat and salinity found in Matagorda Bay with drop-trap data collected in other Texas bays,
- evaluate potential correlations of abundance within distinct habitats with simultaneous TPWD bag seine efforts in the project area, and
- support the evaluation of the role of salinity and inundation relative to marsh community dynamics within the project area.

The biological collection effort focused on the key MBHE project species (not including the Eastern oyster) within shallow water habitats. Key project species expected to be sampled included the brown shrimp, white shrimp, blue crab, Gulf menhaden, spotted seatrout, Atlantic croaker, and red drum. The concurrent marsh plant productivity sampling effort focused on low and high estuarine marsh, and evaluated seasonal aboveground plant biomass and stem density measurements for wetland plant species common throughout the project area.

5.1 Methods

Three one-week sampling efforts were conducted during the vegetative growing season in April, August and October 2006. Shallow water and marsh areas along five transects were sampled within the project area (Figure 5.1). Two transects were located within The Nature Conservancy's Mad Island Marsh Preserve (MIMP) and extended 100-200m across SNB, LEM edge and HEM interior habitats. Three transects were located within the new Colorado River delta (NCRD) area and extended 100-200m across SNB, LEM edge and LEM interior habitats. The vegetation within low estuarine marsh edge sites at all MIMP and NCRD transects is comprised of monotypic stands of smooth cordgrass. However, the interior marsh communities within MIMP and NCRD sites differ in species composition, and are therefore classified differently as high estuarine marsh (HEM) and low estuarine marsh (LEM) respectively. Each transect was surveyed once during the fieldwork effort to provide elevation information for each of the sampling sites across the marsh from open water to marsh interior (Figure 5.2). These transect sites were representative of the variability in salinity, elevation and vegetation types typically found in each of the two regions.

By nature, tidal wetland systems are periodically inundated and those within Matagorda Bay have a typical tidal range of 1.3 feet. Sampling events were conducted during daylight hours, and were designed to occur within three hours of local high-tide on each day of the sampling event in order to sample habitats while they were equally available to all organisms (in terms of water depth) and to maintain consistency between sampling events. Sites were sampled April 24-May 3, August 7-9, and October 17-19 in 2006.

Figure 5.1 - Locations of the transects sampled within Mad Island Marsh Preserve (MIMP) and the new Colorado River delta (NCRD) region.

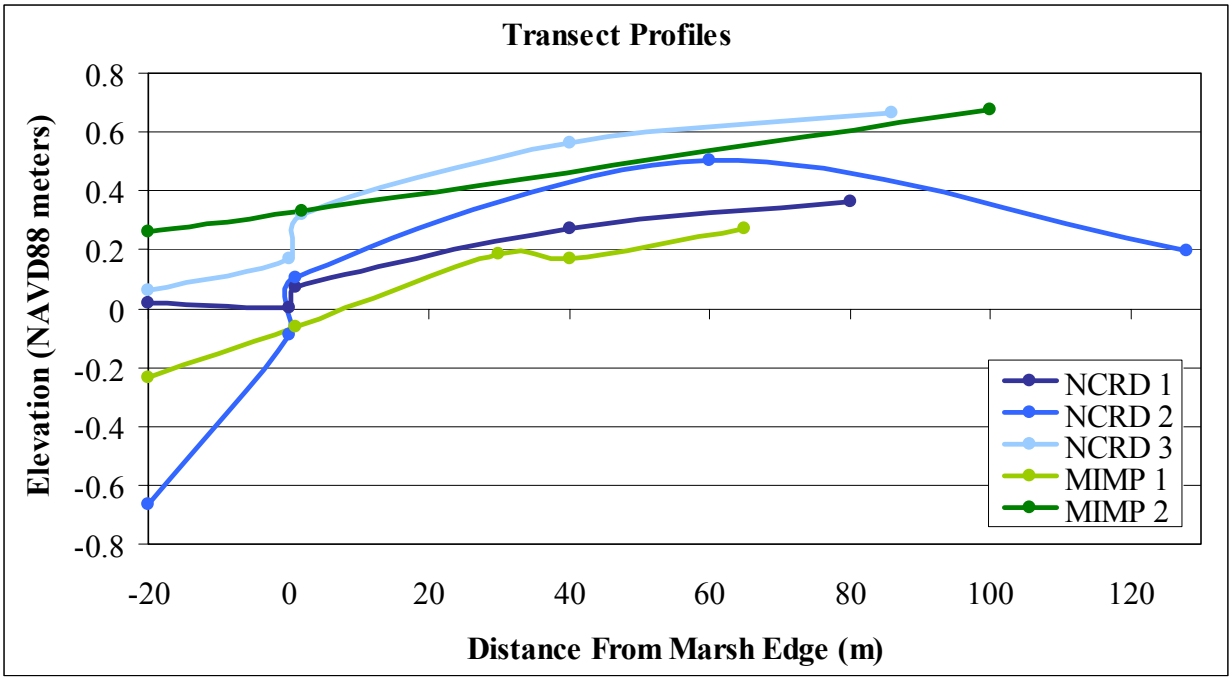

Figure 5.2 - Profiles of the five transects sampled within the new Colorado River delta (NCRD) region and the Mad Island Marsh Preserve (MIMP). Transects extend from shallow non-vegetated bottom habitat (-20m from marsh edge) to the interior of the marsh (>60m from marsh edge).

5.1.1 Throw Drop Trap Sampling

Previously, the NMFS has employed a drop trap sampling method to measure animal densities on marsh surfaces and in adjacent subtidal habitat. This method is described in Zimmerman et al. (1990) and involves dropping a large cylindrical sampler (1.8m diameter) from a boom on a skiff to entrap organisms in a 2.6m^2 area. Fauna are collected with dip nets as water is pumped out of the sampler through a 1mm square mesh plankton net. After the sampler is drained, any remaining animals are collected by hand. Organisms are preserved and transported to a laboratory for identification. This technique requires a substantial effort both in the field and subsequently in the laboratory to process the samples. During scope development, the project team had several discussions with Dr. Greg Stunz (SRP member) who participated in many of the original NMFS drop trap sampling efforts. In his current research, Dr. Stunz uses a modified throw drop trap for sample collection in shallow water habitats. In his research, Dr. Stunz has found that results from this modified methodology are directly comparable to the original NMFS drop trap technique; hence, a modified throw drop trap was employed in the MBHE field effort.

The modified throw drop trap sampler consists of a 1m x 1m x 1.5m aluminum frame with 1mm square mesh on all four side panels (Figure 5.3). The bottom of the sampler has a thin, six inch metal edge along all four sides that cuts into the sediment, holds the sampler steady, and prevents fauna from escaping the enclosure at the sediment surface. The throw drop trap is lighter and more maneuverable than the NMFS drop trap, and is therefore able to be thrown

into sampling habitats rather than being lowered from a boom. Fauna are collected with a 0.9m^2 dip net that is swept along the sediment surface from one end of the throw drop trap to the other. A total of ten sweeps were conducted within each throw drop trap sample, unless an organism was caught in the dip net on the tenth sweep. Then an additional three sweeps were conducted, until no organisms were caught on the last sweep.

Figure 5.3 - The 1m^2 throw drop trap sampler modified design utilized in the 2006 LSWP field study.

During each sampling event, five replicate 1m^2 throw drop trap samples were collected in SNB habitat and in vegetated marsh edge ME habitat at each of the five transects (Figure 5.1). Each transect began in the SNB habitat approximately 20m away from edge habitat and ended within the interior marsh community (Figure 5.4). Due to the less frequent flooding to the required depth of inundation (10cm), throw drop trap sampling was only conducted at the interior marsh sites in October. Fauna were collected in 100mL HDPE bottles and preserved in 10% formalin solution. Samples were transported back to the laboratory, identified to species and the first 25 individuals of each species per sample were measured to the nearest millimeter. Shrimp were measured from the tip of the rostrum to the end of the telson (total length), and carapace width was measured for crabs. Any organisms larger than the bottle were identified,

measured and released in the field. Additionally, information on the wetland vegetation cover present in the throw drop trap samples was collected at marsh edge and marsh interior habitats (Section 5.1.3).

Figure 5.4 - Throw drop trap sampling locations from upper left to lower right (marsh edge, shallow non-vegetated bottom, marsh interior, marsh edge close-up).

5.1.2 TPWD Concurrent Bag Seine Sampling

During study design, the project team coordinated with Mr. Bill Balboa (TPWD Matagorda Bay Ecosystem Team Leader – Palacios, Texas) who agreed to conduct concurrent TPWD bag seine collections in the open water areas adjacent to our sampling transects. Therefore, during each of the sampling trips, TPWD biologists were able to pull bag seines according to their specific guidelines adjacent to our throw drop trap sampling locations (Figure 5.5). The project team greatly appreciates TPWD's assistance in this preliminary comparison of gear types in areas typically not sampled in the routine TPWD coastal fisheries monitoring program.

Figure 5.5 - TPWD bag seine haul adjacent to New Colorado River Delta transect.

5.1.3 Vegetation, Water and Soil Quality

Vegetation, soil and water quality at each of the five transects were sampled simultaneously with the throw drop trap sampling. Surface water quality parameters including temperature, pH, salinity, conductivity, dissolved oxygen (DO) and percent saturation of DO were measured at all sites, excluding the MIMP interior sites in April and August, using a handheld YSI 6920 probe, provided water depth was at least 10cm. Porewater was sampled at all sites at a depth of 4-6cm using a modified extraction method from Winger and Lasier (1991). Salinity of the porewater was measured using a handheld refractometer. Soil quality parameters including temperature, pH and redox potential were measured at a depth of 4cm at all sites using a handheld Oakton pH 11 meter. One 250mL surface water grab sample was collected at each site, excluding the MIMP interior sites, for dissolved organic carbon (DOC) analysis. Water samples were transported to the laboratory, refrigerated at 34°F for two weeks and analyzed for TOC content by high temperature catalytic oxidation (HTCO) and infrared detection using a Shimadzu TOC-5000. Carbon concentrations were determined against potassium hydrogen phthalate standards. Samples were measured in triplicate with a fixed c.v. of 2%; otherwise, further replicates were automatically carried out by the instrument.

Duplicate vegetation plots (0.25 m^2) were randomly selected in the ME and MI marsh plant communities and all standing plant material within each plot was clipped at ground level and placed in plastic bags. Live and dead plants were separated, and live plants were further separated by species and counted. All harvested plant material was oven dried at 60°C to constant weight. Aboveground biomass was determined for live plant species individually and dead plants overall. Within each plot, one 10cm deep soil core was collected. Soil cores were placed in individual plastic bags, temporarily stored on ice and refrigerated at 34°F for one week before analysis. Each soil core was homogenized and 15mL volume of soil was dried at

60°C for 72 hours, weighed and combusted at 500°C for 4 hours to determine ash-free dry mass (AFDM). AFDM was determined on these cores as a proxy for soil organic content (SOC).

Since changes in vegetation composition may occur from year to year in marsh habitats (Visser et al. 2003), the project team also investigated potential change in plant species composition at each transect. A single vegetation monitoring plot (1.0 m^2) was set within each ME and MI community along the five transects during the first sampling event in April (10 monitoring plots total). Vegetation within each plot was identified by species and stem densities of each species were recorded. The vegetation within these monitoring plots was assessed again during the August and October sampling events to address plant community change over the 2006 growing season.

5.2 Results

5.2.1 Throw Drop Trap Sampling

A total of 175 throw drop trap samples and 7,404 individuals made up of 33 species of fish and invertebrates were collected during 2006 fieldwork (Table 5.1). Of these, 75 throw drop trap samples were collected in SNB habitat, 75 in edge marsh habitat, and 25 in interior marsh habitat. This fieldwork effort provided valuable information on the use of SNB and LEM edge habitat by key project species. The throw drop trap was effective in sampling both SNB and LEM edge habitats, but proved somewhat less effective in more densely vegetated marsh interior sites. Sampling in interior marsh sites was modestly ineffective primarily because of the inability to run the sampling net flush against the substrate due to vegetation clumps.

Table 5.1 is divided by the key project species and other aquatic species caught during the sampling, the sample date, habitat type sampled in, and total number (average size of first 25 individuals measured). Overall, six of the original seven key species were collected during the 2006 sampling effort. Red drum was the only key species that was not collected, and spotted seatrout and Atlantic croaker were only collected in limited numbers. The timing of the 2006 sampling events is likely the reason no red drum were collected. However, very few red drum are present in the NMFS data set which consists of multiple collections over different seasons. As previously noted, due to limited NMFS data for red drum and spotted seatrout in marsh areas, and corresponding 2006 field sampling results, these two species were eliminated from consideration in the habitat model.

Four (blue crab, brown shrimp, white shrimp, and Gulf menhaden) of the remaining five key species were routinely collected depending on season. For this reason, an evaluation of when the key species were collected and the relative level of abundance during the three sampling trips was conducted to compare to the TPWD bag seine abundance data for Matagorda Bay (Table 4.1). Table 5.2 shows the comparison between the TPWD data (habitat model proposed input) and the LSWP 2006 sampling effort. Each of the five remaining key species were collected in the greatest abundance in accordance with the TPWD bag seine data for Matagorda Bay. Although anticipated, it was a good confirmation of the project site-specific data from these marsh areas.

Overall more organisms were collected in low estuarine marsh (LEM) than shallow non-vegetated bottom (SNB), but this varied among individual species. For instance, the shellfish (blue crab, brown shrimp, and white shrimp) were all collected in much greater numbers in LEM than the adjacent SNB. The inverse was true for Gulf menhanden and Atlantic croaker (although only 4 individual croaker were collected). The large numbers of shellfish collected in LEM during their abundant seasons was impressive and confirms the importance of this physical habitat type to juvenile shellfish species in Matagorda Bay. A comparison of the abundance of key species in LEM edge and SNB habitats was made between data collected during the LSWP fieldwork and the NMFS combined dataset (see Section 5.3.1).

In writing a scientific publication, a great deal more interpretation from Table 5.1 could be conducted and reported, but for the purpose of this progress report, the important points from the LSWP 2006 sampling effort are as follows:

- the throw drop trap was an effective method of data collection in shallow water habitats in the project area (33 species, 7,404 individuals collected),
- key species collected confirmed the time in bay assumption proposed for use in the habitat model (Table 5.2),
- importance of project area marsh habitat to juvenile shellfish was supported (Table 5.1),
- physical habitat suitability criteria developed using NMFS combined dataset was supported by project specific data for key species (Section 5.3.1).

Finally, although too few comparative samples have been collected to make meaningful comparisons of TPWD bag seine data to throw drop trap data in similar and adjacent habitats, the foundation for this comparison has been established by this effort. Continued coordination with TPWD will be conducted in 2007 as additional throw drop trap data collection is performed.

Table 5.1 - Species list of organisms sampled with the throw drop trap in shallow non-vegetated bay bottom (SNB), low estuarine marsh edge (Edge) and high intermediate/estuarine interior marsh (Interior) habitats during each sampling period in 2006. Data presented as total number (average size of first 20 individuals measured).

Organism	April		August		October		
	SNB	Edge	SNB	Edge	SNB	Edge	Interior
Key species							
Atlantic croaker (*Micropogonias undulatus*)	4 (66.3)	-	-	-	-	-	-
Blue crab (*Callinectes sapidus*)	13 (16.8)	132 (19.7)	5 (7)	40 (14.8)	32 (10.2)	83 (11.2)	18 (11.3)
Brown shrimp (*Farfantepenaeus aztecus*)	199 (35.6)	562 (38)	4 (15)	12 (39.9)	19 (45.9)	52 (37.2)	1 (53)
Gulf menhaden (*Brevoortia patronus*)	106 (26.6)	7 (24.4)	1 (40)	-	-	-	-
Red drum (*Sciaenops ocellatus*)	-	-	-	-	-	-	-
Spotted sea trout (*Cynoscion nebulosus*)	-	-	1 (28)	1 (45)	2 (51.5)	1 (80)	1 (70)
White shrimp (*Litopenaeus setiferus*)	-	-	23 (35.9)	550 (47.3)	39 (35.1)	68 (30.5)	-
Additional species							
Bay anchovy (*Anchoa mitchilli*)	24 (21.3)	19 (22.2)	10 (24.8)	1 (21)	17 (23.3)	-	-
Bay whiff (*Citharichthys spilopterus*)	2 (36)	1 (65)	-	-	1 (15)	-	-
Bayou killifish (*Fundulus pulvereus*)	-	-	11 (26.5)	7 (25.7)	-	1 (17)	6 (31)
Clown goby (*Microgobius gulosus*)	-	-	6 (36.7)	2 (42)	2 (44)	-	-
Code goby (*Gobiosoma robustum*)	-	-	3 (22.3)	-	-	-	-
Darter goby (*Gobionellus boleosoma*)	9 (35.1)	36 (31)	11 (31)	22 (28)	21 (23.5)	28 (26.9)	1 (21)
Fat sleeper (*Dormitator maculatus*)	-	-	1 (55)	4 (47.5)	-	-	1 (61)
Fiddler crab (*Uca rapax*)	-	6 (8.83)	-	-	-	1 (20)	4 (21.8)
Flagfin mojarra (*Eucinostomus melanopterus)*	-	-	-	-	2 (43.5)	1 (15)	1 (22)
Grass shrimp (*Palaemontes vulgaris*)	96 (27.6)	2119 (31.1)	20	1276	26	744	62
Green goby (*Microgobius thalassinus*)	-	-	-	-	7 (27.4)	1 (27)	-
Gulf killifish (*Fundulus grandis*)	1 (48)	18 (34.7)	2 (32.5)	39 (36.4)	1 (14)	2 (31.5)	27 (22.3)
Gulf pipefish (*Syngnathus scovelli*)	-	-	-	-	2 (36)	-	-
Inland silverside (*Menidia beryllina*)	43 (28.4)	37 (26.2)	1 (33)	19 (39.6)	2 (60.5)	1 (25)	-
Inshore lizardfish (*Synodus foetens*)	1 (54)	5 (25.8)	-	-	-	-	-
Ladyfish (*Elops saurus*)	4 (27.8)	14 (30.1)	-	-	-	-	-
Lined sole (*Achirus lineatus*)	-	-	2 (25)	4 (24.5)	-	1 (38)	-
Mosquitofish (*Gambusia affinis*)	-	-	47 (19.7)	8 (23.5)	1 (10)	-	2 (10)
Naked goby (*Gobiosoma bosc*)	-	-	-	-	8 (23.9)	11 (28.1)	-
Pinfish (*Lagodon rhomboides*)	5 (29.6)	29 (29)	-	1 (78)	-	-	-
Rainwater killifish (*Lucania parva*)	-	3 (38)	21 (22.1)	9 (21.4)	11 (15.4)	11 (19.5)	8 (19.1)
Sailfin molly (*Peocilia latipinna*)	-	-	2 (26.5)	56 (35.4)	1 (12)	1 (18)	51 (26.1)
Sheepshead minnow (*Cyprinodon variegatus*)	-	-	55 (17.2)	110 (28.2)	1 (12)	6 (17.3)	49 (33.6)
Silver perch, silver croaker (*Bairdiella chrysoura*)	-	-	-	23 (32.8)	-	-	-
Speckled worm eel (*Myrophis punctatus*)	-	-	-	1 (135)	1 (240)	2 (134)	-
Spot croaker (*Leiostomus xanthurus*)	3 (43.7)	5 (43.6)	-	-	-	-	-
Striped mullet (*Mugil cephalus*)	-	28 (67.8)	-	15 (92.3)	-	4 (173)	-

Table 5.2 - Comparison of time period for which each key species is most abundant in Matagorda Bay

Species	TPWD Coastal Fisheries Database	LSWP 2006 Fieldwork
	Bag Seine	**Throw Drop Trap** Month collected (Percentage of maximum catch*)
Blue crab	February-June, October-November	April (100%), August (31%), October (79%)
Brown shrimp	April-July	April (100%), August (2%), October (9%)
White shrimp	July-November	August (100%), October (19%)
Atlantic croaker	January-June	April (100%)
Gulf menhaden	April-August	April (100%), August (<1%)

* Data included from LEM edge and SNB habitats only.

5.2.2 Water Quality, Soils and Vegetation

Most of the Texas coast has a subtropical humid climate, including Matagorda Bay. Typical of Texas weather, rainfall conditions during the 2006 sampling period were highly variable. The April 2006 sampling event was conducted during a relatively dry period for both the lower Colorado River watershed and localized Matagorda Bay watershed. Although the lower Colorado River watershed remained in extremely dry conditions in August, the localized Matagorda Bay watershed received multiple large rainfall events in late July and early August. The October sampling was conducted under continued extreme dry conditions in the lower Colorado River watershed and continued wetter than average conditions for the localized Matagorda Bay watershed.

Water quality conditions were recorded at all throw drop trap sample locations and are presented in Table 5.3. During the sampling events, water temperatures at sampling sites ranged from 26.49-32.46°C in April, 25.2-38.3°C in August, and 23.9-31.6° in October. Salinities at sampling sites ranged from 16.0-28.0ppt in April, 2.6-9.0ppt in August, and 3.6-17.0ppt in October. These salinity concentrations correspond directly with the weather patterns discussed above. In April 2006, salinity concentrations were already approaching the mid-20s (ppt) due to the dry conditions. At that point, concerns regarding extremely high salinity concentrations for the upcoming summer were a reality. However, salinity concentrations were alleviated in late summer by the localized heavy rainfall events, and nearly freshwater conditions were experienced in both the marsh and delta areas during the August sampling. Continued localized rainfall again shaped fresher than average conditions during October.

Average temperature, pH, salinity and conductivity conditions varied more between seasons in the MIMP sites, while average dissolved oxygen (DO) conditions varied more between seasons in the NCRD sites. In fact, the lowest DO levels during the study (1.14-2.49 mg/l) were recorded in October at the site closest to the mainland in the new Colorado River diversion delta (NCRD 3). The extremely low DO concentrations recorded at NCRD 3 were likely a result of recent rainfall events, subsequent organic matter input, and poor circulation. Fish kills were observed in the immediate area and were reported to TPWD biologists. During the same trip, dissolved oxygen conditions at the NCRD 1 and 2 sites (both closer to the delta mouth) were

fine and no unusual fish behavior was observed. Results from the DOC analysis are not yet available, but will be provided in the technical report to be completed in 2007.

Soil conditions were measured within all SNB, marsh edge and interior marsh habitats and are presented in Table 5.4. During the study period, soil temperatures ranged from 26.2-30.6°C in April, 27.4-36.4°C in August, and 25.7-27.7°C in October. As expected, soil temperatures were generally lower than the inundating water column and were overall less variable than water temperatures (not shown). Soil pH values were generally neutral and were consistently lower than those of the inundating water column, ranging from 6.4-7.97 throughout the study period. The redox potential values of the soils were more negative (reduced) in habitats with sustained standing water. The bulk density and organic matter content of the soils at each site were determined from soil cores taken during each sampling event. Organic content of the soils increased from shallow non-vegetated habitat to edge and interior marsh habitats, with interior marsh site soils containing up to 3 times as much organic matter as the non-vegetated sites. Soils in the SNB and edge habitats in NCRD sites contained slightly more organic matter than the same habitats in MIMP sites. This may be due to more organic matter production at the NCRD edge sites, or differing organic matter accretion rates in the soils of the two marsh complexes.

As expected, a porewater salinity gradient was evident along MIMP transects, as well as a slight gradient along NCRD transects (Table 5.4). However, there was a large difference in porewater salinities between the more isolated marsh (MIMP) and the delta (NCRD), with the MIMP transects being more highly stratified. This is an important point, in that during extended drought conditions, the marsh vegetation in these more isolated areas north of the Gulf Intracoastal Waterway (GIWW) will likely experience elevated porewater salinity concentrations. The resulting effect will be shifts in vegetative community composition and varying levels of vegetation productivity reduction depending on the species of vegetation.

The vegetation communities sampled during the fieldwork effort were representative of their respective mapped marsh community types (see Section 4.1). The vegetation communities at all marsh edge sites were classified as LEM in the habitat delineation and at the study sites they were comprised of monotypic stands of smooth cordgrass. Interior marsh sites at MIMP are classified as HEM in the habitat delineation and the sampled vegetation communities were comprised of saltwort, sea ox-eye daisy, saltgrass, marsh-elder, salt flat grass, glasswort, and seepweed. Dominant plant species in the interior HEM sampling plots were sea ox-eye daisy, saltgrass, and salt flat grass. Interior marsh sites at NCRD are classified as LEM in the habitat delineation and the sampled vegetation communities were comprised of sea ox-eye daisy, marsh-elder, glasswort, sturdy bulrush, smooth cordgrass, and perennial saltmarsh aster. Dominant plant species in the interior LEM sampling plots were smooth cordgrass, glasswort, and perennial saltmarsh aster.

Productivity measurements of standing live and dead aboveground biomass were sampled seasonally from April to October at all edge and interior marsh sampling sites (Figures 5.6 and 5.7). At the beginning of the growing season (April), live biomass was lowest at the edge marsh sites and highest at the interior HEM marsh sites. Live biomass at both edge and interior LEM increased between the April and August samplings, while interior HEM live biomass remained constant. Some interior HEM sites showed an increase in live biomass during October, while several showed a decrease. A series of photographs from monitoring plots at one interior HEM site and one interior LEM site illustrate some of the changes in vegetation biomass at the

interior marsh sites over the course of the study period (Figure 5.8). Another series of photographs from monitoring plots at the edge marsh sites (both LEM) illustrate the beginning of the growing season, the peak live biomass measured in August and the decline in live biomass sampled in October (Figure 5.9).

Table 5.3 - Seasonal average water quality conditions in shallow water habitats within Mad Island Marsh Preserve and the new Colorado River delta during 2006. Single dash indicates missing values.

Season	Temperature (°C)	pH	Salinity (ppt)	Conductivity (mS)	D.O. (mg/l)	D.O. Saturation (%)
Mad Island Marsh Preserve						
April	28.7	8.02	23.0	36.5	4.89	67.6
August	33.1	8.67	3.4	5.9	5.98	87.2
October	28.7	7.39	6.8	11.9	5.01	67.7
New Colorado River Delta						
April	29.5	8.33	21.0	29.3	7.83	105.4
August	29.6	8.00	7.4	-	5.70	75.7
October	26.4	7.56	7.8	13.47	3.80*	48.53

* Dissolved oxygen values ranged from 1.14-2.49 mg/l at site NCRD 3.

Table 5.4 - Average soil quality conditions at shallow non-vegetated bay bottom (SNB), low estuarine marsh (LEM) edge, LEM interior, and high estuarine marsh (HEM) interior sampling locations within Mad Island Marsh Preserve and the new Colorado River delta during 2006.

Site	Temperature (°C)	pH	Redox (mV)	Bulk Density (g/mL)	Organic Content (g/mL)	Organic Content (%)	Porewater Salinity (ppt)
Mad Island Marsh Preserve							
SNB	28.85	7.31	-31.93	1.21	0.02	1.90	9 ± 3.2
LEM Edge	28.48	7.10	-19.37	1.02	0.03	2.77	13 ± 2.9
HEM Interior	29.98	7.06	-16.83	1.22	0.07	6.05	22 ± 5.9
New Colorado River Delta							
SNB	27.89	7.30	-32.29	1.19	0.03	2.87	14 ± 6.9
LEM Edge	28.08	7.04	-16.78	1.03	0.04	3.77	14 ± 7.1
LEM Interior	27.90	7.06	-13.01	1.06	0.05	5.18	14 ± 8.3

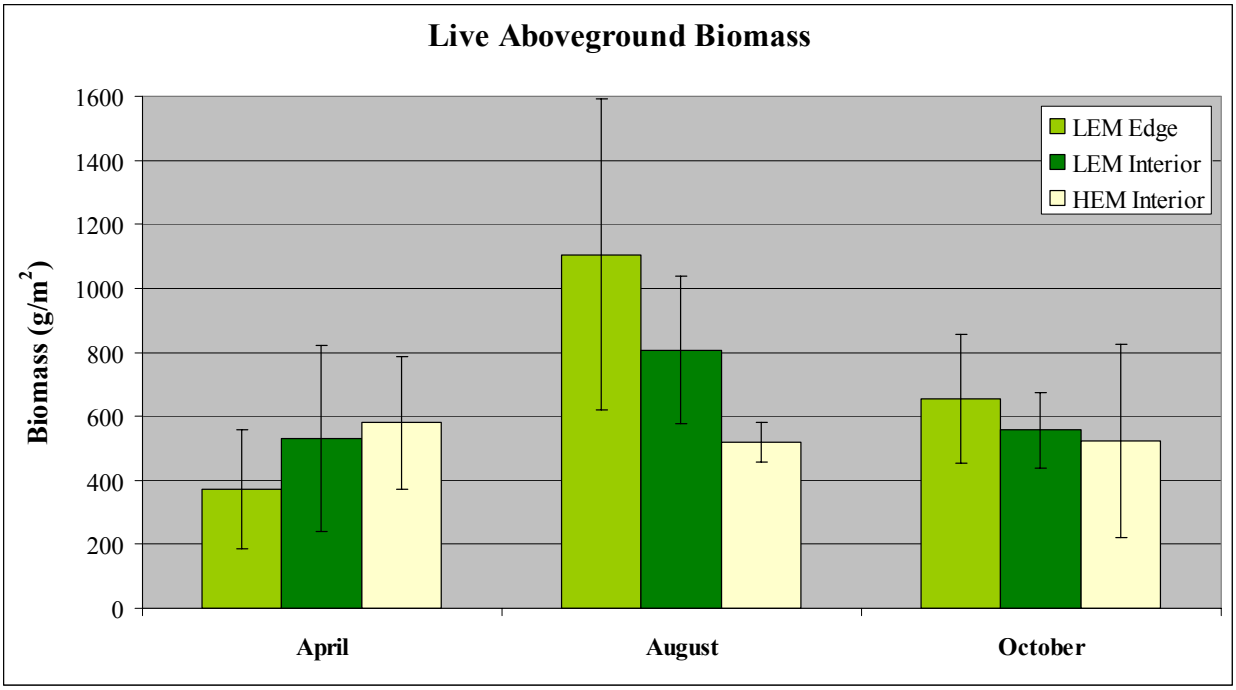

Figure 5.6 - Seasonal live aboveground biomass measurements (g/m² ± standard deviation) within low estuarine marsh edge (LEM Edge), low estuarine marsh interior (LEM Interior), and high estuarine marsh interior (HEM Interior) habitats.

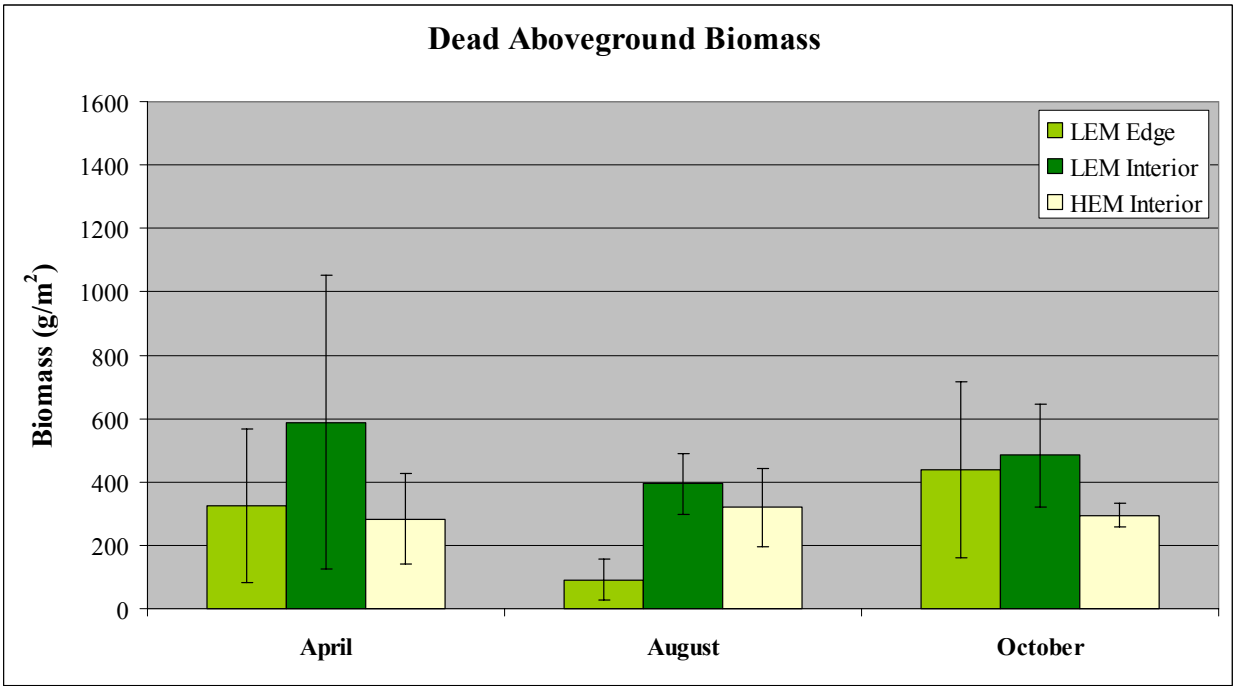

Figure 5.7 - Seasonal dead aboveground biomass measurements (g/m² ± standard deviation) within low estuarine marsh edge (LEM Edge), low estuarine marsh interior (LEM Interior), and high estuarine marsh interior (HEM Interior) habitats.

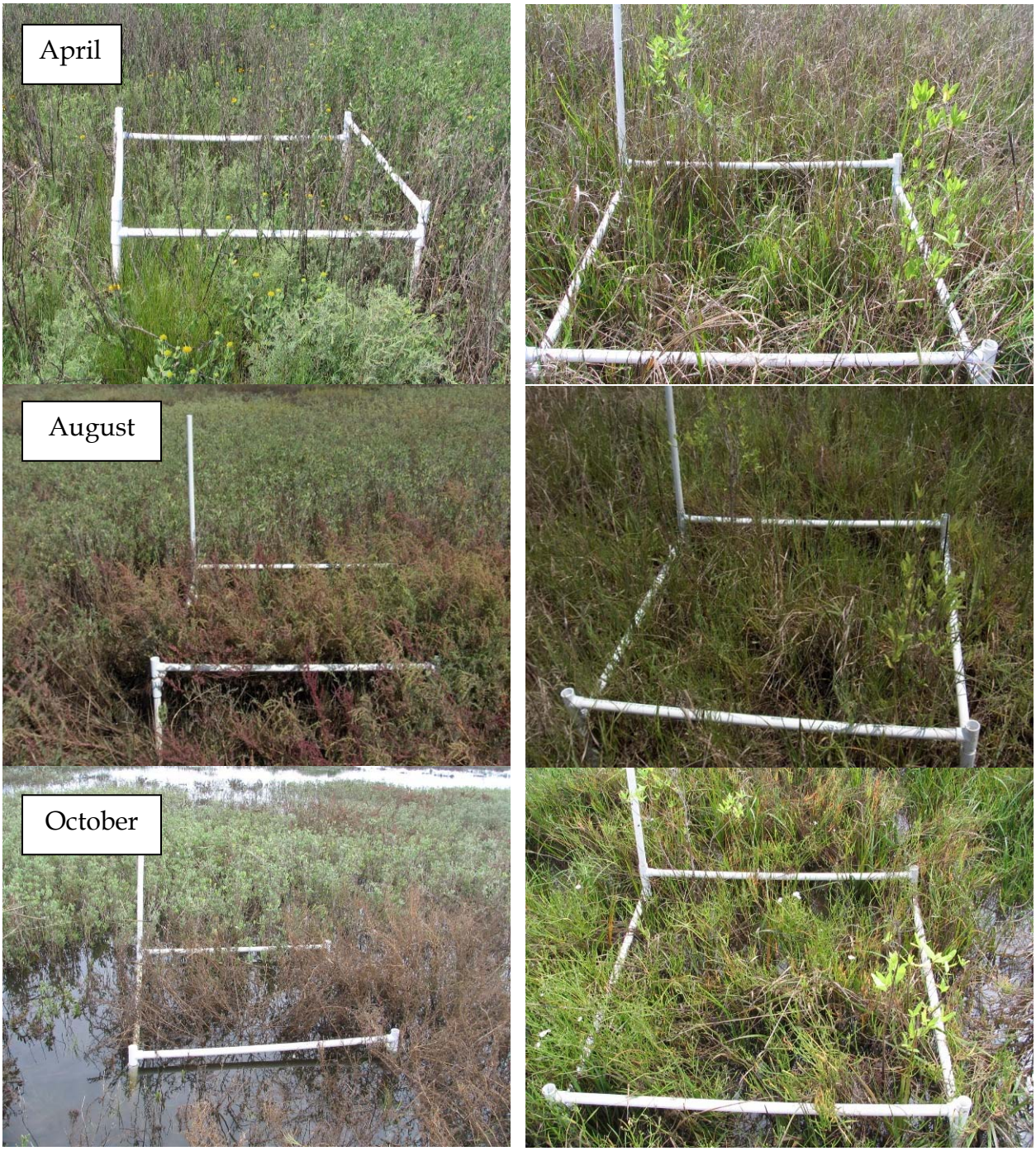

Figure 5.8 - Seasonal photographs of the one of the interior HEM monitoring plots (MIMP 1; left) and one of the interior LEM monitoring plots (NCRD 2; right) taken in April, August, and October, 2006.

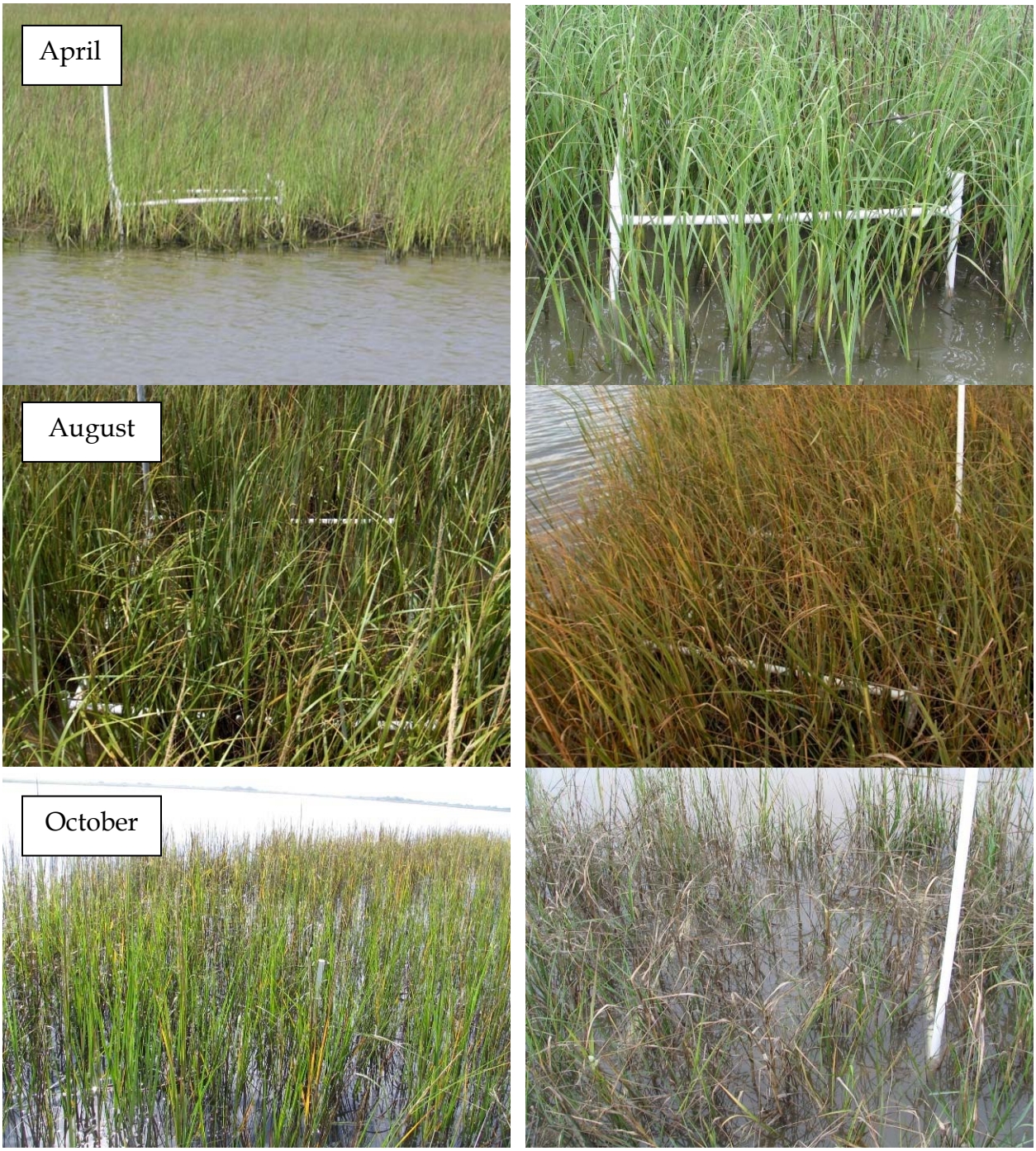

Figure 5.9 - Seasonal photographs of edge LEM monitoring plots in Mad Island Marsh Preserve (left) and edge LEM monitoring plots in the new Colorado River delta (right) taken in April, August, and October, 2006.

5.3 Comparison of LSWP Fieldwork Data to Habitat Model Input Data

This fieldwork effort provided valuable information on the use of SNB and LEM edge habitat by key project species. Data collected on seasonal marsh productivity will also serve to enhance the analysis of the influence of freshwater inflow and seasonality on plant productivity in the project area. While this seasonal sampling does not provide results for all of the key project species, the collection and analysis of this type of data does serve as a positive step in the validation process for the habitat assessment.

5.3.1 Physical Habitat Use Data

As discussed in section 4.3.1, physical habitat suitability criteria were based on NMFS drop trap data collected in Matagorda, Galveston, Lavaca, and San Antonio bays. For comparison, the 2006 LSWP throw drop trap data collected for low estuarine marsh (LEM) and shallow non-vegetated bottom (SNB) were summed across the sites and normalized by abundance (habitat with the highest abundance as 1). Figures 5.10 - 5.13 illustrate the comparison of LEM and SNB habitats for the four key species for which enough data was available.

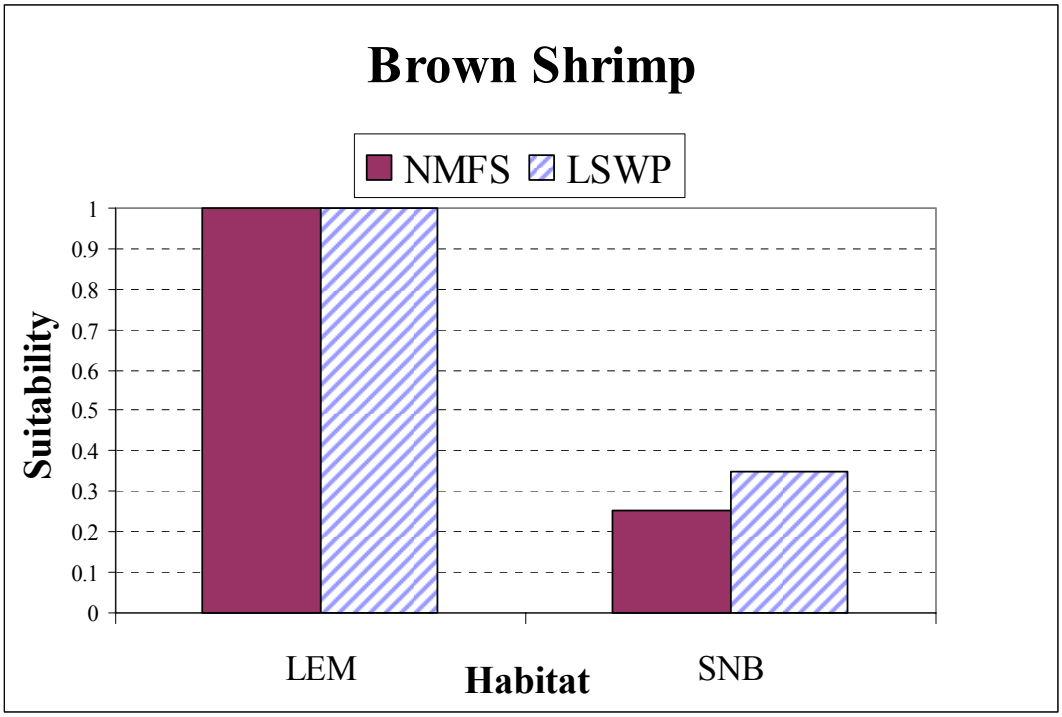

Figure 5.10 - Habitat suitability comparison for juvenile brown shrimp use of low estuarine marsh (LEM) and shallow non-vegetated bottom (SNB).

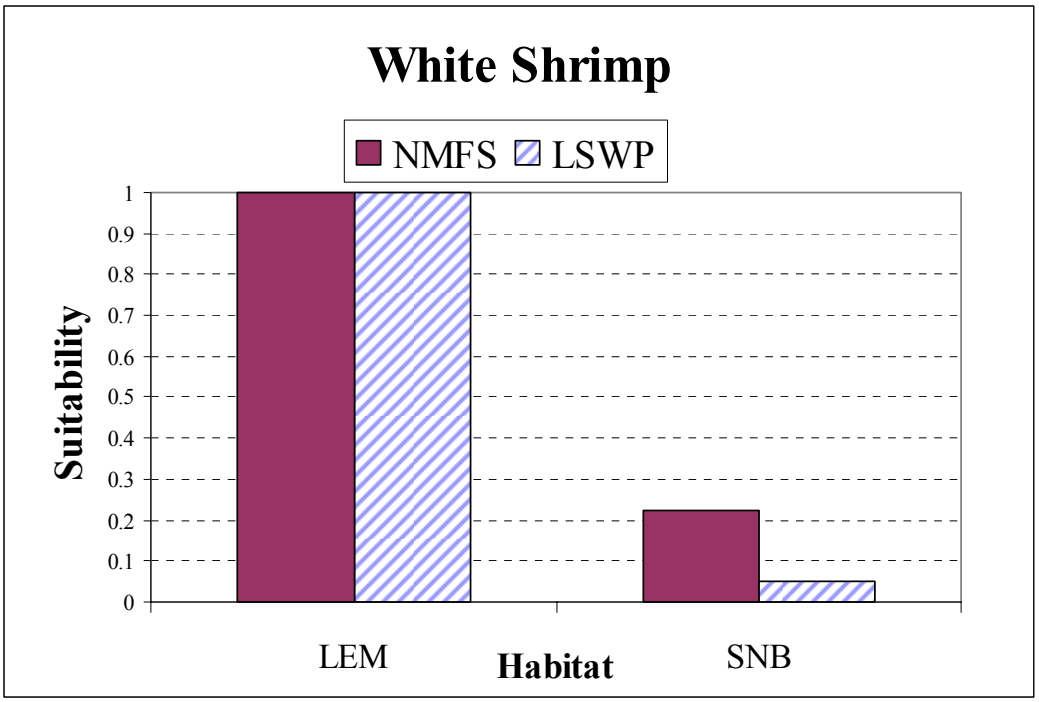

Figure 5.11 - Habitat suitability comparison for juvenile white shrimp use of low estuarine marsh (LEM) and shallow non-vegetated bottom (SNB).

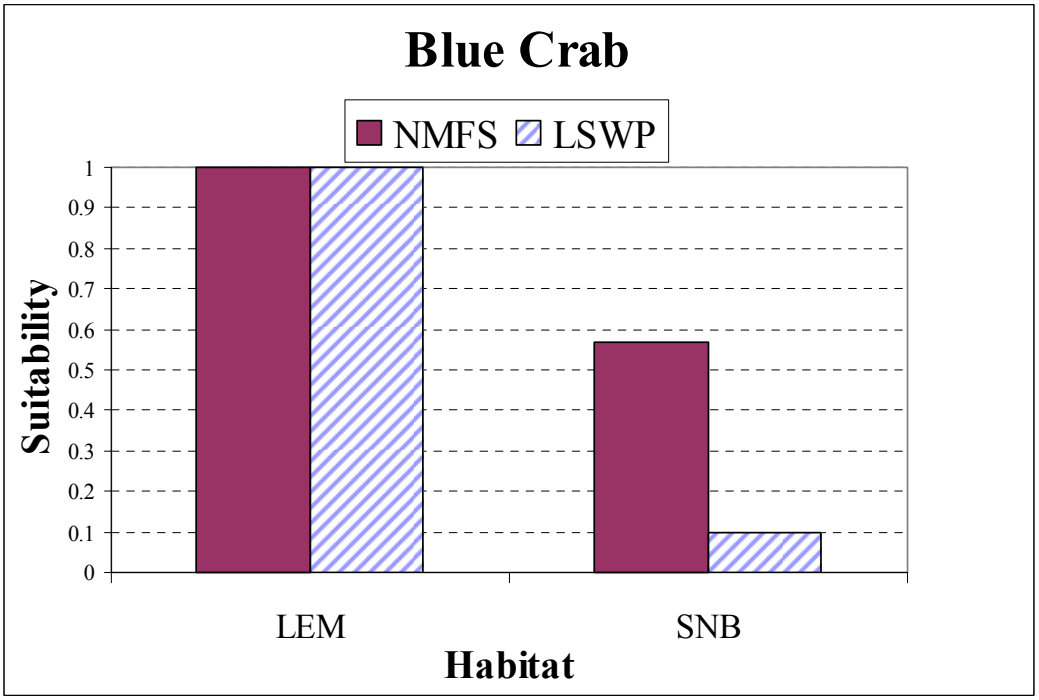

Figure 5.12 - Habitat suitability comparison for juvenile blue crab use of low estuarine marsh (LEM) and shallow non-vegetated bottom (SNB).

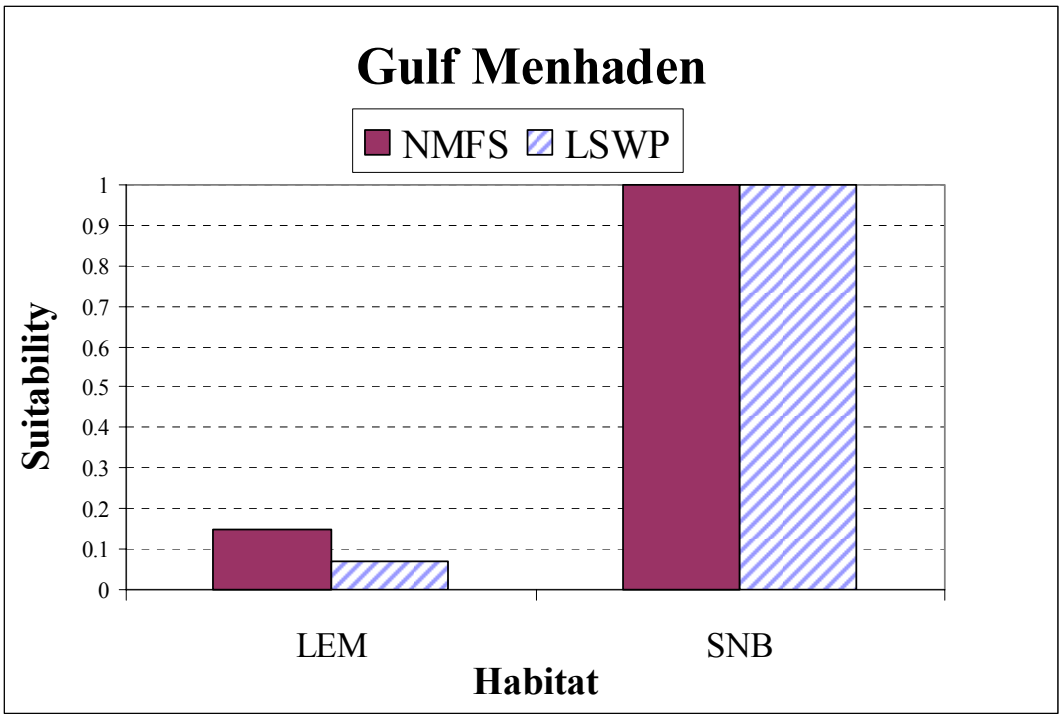

Figure 5.13 - Habitat suitability comparison for juvenile Gulf menhaden use of low estuarine marsh (LEM) and shallow non-vegetated bottom (SNB).

As discussed, LSWP samples were limited to five throw drop trap samples within two habitats at five sites during three sampling events, for a total of 75 samples per habitat type. Although not an exhaustive data set, the site specific results are very encouraging. Each of the four key species that had sufficient data for comparison exhibited the same selection trend relative to LEM and SNB. The comparative trend involved the three shellfish selecting LEM over SNB with Gulf menhaden selecting the opposite. The relative percentages of the lesser selected habitat are also very similar for brown shrimp and Gulf menhaden and not quite so close for white shrimp and blue crab. Overall, the 2006 throw drop trap sample results provide a strong indication that the full set of NMFS data from Matagorda and adjacent Texas bays is applicable for suitability curve development specific to the MBHE. To further support this finding, the 2007 MBHE scope of work includes a larger, spatially extended throw drop trap effort in April 2007.

5.3.2 Vegetation Communities

Measurements of plant community composition, species density and aboveground biomass were made to enhance the understanding of marshes located within the project area. The project team was able to identify the same plant species within the sampling sites as were mapped in the habitat delineation, with dominant plant species similar to those included in greenhouse productivity studies utilized to develop productivity algorithms in the Visser et al. (2003) report. Live and dead aboveground biomass measurements allow for the calculation of marsh productivity (g m^2 yr^{-1}) based on the marsh function output from the habitat model. However, as these measurements are still being analyzed, this step is not included in this progress report.

6.0 HABITAT INTEGRATION

The framework for the habitat model was described in the 2005 Habitat Assessment Progress Report (MBHE 2005b). During 2006, several of the habitat relationships for key project species were supported by data collected from the throw drop trap sampling effort (Section 5.0). These relationships were included in the habitat model. By way of example, baseline habitat conditions in the project area were assessed for brown shrimp, white shrimp, and marsh function in 1996 and 1997. These years were chosen because they are representative of two different extreme conditions (1996 – dry, 1997 – wet). The output presented below is preliminary and used in this progress report for illustration purposes only. Only three of the five marsh complexes are included in this preliminary evaluation. As additional salinity model output for the remaining marshes becomes available and overall quality assurance review of salinity output is conducted, these analyses will be revised. Additionally, only two of the five key species are evaluated in the example. In early 2007, complete baseline analysis with all marsh complexes and key species included will be conducted for 1996-2003 as salinity model output becomes available. This section provides an overview of the salinity model input used in the habitat analysis, the development and progress of the GIS habitat model, and preliminary results.

6.1 Salinity Model

A hydrodynamic model (RMA-2) coupled with a salinity model (RMA-4) was developed by the MBHE project team to assess future conditions in Matagorda Bay (MBHE 2006) The overall boundary of the salinity model is presented in Figure 6.1. The hydrodynamic/salinity model supplies projected salinity, inundation depth and inundation frequency into the habitat model to assess future habitat conditions as a result of climatic and hydrologic inputs. The hydrodynamic/salinity model provides output in node, or point, format throughout Matagorda Bay and up into five marsh complexes north of the GIWW (Figure 6.2, top). This nodal output is formatted by the project team to provide salinity and inundation data across approximately 10m x 10m grids within the entire project area.

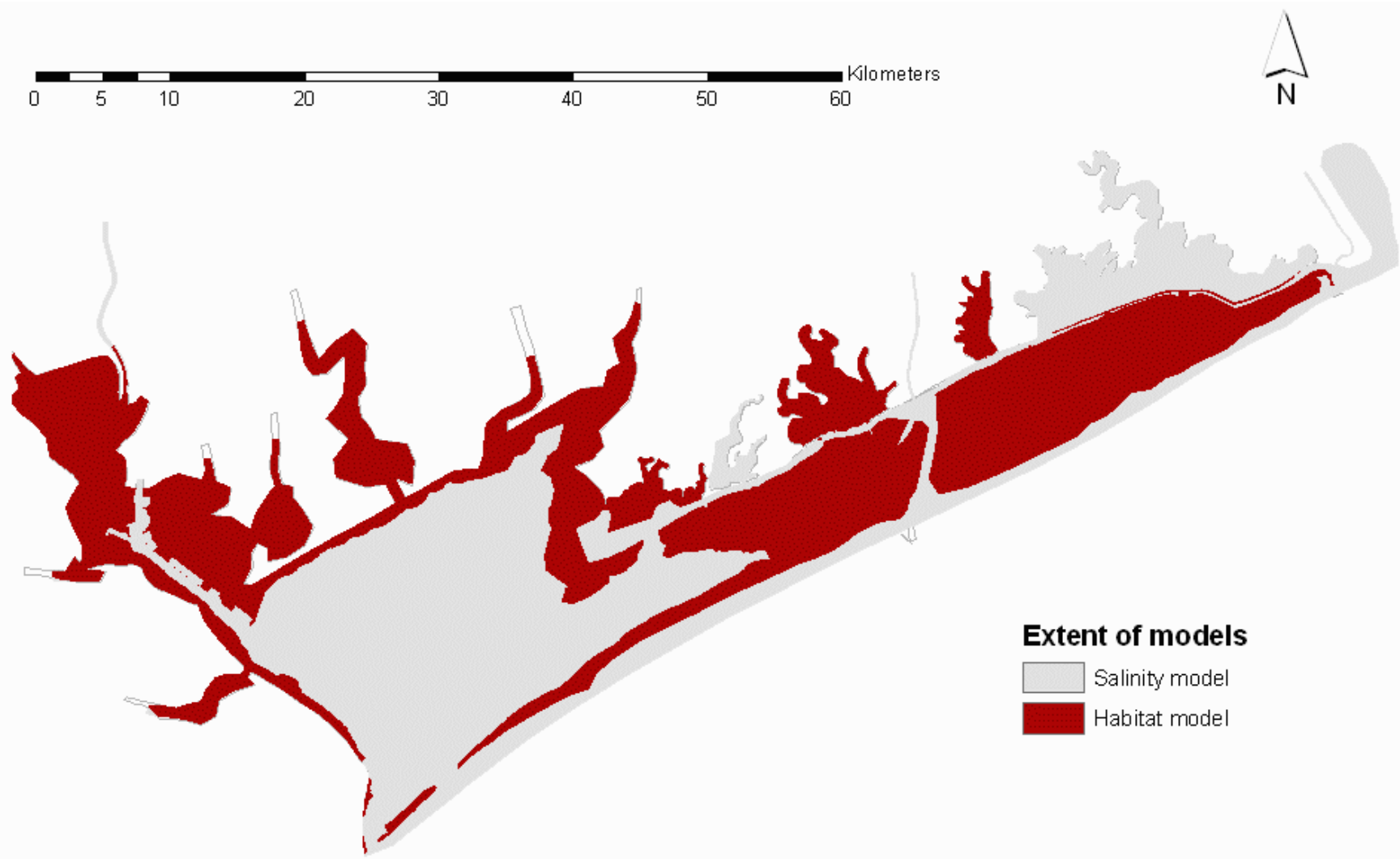

Figure 6.1 - Map of the current extent of the salinity model within the Matagorda Bay system and habitat model used in this preliminary assessment. The habitat model extent will be updated as QA/QC of the salinity model output is completed.

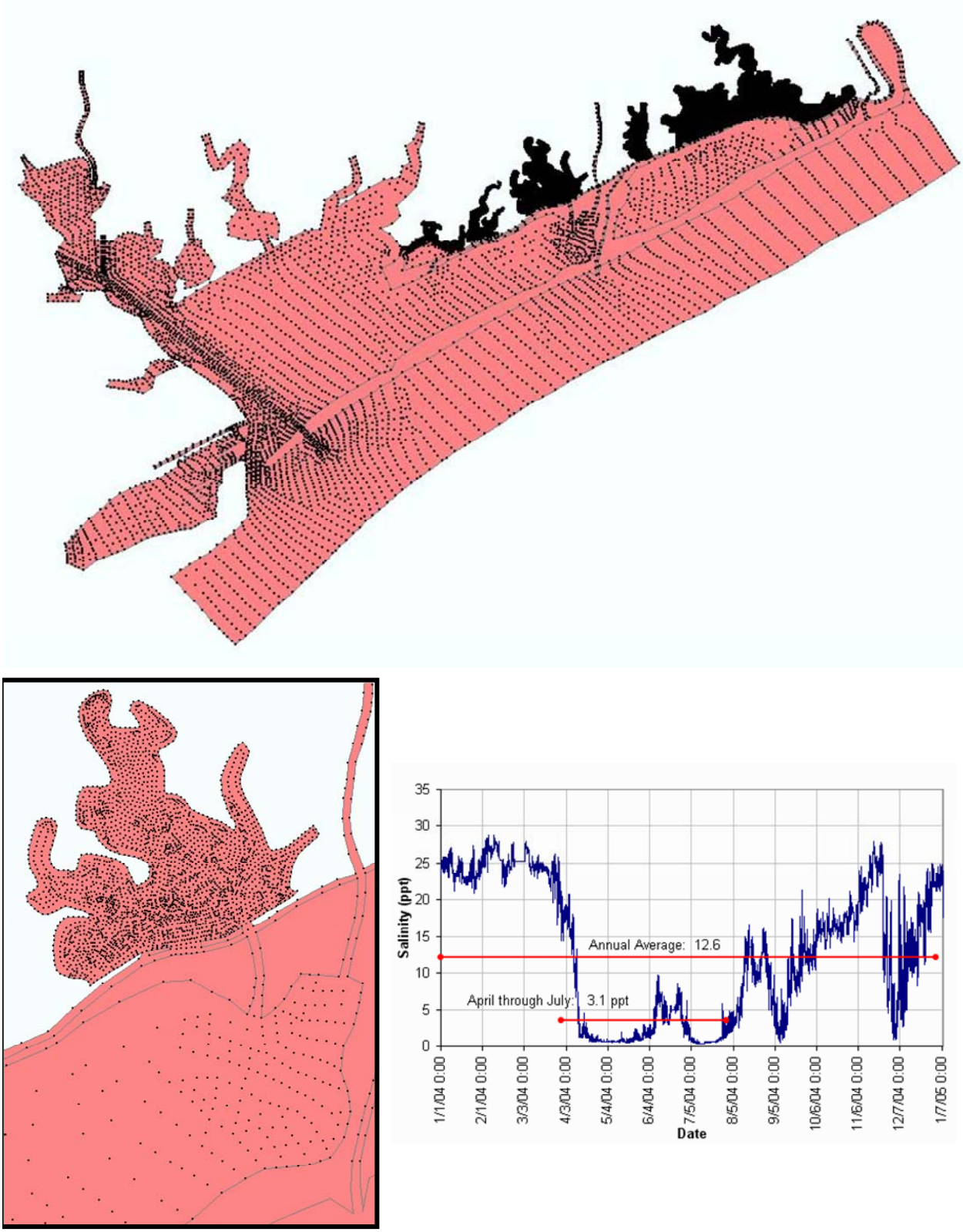

Figure 6.2 - Representation of salinity model nodal output and average salinity calculations over varying time periods.

6.2 GIS Habitat Model Development

For the GIS habitat model, available habitat is defined as an area (10m^2 scale) that possesses a combination of physical and chemical qualities with the potential to support the juvenile life stage of a particular organism. Available habitat output will be provided separately for the five key project species. The habitat model uses additional relationships between marsh plant productivity and salinity and inundation to provide an output of marsh function within the project area. Marsh function is defined in this assessment as plant primary productivity (percent of maximum productivity, based on published data) and is only estimated for marsh habitat zones within the model boundary (LIM, HIM, LEM, and HEM). Output is provided for the marsh habitats within the extent of the hydrodynamic/salinity model, in the form of acreage of certain percent productivity values within each marsh zone. The percent productivity of each marsh area (10m^2 scale) will be multiplied by the average productivity rate of its respective marsh zone to estimate the annual plant primary productivity for the defined project area in future analyses. Marsh complexes may also be assessed individually to potentially determine areas of concern or importance and to address potential marsh enhancement opportunities.

In addition to coastal wetlands, oyster reefs also play a vital role in estuarine ecology and provide physical habitat for several of the indicator species. The American oyster is being considered separately (Section 3.0, Appendix A) due to its sessile nature and the added influence of temperature and dermo infestation on oyster communities in the bay.

6.3 GIS Habitat Model Progress

Currently, the habitat assessment is in the stage of evaluating the existing, or baseline habitat condition of the project area for 1996-2003 as the salinity model output becomes available. As discussed above, a preliminary analysis of brown shrimp and white shrimp habitat availability, as well as plant productivity for 1996 and 1997 is provided in this progress report for illustrative purposes. Output from the habitat model can be provided in tabular form detailing the aerial extent of output with associated CSI values, as an aerial extent of habitat with a minimum CSI value, as a weighted habitat value overall, and in spatial form, with the potential to be integrated or correlated with other spatial information and analyzed based on location of interest.

The habitat model boundary as used in this progress report extends across Matagorda Bay and East Matagorda Bay, and into the marshes at Oyster Lake, Mad Island Marsh Wildlife Management Area, and Little Boggy Bayou (Figure 6.1). The current marsh model area covers 725.8 km^2 of the Matagorda Bay system, with 1441.9 km^2 included in the salinity model. Areas greater than 2m in depth are not included in the habitat model. As previously mentioned, for this progress report, the Mad Island Marsh Preserve and Lake Austin marsh complexes were also not included. As salinity model output for the Mad Island Marsh Preserve and the Lake

Austin marsh complex are concluded, these marshes will be included in the habitat model boundary as well.

6.3.1 Habitat Model Inputs

The two main inputs to the habitat model are the physical habitat provided by the marsh characterization task (Figure 4.1) and the chemical habitat (Figures 6.3 and 6.4) provided by the salinity model. The salinity model output is averaged at each node within the project area over a specific period of time for each organism. This salinity model is comprised of 40,133 points (Figure 6.2, top) and provides output at each node on a 30-minute time-step. Average salinity applicable to each species was calculated over a time period significant to that species. Juvenile brown shrimp, for example, are most abundant in Matagorda Bay between April and July; therefore, habitat suitability was determined for brown shrimp using salinity output from that period (Figure 6.2, bottom right). After salinity model output has been averaged for a particular time period, it is plotted in GIS and serves as the chemical habitat input for the analysis of that particular organism. This means that the salinity input for each organism analysis is different, because they are based on salinities from different time periods. The time period analyzed for each organism is detailed in Section 4.2. A one-year period was used to determine average salinity for all marsh habitats. The spatial gradients of one-year average salinity utilized as marsh chemical habitat input are illustrated in Figure 6.3 (1996) and Figure 6.4 (1997). The physical habitat input remains the same for all analyses.

6.3.2 Habitat Model Relationships

Within GIS, the area encompassed by the habitat model was divided into square 10m grid cells for both the physical habitat and chemical habitat inputs. The HSI value corresponding with each physical habitat and chemical habitat type for a particular organism was assigned to the cells within both of the input files. Both physical habitat HSI and chemical habitat HSI values range from 0 to 1. Recall that a selection value of 1 is the highest value assigned and indicates juvenile organisms of that species are found in the highest abundance within this habitat. Lower selection values are assigned to other habitats with proportionally lower populations of juveniles. Any habitat which is not suitable for a juvenile species receives a ranking of zero and is consequently designated as area that is not available for the organism. The two habitat inputs are overlaid in GIS, so that every grid cell has a corresponding physical habitat attribute and chemical habitat attribute. The overall suitability of each grid cell is evaluated by calculating a habitat composite suitability index (CSI) represented by the equation:

$$CSI = PSa * CSa$$

Where CSI is the product of the physical HSI (PS) for an organism (a) and chemical HSI (CS) of each grid cell.

6.3.3 Habitat Model Outputs and Preliminary Results

Hydrodynamic/salinity model output from 1996 and 1997 was used to begin analyses with the habitat model to evaluate existing habitat conditions in the project area. The average annual salinity across both Matagorda Bay and East Matagorda Bay was higher in 1996 than in 1997 (Figures 6.3 and 6.4). Freshwater inflow from the Colorado River for these periods was

approximately 412,743 in 1996 and approximately 4,286,226 in 1997, based on gauged monthly flow data. A comparison of these two years with historical inflow from the Colorado River (1977-2003) indicates 1996 exhibited very dry conditions, while 1997 exhibited extreme high flow conditions. A slight salinity gradient is apparent in 1996 in the new delta region in the Eastern Arm of west Matagorda Bay (EAMB) and simulated salinities in the Oyster Lake and Mad Island Wildlife Management Area marsh complexes are lower than in the main bays (Figure 6.3). As expected, a much larger salinity gradient in 1997 is shown near the delta and in the EAMB (Figure 6.4).

The habitat model was run for 1996 and 1997 to evaluate juvenile brown shrimp habitat availability, juvenile white shrimp habitat availability, and marsh function. Salinity model output from April to July was averaged separately for 1996 and 1997 for brown shrimp analysis. In the same way, salinity model output from July to November was used for white shrimp analysis. Average annual salinity for each year was used for marsh function analysis.

The brown shrimp habitat analysis is focused on the juvenile life-stage, and physical habitats such as low estuarine marsh and submerged aquatic vegetation are considered the most suitable for this life stage (Figure 4.2). Only oyster reef habitat was considered 'not available' for use by this species, however SNB habitats greater than 2m deep are not included in the habitat model. Also keep in mind that salinity plays a major role in the habitat suitability as well (Figure 4.4) and brown shrimp tend to select for slightly higher salinities than the other key shellfish species being evaluated. The habitat model indicates that the total usable area for brown shrimp was 192.4 km^2 in 1996 (April to July) (Figure 6.5). Of the usable area, 44.7 km^2 of suitable habitat > 0.5 CSI was present. In 1997, the habitat model indicates that the total usable area for brown shrimp was 162.7 km^2 (Figure 6.6). This decrease in the amount of usable habitat is a function of lower salinities in 1997. The > 0.5 suitable habitat area also decreased into 1997 to 33.6 km^2. Overall, April to July conditions experienced during 1996 provided more usable habitat area, with a 25% reduction in > 0.5 suitable habitat area in 1997. Again as expected, marsh areas around the new Colorado River delta are where the greatest differences occur.

The white shrimp analysis is also focused on the juvenile life-stage, and habitats including low estuarine marsh and submerged aquatic vegetation (to a lesser extent) are considered the most suitable for this life stage (Figure 4.2). As with the brown shrimp, oyster reef was considered 'not available' for use by this species. Keep in mind that white shrimp select for less saline conditions than brown shrimp (Figure 4.4), and the habitat availability output represents a different time period in the bay (July to November). The habitat model indicates that in 1996 the total usable area for white shrimp was 59.8 km^2, with suitable habitat > 0.5 CSI only extending 8.4 km^2 (Figure 6.7). In 1997, the habitat model indicates that both the total usable area and suitable habitat > 0.5 CSI for white shrimp expanded dramatically to 164.8 km^2 and 34.5 km^2, respectively (Figure 6.8). This increase in both usable and suitable habitat > 0.5 CSI is a function of the suitability of fresher conditions for the white shrimp. Overall, July to November conditions in 1997 provided more usable habitat, with a 311% increase in suitable habitat > 0.5 CSI over the same time period in 1996.

The marsh function analysis is focused on primary productivity of the HIM, LIM, HEM and LEM habitats within the project area, and only those that are included within the hydrodynamic/salinity modeling boundary. This means that several marshes behind water

control structures and many marshes around Matagorda Bay, Tres Palacios Bay, Carancahua Bay and Lavaca Bay are not included in the assessment. The total marsh area currently includes 61.96km^2. When salinity model output for the Mad Island Marsh Preserve and the Lake Austin marsh complex are concluded, these marshes will be included in the marsh function analysis as well. Also, the QA/QC process is currently being conducted on overall salinity output and may result in adjustments to the model. For illustrative purposes, all four marsh zones are presented together in the following example. The habitat model indicates that the area of marshes functioning at a productivity level of 50% or above was 36.4km^2 in 1996 (Figure 6.9). This is a function of both relatively high annual salinities in the marshes in 1996, and the compound effect of higher salinities on HIM and HEM habitats, as they are generally less productive to begin with due to their inundation regime. In 1997, the habitat model indicated that the area of marshes with productivity of 50% or above increased to 47.4km^2 (Figure 6.10). Overall, the less saline conditions in 1997 increased the area of marshes functioning above 50% productivity in the project area by approximately 30%.

Figures 6.5 – 6.10 are included in this progress report to provide several specific examples of habitat model output and preliminary results during different hydrologic regimes. From these preliminary habitat model runs, a couple of key points are as follows. The change in marsh productivity between flow regimes appears to be less dramatic than changes in key species habitat. This was anticipated by TPWD regional biologists at the March 2006 workshop. However, changes of marsh productivity on the scale of the entire project area may not reflect the responses of individual marsh complexes. Confirmation of these predictions will most likely require field validation through long-term monitoring. Identifying potential marsh enhancement opportunities will be aided from evaluations of individual marshes, where the addition of freshwater during drought conditions should provide increases in marsh productivity. Additionally, even though the two extremes evaluated here show various estimates of change, this does not necessarily mean that one of the extreme flow conditions (low or high) represent the most selected for habitat conditions. It is very likely that a flow regime somewhere within this range will provide the greatest amount of suitable habitat for a given species. It is also quite evident that each species will react differently and thus, a method of reconciling the results will need to be considered.

Finally, many different spatial and temporal variations of employing the GIS habitat model can be conducted (i.e. full bay system, individual marshes, different time periods, different time scales [weeks, months, time in bay], successive years, etc). Therefore, coordination with LCRA and SAWS technical staff, along with the SRP and AG will be extremely important in 2007 as full model implementation is employed. On a larger scale, several other MBHE components are concurrently being evaluated and thus integration remains a topic for continued discussion. As more results become available in 2007, the habitat team anticipates evaluating the applicability of incorporating results from the GIS habitat model, oyster reef suitability criterion model, and MBHE benthic macroinvertebrate work being led by Dr. Paul Montagna into some form of trophic level evaluation.

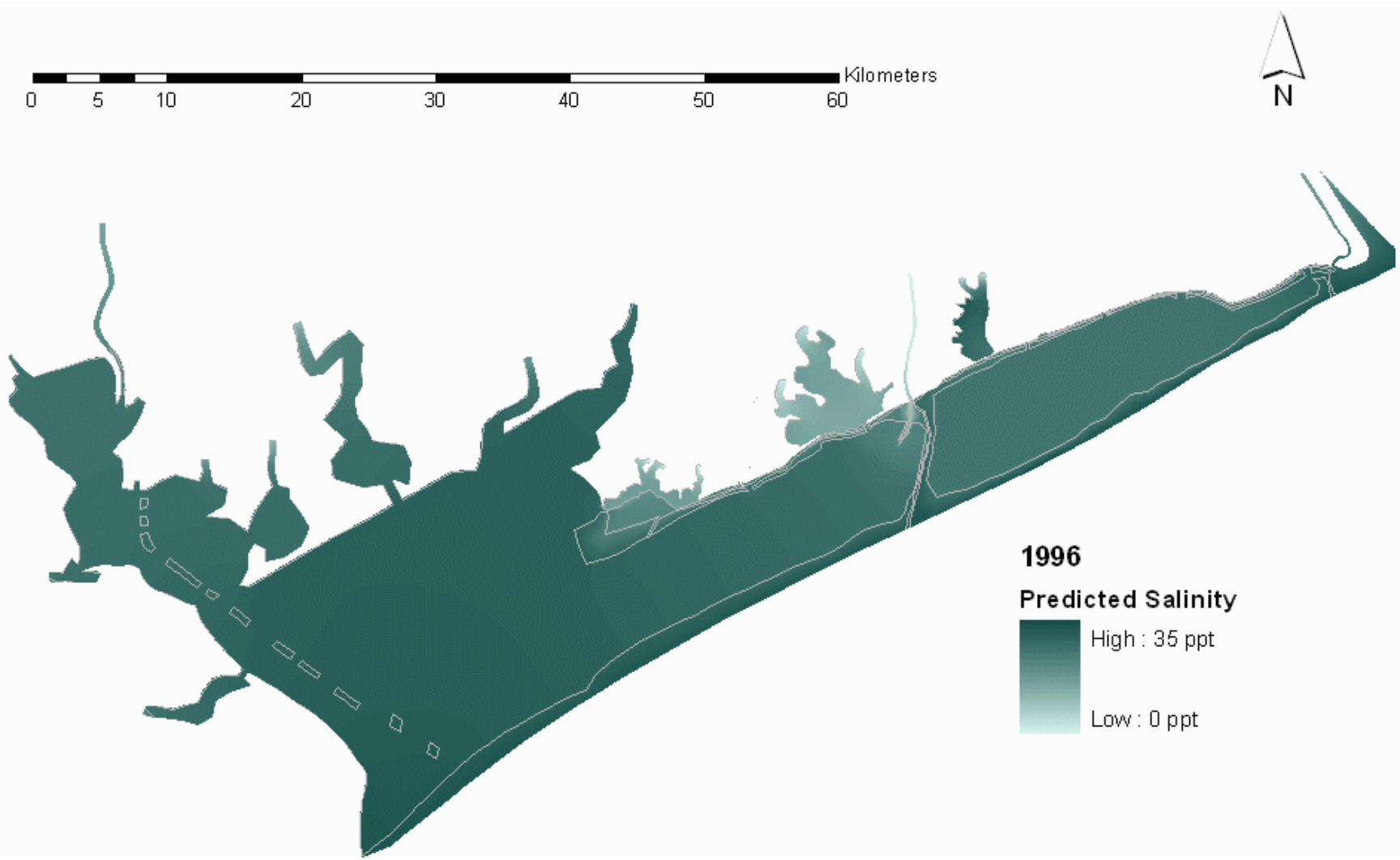

Figure 6.3 -Chemical habitat input to the GIS habitat model, based on nodal output from the salinity model.

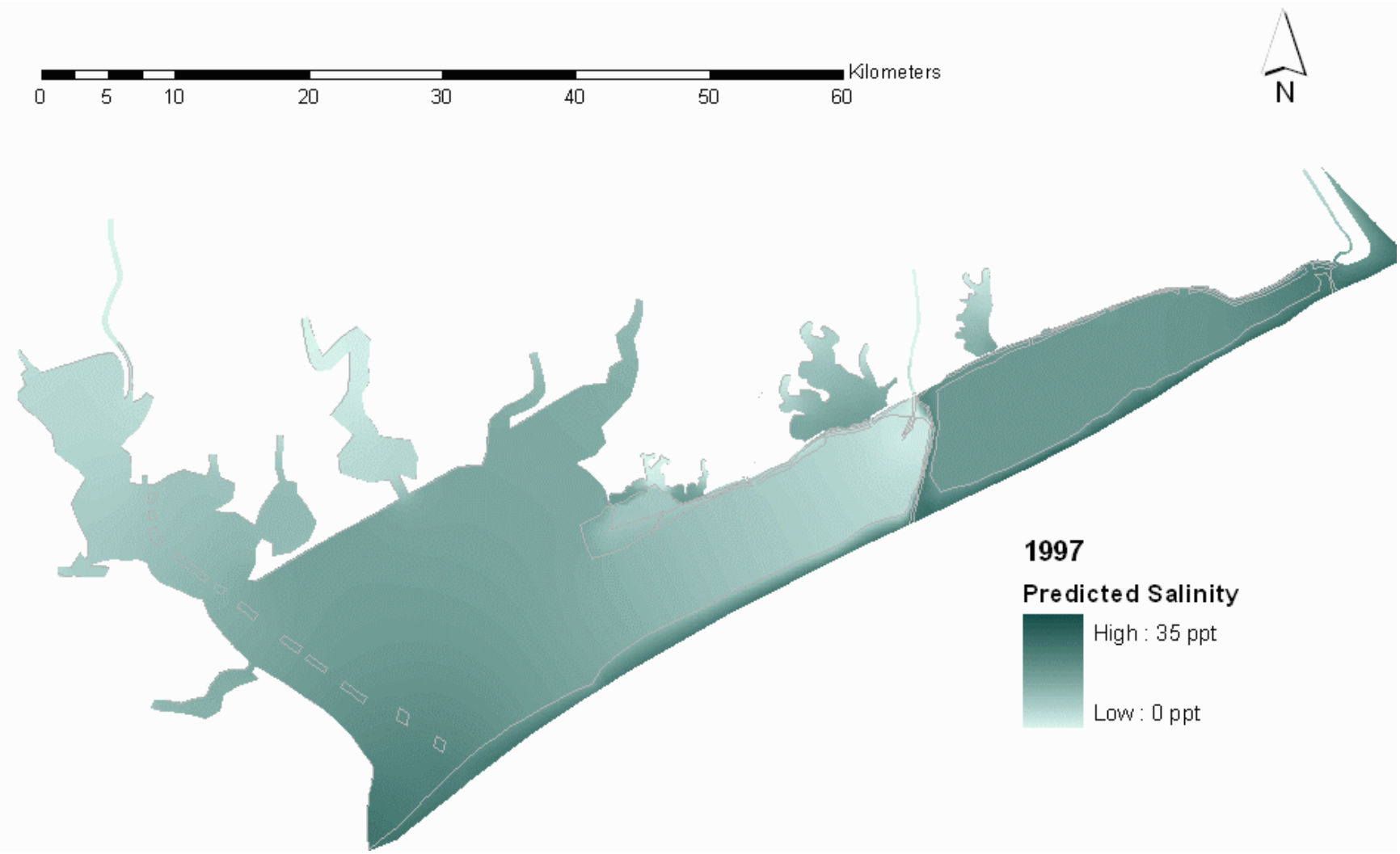

Figure 6.4 - Chemical habitat input to the GIS habitat model, based on nodal output from the salinity model.

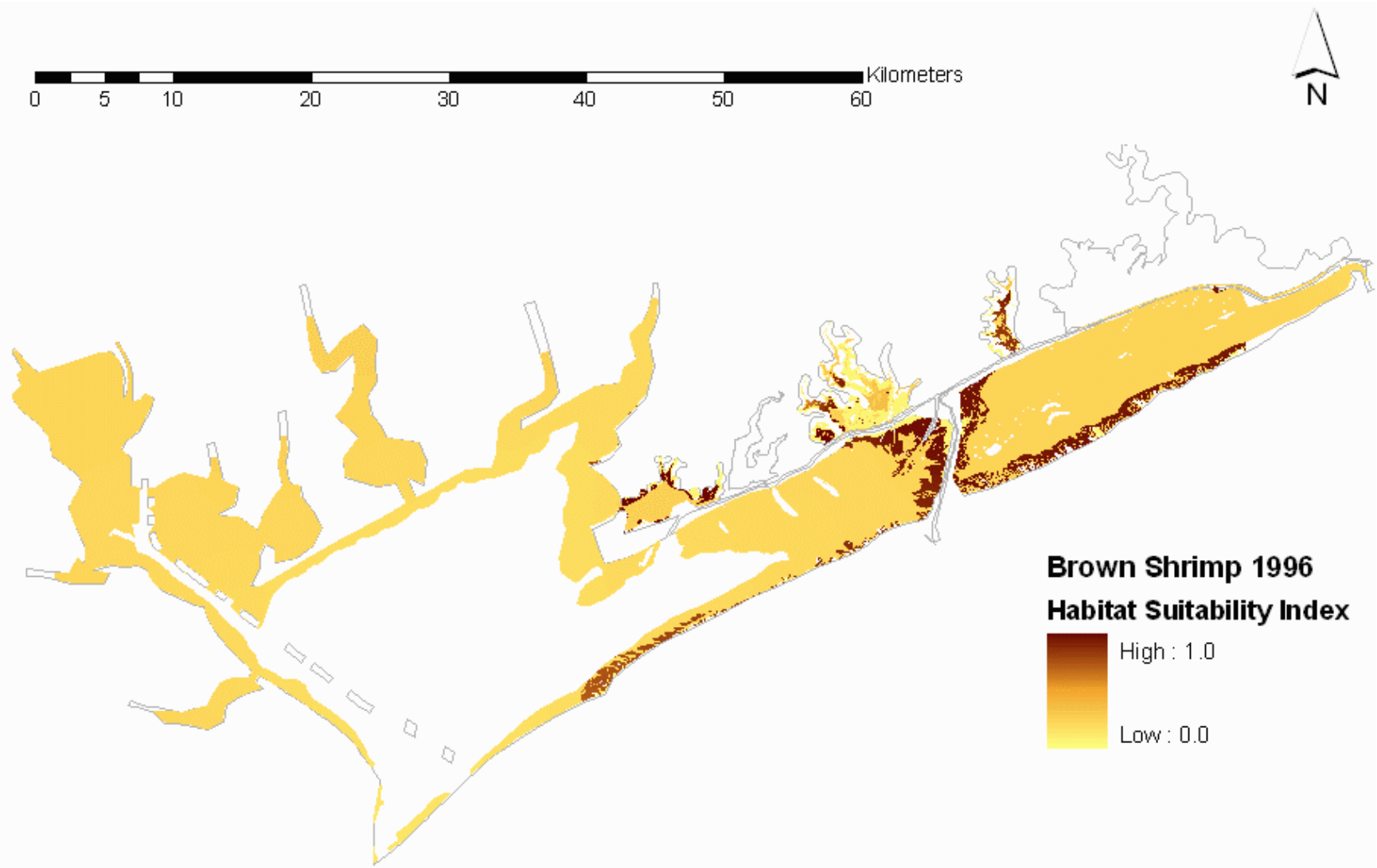

Figure 6.5 - Brown shrimp habitat suitability within shallow water habitats (<2m depth) in the project area in 1996.

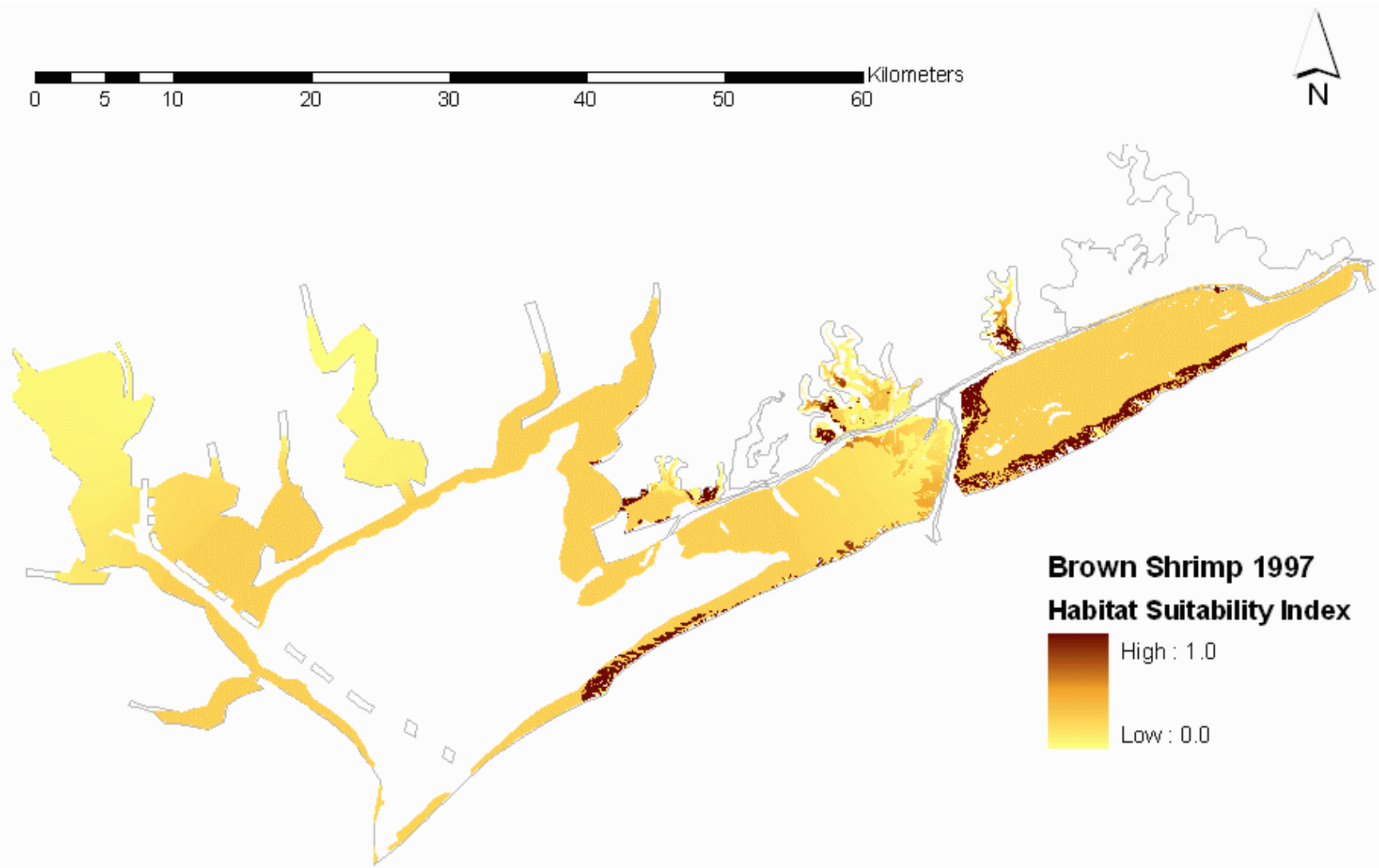

Figure 6.6 - Brown shrimp habitat suitability within shallow water habitats (<2m depth) in the project area in 1997.

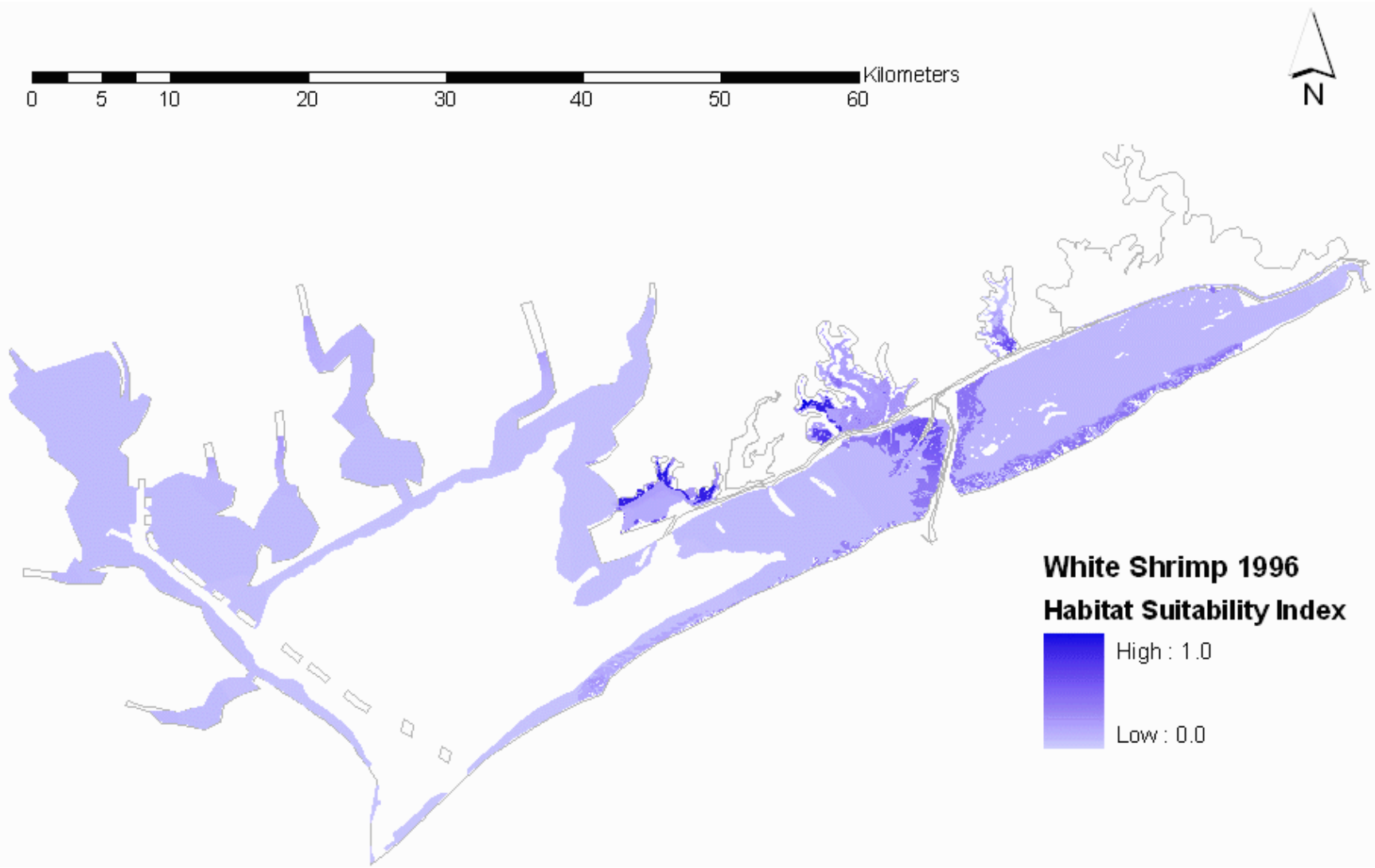

Figure 6.7 - White shrimp habitat suitability within shallow water habitats (<2m depth) in the project area in 1996.

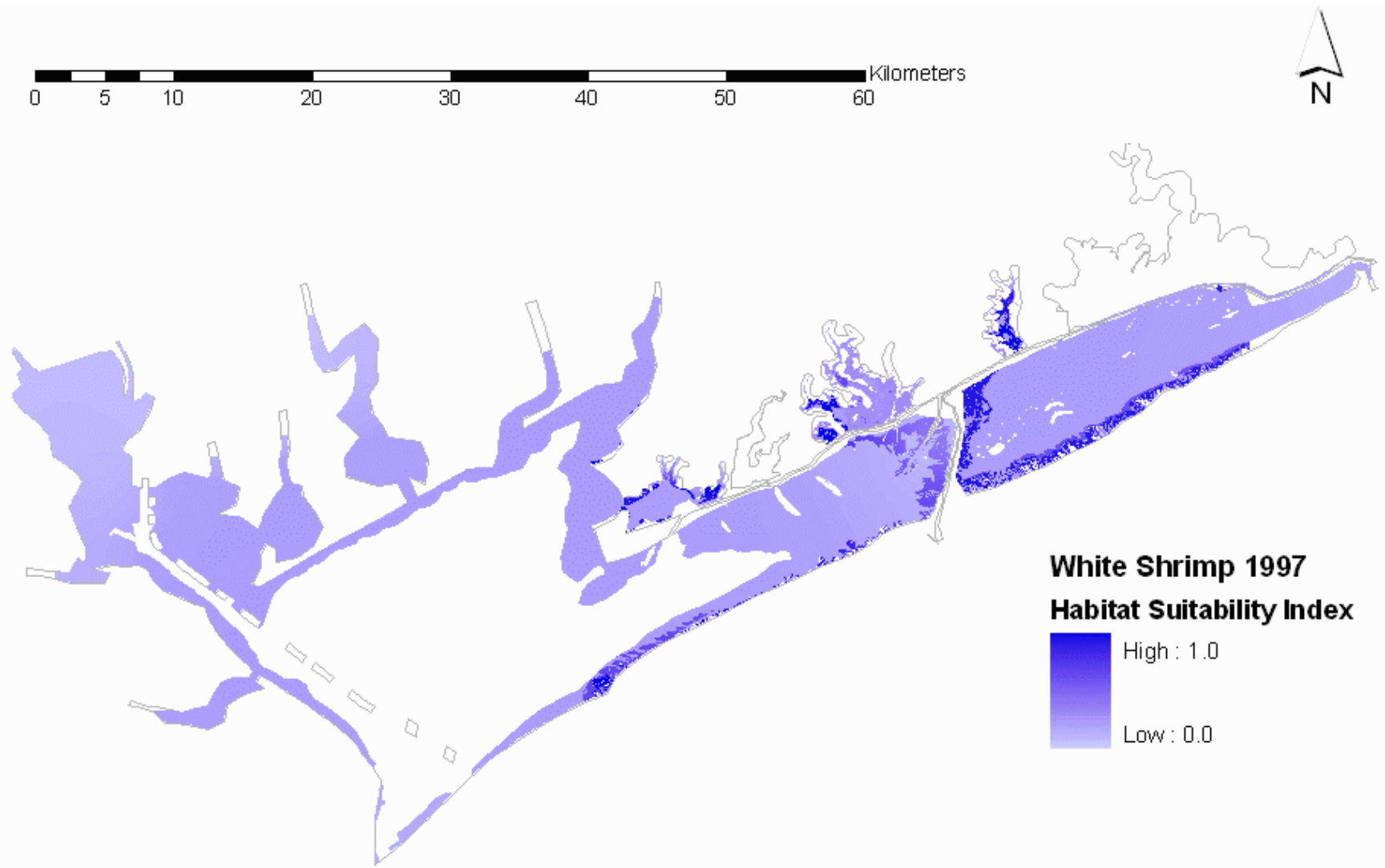

Figure 6.8 - White shrimp habitat suitability within shallow water habitats (<2m depth) in the project area in 1997.

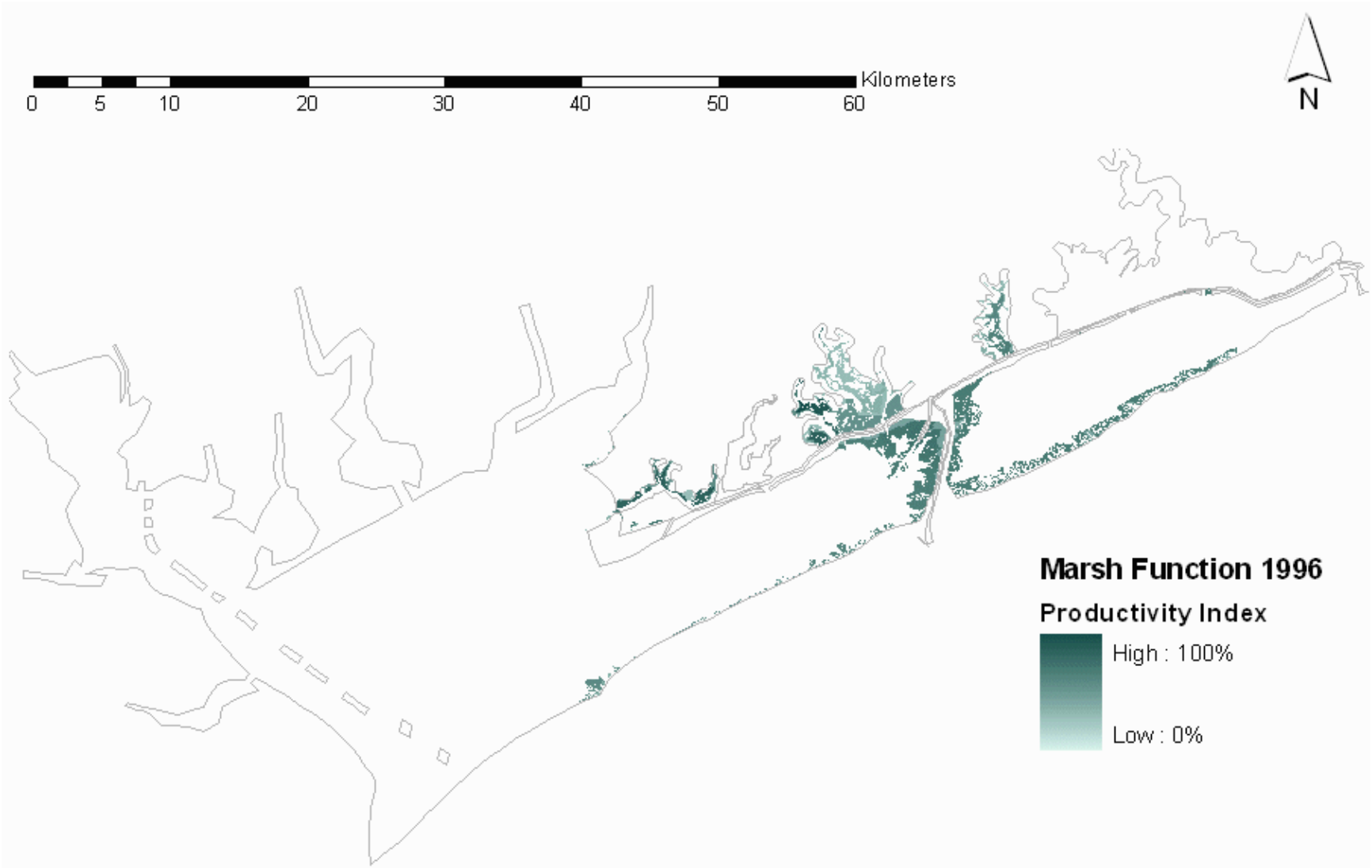

Figure 6.9 - Marsh function of all four marsh habitat types (HIM, LIM, HEM, LEM) within the project area in 1996.

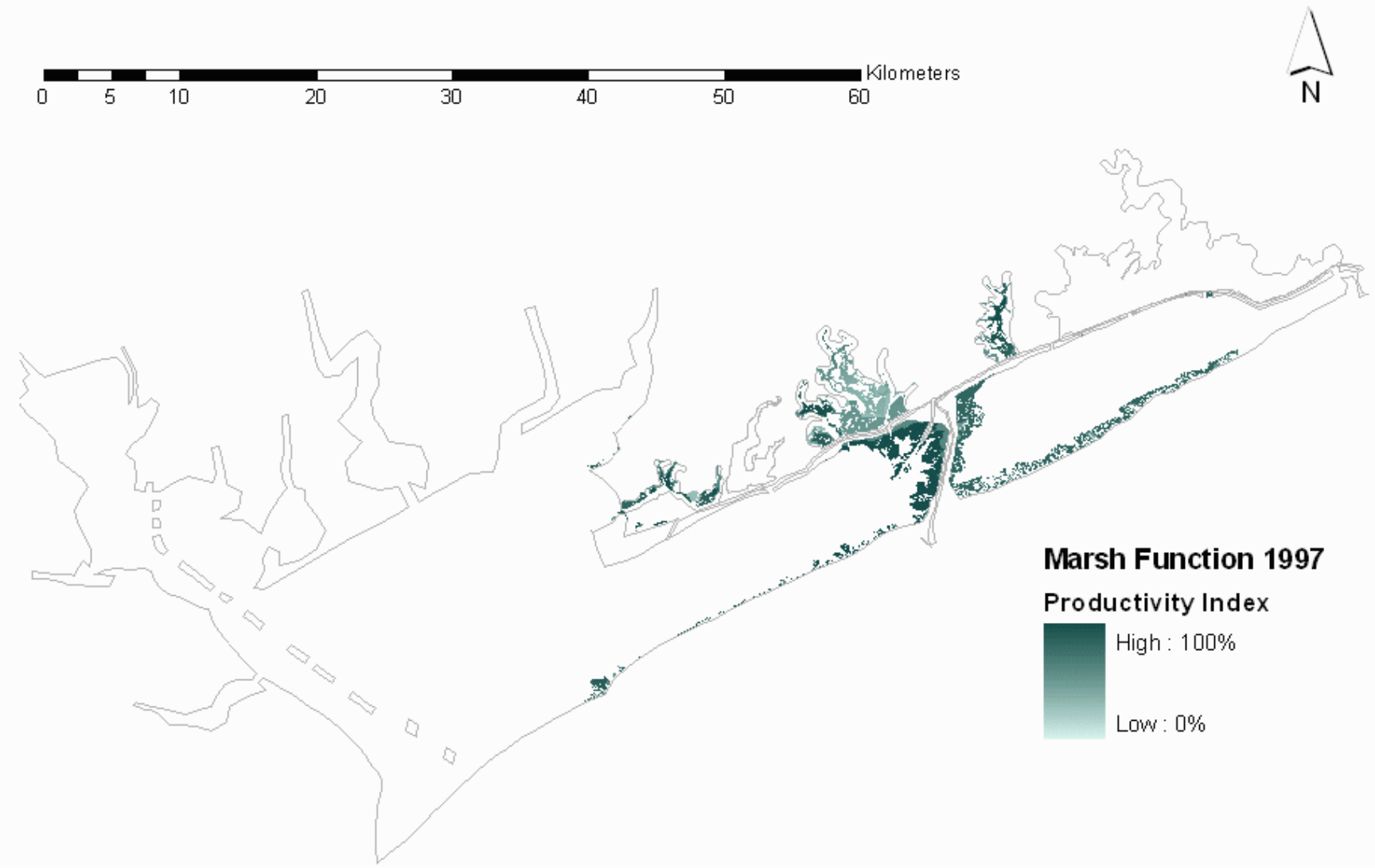

Figure 6.10 - Marsh function of all four marsh habitat types (HIM, LIM, HEM, LEM) within the project area in 1997.

7.0 FUTURE WORK

Initial activities in 2007 will focus on continued evaluation of habitat availability output from the habitat model based on the historical salinity model runs in order to characterize existing conditions. Also, as discussed above, considerable oyster reef formation around the new Colorado River delta (NCRD) area was found in 2006 field activities. As such, a one time mapping effort will be conducted in early 2007 to delineate these reefs and incorporate them into the existing habitat conditions used in the model.

Following the NCRD oyster reef inclusion and existing conditions update, the focus of the 2007 habitat assessment will shift to assisting in the development of freshwater inflow criteria, evaluation of potential enhancement opportunities, and project alternatives analysis. Additional habitat tools (GIS habitat model and Oyster Reef statistical models) validation will also continue during the first half of 2007.

In order to further the validation of the habitat tools, a one-time spatially-extended field effort will be conducted in spring 2007. This effort will consist of throw-drop trap sampling for the key project species in both shallow non-vegetated bottom (SNB) and marsh edge (ME) areas in eight locations within the Matagorda Bay system. A limited evaluation of vegetation, soil and water quality parameters will be assessed within SNB, ME and vegetated marsh interior (MI) sites to evaluate plant productivity within these areas. These locations include the 2006 locations (MIMP and NCRD), Lake Austin complex, East Matagorda Bay, Oyster Lake, Tres Palacios Bay, Carancahua Bay, and on the bayside of the West Matagorda Bay barrier island. As in 2006, coordination with TPWD will be employed to ensure that throw drop trap sampling in these locations will be conducted at similar times as the TPWD bag seine collections taken during their routine coastal monitoring effort. Validation of the oyster reef suitability criterion model will involve using a separate validation data set. Dermo watch monitoring program data though 2005 were used in the oyster suitability criterion development. The 2006 field data from the same programs and sites, as well as data from additional sites from these programs, will be used for model validation.

Additional 2007 activities include the initiation of certain biological components of the MBHE long-term monitoring program. The project team anticipates the results of the 2007 validation field collection effort will inform the project team on important locations to properly scope the long-term habitat monitoring program. The project team will conduct summer and fall throw drop trap sampling at four to five of the sites evaluated during the validation effort. Sampling would occur in August and October 2007 to span the vegetative growing season, similar to 2006. It is anticipated that the NCRD and MIMP sites would be included plus some additional sites for immediate project area and reference comparisons. Close coordination with the MBHE long-term marsh transect monitoring effort will be maintained to maximize efficiency and resources.

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Appendix A

Development of Oyster Reef Condition Indices and Oyster Suitability Criterion Models for the Matagorda Bay Health Evaluation

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Executive Summary

This document presents the development of a suitability criterion model relating salinity and temperature to oyster reef condition in the Matagorda Bay system. The objective of 2006 tasks was to develop a suitability criterion model to enable the biological linkage of American (also called eastern) oysters, *Crassostrea virginica*, to the Matagorda Bay hydrodynamic/salinity model. A specific goal of the oyster biological linkage task for 2006 was to incorporate severity of infestation by the leading oyster parasite *Perkinsus marinus* (dermo), as well as other indicators of oyster population quality, in the biological linkage task.

This report includes a review of existing research and data associated with direct and indirect effects on oyster growth and survival in relation to temperature and salinity. An assessment of the available data follows to determine the data that best suit the development of an oyster condition index and related suitability criterion model. Prior to construction and development of the condition index and suitability criterion model, data from multiple sources and locations were aggregated to provide better oyster population information and to improve data coverage spatially and temporally.

Four different oyster condition indices were created based on available data, such as oyster abundance, size, and/or dermo infestation. Regression models for condition as a function of salinity and temperature parameters were developed and evaluated in order to determine the best predictive regression model for each condition index. These best models were designated as suitability criterion models for oyster reef condition in Matagorda Bay. All four oyster condition indices were more strongly driven by salinity parameters than by temperature parameters. The oyster abundance indices had intermediate salinity optima, while the condition indices that incorporated dermo intensity had negative relationships with salinity– dermo intensity increased (hence condition decreased) with salinity.

These suitability criterion models can now be linked with output from the hydrodynamic/salinity model in order to predict the effects of inflow patterns on oyster reef condition throughout Matagorda and East Matagorda Bays.

1.0 Introduction

Estuarine habitats, such as those within Texas' coastal bays, are characterized by large changes in salinity over a broad range of temporal and spatial scales. As detailed in the 2006 Statement of Work for Matagorda Bay Health Evaluation (MBHE) for the Lower Colorado River Authority (LCRA) and San Antonio Water System (SAWS) Water Project (LSWP), a major goal of the MBHE is to determine freshwater inflow criteria that maintain Matagorda Bay health. One approach to meet this goal has been to develop a hydrodynamic/salinity model for Matagorda Bay which can be linked to biological responses. This linkage is to be established by developing condition indices for a wide range of estuarine biota and developing suitability criterion models that predict changes in these condition indices in response to salinity and temperature forcing functions. The suitability criterion models therefore enable the determination of whether or not a habitat is suitable for a specific target organism under a given salinity and temperature regime.

This report describes the development of condition indices and suitability criterion models providing the biological linkage of American (also called eastern) oysters, *Crassostrea virginica*, to the Matagorda Bay hydrodynamic/salinity model. As a popular seafood, oysters are of vital economic and cultural importance to the Gulf of Mexico region. Additionally, oysters provide a number of key ecosystem functions: oyster spawn and larvae comprise a large proportion of the planktonic biomass in Texas bays providing a vital food source for many planktivores; oyster reefs provide an important physical habitat for a diverse group of benthic organisms; and oyster filter feeding plays a key role in maintaining water clarity (Kennedy et al. 1996). Consequently, maintaining the health of the Matagorda Bay oyster population is consistent with the objectives of the LSWP.

1.1 Purposes and Limitations of Study

The main purpose of the suitability criterion model is to link oyster reef condition to output from the hydrodynamic/salinity model currently being developed for Matagorda Bay and East Matagorda Bay (MBHE 2005), and to long-term water temperature data for these bays. Given this focus, the suitability criterion model includes only salinity and temperature derived parameters. Additional factors such as food availability and contaminants will not be considered as predictors of oyster condition at this time, and interactions with other species (parasites, predators) will only be incorporated indirectly via how their impact on oysters is dependent on salinity and temperature.

Although, interactions with other species are not specifically considered as predictors of oyster reef condition; infestation by the parasite *Perkinsus marinus*, commonly called dermo (the term "dermo" describes both the infection and the organism, formerly classified as *Dermocystidium marinum*), must be included in the description of oyster condition. This is because high levels of dermo infestation can severely reduce oyster reproduction and survival rates and also decrease the market value of oysters by degrading their meat. In response, dermo infestation levels will be included in oyster condition indices developed in this report.

Larval oysters are induced to settle by the presence of hard substrate, such as shells, and by chemicals produced by adult conspecifics, so oyster reefs tend to be self-perpetuating. Unlike some

regions, such as the Chesapeake Bay, oysters in Texas bays are almost always harvested in the reefs where they settle rather than moved post-settlement to designated growing locations. As a result, the entire post-larval life of these oysters will depend on specific conditions at the reefs. While regions within the bay that do not currently contain reefs may develop new reefs, there are many other factors besides salinity and temperature that will determine reef placement and these factors are beyond the scope of the current modeling effort. For these reasons, the suitability criterion model will focus on predicting oyster condition on existing reefs and will not consider data from non-reef areas or attempt to predict areas where new reef formation might occur.

1.2 Outline of Report

This report includes five main sections:

Review of Existing Research is a review which focuses on the research and data associated with direct and indirect effects of temperature and salinity on oyster growth and survival.

Assessment of Available Data reviews the procedure involved in determining the best utilization of available data. The first step in developing an oyster condition index and related suitability criterion model for Matagorda Bay was to determine the type of data ideally suited for those tasks. The next step was to find and evaluate potential data sources that best met these ideals. This section describes these processes with respect to data types, spatial scales, temporal scales, and geographic origin.

Data Processing and Aggregation describes the pre-processing and aggregation of data that was necessary before undertaking condition index construction and suitability criterion model development. The approach for obtaining suitable data to develop an oyster suitability criterion model was to combine DermoWatch data (http://dermowatch.org/) and Texas Parks and Wildlife Department's (TPWD) coastal fisheries oyster dredge data at the spatial scale of the reefs sampled in DermoWatch. This data aggregation accomplished two goals: it combined oyster population data with dermo data and it improved the temporal consistency of the data, which aided in modeling efforts. Data were utilized from Matagorda Bay, Lavaca Bay, Galveston Bay, and San Antonio Bay. There were no suitable data from East Matagorda Bay, an unfortunate circumstance as this area is important to the MBHE.

Oyster Reef Condition Index Development describes the four indices of oyster condition that have been developed for this report, each providing a different indicator of the health of a reef population. Oyster Condition Index 1 (OCI 1) is an index based on commercial-sized oyster abundance, Oyster Condition Index 2 (OCI 2) is an index based on total oyster abundance, Dermo Condition Index (DCI) is an index of dermo infection intensity in commercially-sized oysters, and Oyster-Dermo Condition Index (ODCI) combines the OCI 1 and DCI, hence combining indicators of the abundance and health of the commercial-sized oyster population.

Multiple indices were created to allow for differences in available data types: dermo infestation data are less available than oyster abundance data. Oyster size data may also be less available than oyster abundance data, although not with the data used here. The availability of different indices also enables flexibility in a user's interpretation of which oyster population characteristics best indicate oyster reef condition.

Suitability Criterion Model Development describes the methodology and results involved in developing the oyster suitability criterion models. Multiple regression model-building techniques

were used to explore the predictive ability of a wide range of temperature and salinity parameters, both alone and in combination. The objective of these analyses was to develop relatively simple models (few terms) that had high predictive power as well as biological plausibility.

Separate analyses were performed for all four oyster condition indices to determine the best predictive regression model for each index. These best models were the designated suitability criterion models for oyster reef condition in Matagorda Bay. Depending on the condition index and model, 29% to 81% of the variation in oyster condition index was predicted by the suitability criterion models. The majority of that variation was accounted for by salinity rather than by temperature terms. Oyster abundance indices (OCI 1 and OCI 2) had an intermediate salinity optimum; while condition indices with dermo (DCI, ODCI) declined linearly with salinity, dermo parasitism increased with salinity.

2.0 Review of Existing Research

This review focuses on the research and data associated with direct and indirect effects on oyster growth and survival in relation to temperature and salinity. The focus is the American oyster, *C. virginica,* and all information in this review pertains specifically to this species of oyster. This review was used to guide development of oyster condition indices and oyster suitability criterion models presented later in this report.

2.1 Effects of Temperature and Salinity on Oysters

Oysters can survive in salinities ranging from approximately 5 to 40 ppt; however, growth is generally stunted below 7.5 ppt (Kennedy et al. 1996). Oyster reefs that are subjected chronically or episodically to salinities that are too low due to excessive freshwater inflow may experience complete or partial population mortality and/or stunted growth within the oyster community. Oysters grow optimally in salinities between 10 and 25 ppt (Cake 1983). Salinities greater than 25 ppt are not only suboptimal physiologically, but reefs located in regions of chronic or seasonally high salinities (>25 ppt) will have a greater mortality due to predation and to dermo, a parasite and parasitic infection caused by *P. marinus* (Kennedy et al. 1996).

Optimal water temperature for oysters is approximately 25°C while temperatures over 30°C can cause cessation of filter feeding (Kennedy et al. 1996; summer temperatures in Texas coastal estuaries are frequently at or slightly above 30°C). Winter water temperatures in Texas bays are typically not low enough to cause oyster mortality, but they can be low enough to limit growth rates (lowest winter water temperatures typically range from 10 - 15°C). The combination of physiological effects of low temperature and limited food supply can potentially cause individual oysters to lose biomass in winter months in Texas bays (Hofmann et al 1992).

Temperature and salinity can also indirectly impact oysters by affecting parasite levels. Two major parasites impact *C. virginica* populations in the United States, *Haplosporidium nelsoni* (also known as MSX) and *P. marinus* (dermo; Kennedy et al. 1996). However, only dermo is known to be a problem in the Western Gulf of Mexico (Soniat 2005).

Dermo infections can be strongly affected by temperature and salinity regimes. The division rate of dermo cells within oysters is related to both temperature and salinity of the surrounding water (Hofmann et al. 1995). According to Hofmann et al. (1995), at salinities greater than 10 ppt, dermo cell division is primarily affected by and increases with temperature; however below 10 ppt salinity, dermo cell growth decreases sharply with salinity and is also affected by temperature. An inspection of data from the DermoWatch program shows that, in western Gulf of Mexico bays, oyster populations on reefs closer to freshwater inflow sources typically have lower dermo infection intensities than reefs closer to the seawater source at the bay's mouth (see data on DermoWatch.org 2006; MBHE 2005). However, salinities low enough to curtail dermo populations can also stress oysters, so the ideal salinity regime to control dermo is one with episodic freshwater inflows that reduce salinity below 10 ppt, rather than continuously low salinities (Hofmann et al. 1995, Kennedy et al. 1996).

Dermo infestations tend to be most intense in summer, when temperatures are highest. Temperatures above 25°C are associated with high oyster mortality from dermo, and the persistence of high intensity dermo infestations is dependent on extended periods of high temperature (Kennedy et al. 1996). Such periods are common during summers in Texas bays.

Hofmann et al. (1995) modeled dermo growth rate in oysters as the difference between division rate and mortality rate. Soniat and Kortright (1998) used this model along with current dermo infestation levels to estimate a time (in days) to develop a critical level of dermo infestation. Soniat (2005) is currently working to empirically estimate dermo growth rates in western Gulf of Mexico (Louisiana and Texas) estuaries and feels growth rates based on the Hofmann et al. (1995) model may overestimate actual growth rates by as much as an order of magnitude. Notably, the dermo mortality rate from the Hofmann et al. (1995) model is based on the assumption that the activity of oyster phagocytotic immune cells, hemocytes, is directly related to dermo mortality. Other research has shown that hemocytes do not destroy dermo cells and, in fact, may harbor and protect them (Vasta et al. 1995). The dermo division rate (based on temperature and salinity) calculated with the model of Hofmann et al. (1995) was tested during this study as a potential element of the oyster suitability criterion model along with direct measures of temperature and salinity. Dermo growth rate, based on division rate minus death rate, was not tested because of the questionable assumptions of the death rate model.

Many important oyster predators are also limited by low salinities (Kennedy et al. 1996). The most severe predation impact on oysters in the western Gulf of Mexico is from the oyster drill, *Thais haemastoma* (Soniat 1998). Drill predation rates on oysters are limited by both low salinity and low temperature. Lower tolerance levels for drills (7.5 ppt, 12.5°C) also constitute poor conditions for oysters (Kennedy et al. 1996), but drill predation is also reduced in moderate salinities in the range where oysters prosper. In the western Gulf, significant losses to drills increase on reefs farther from freshwater sources (Soniat 2005).

Other oyster predators are limited by low or moderate salinities (Longley 1994, Kennedy et al. 1996). In general, extended periods of salinities greater than 25 ppt allow predator populations to build up and are associated with high predation rates on oyster populations (Kennedy et al. 1996)

2.2 Previous Work on Oyster Suitability Criterion Modeling –Habitat Suitability Index

An oyster habitat suitability criterion model for the Galveston region of the Texas coastal bays, including Matagorda Bay, was first developed by Cake (1983). This model produces a habitat suitability index (HSI) calculated from long-term salinity data and other habitat descriptors, such as substrate condition. Soniat and Brody (1988) modified this model and used monitoring data for field verification of the modified and original models. A further-updated version of this model can be found on Gulf Oyster Watch (http://www.gulfoysterwatch.org/), a site maintained by Soniat that includes an interactive calculator where a user may enter salinity data and (optionally) substrate data to get the calculated HSI.

These oyster HSI models are not based on statistical relationships between environmental parameters and oyster condition, or on modeled physiological and population processes (e.g. Hofmann et al. 1992, 1995; Powell et al. 1995, 1997). Rather, they combine a group of parameters that are set to vary from 0 (inimical to oyster growth) to 1 (optimal for oyster growth), based on

published oyster responses to a set of environmental conditions. The original model (Cake 1983) uses up to eight of these response vectors, denoted as V1 through V8. For example, Cake (1983) states that "oyster larvae will set at salinities between 5 and 35 ppt. Optimal setting occurs between 10 and 30 ppt, and maximum setting between about 18 and 22 ppt." V2, created to represent larval settlement in response to "mean summer salinity" is set to 0 if mean summer salinity is ≤ 5 ppt or ≥ 40, linearly increases from 0 to 1 from 5 to 10 ppt, equals 1 from 10 to 30 ppt, and linearly decreases back to 0 from 30 to 40 ppt (Figure 1; Cake 1983). Soniat and Brody (1988) have modified this term, so that V2 peaks at 20 ppt (Figure 1).

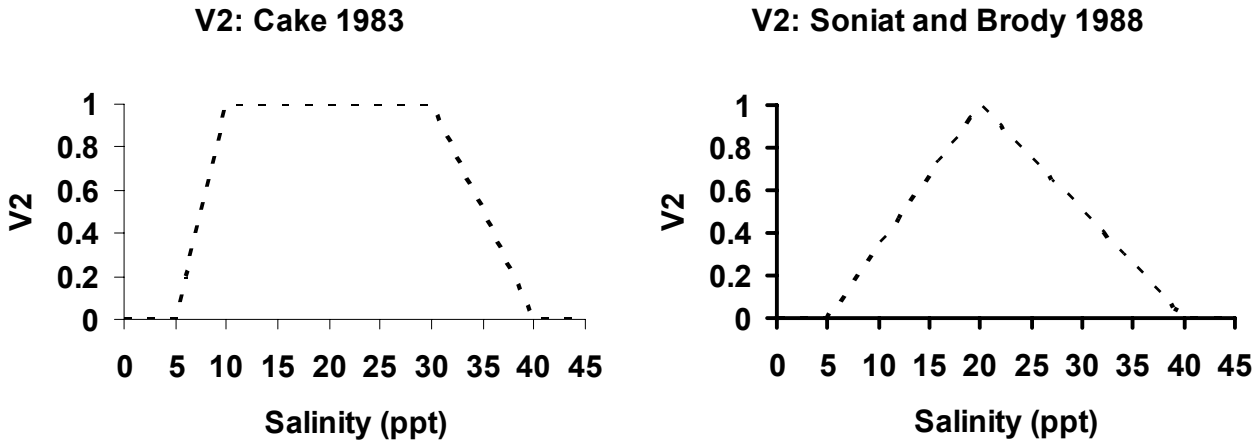


Figure 1. Comparison of V2 parameter for HSI model in response to mean summer salinity.

The number of "V" parameters used to calculate the HSI varies from four to eight depending on the version of model used and whether the user cares to include predators and parasites. These parameters are combined with equal weight to produce the HSI and are therefore not combined or weighted in a manner informed by statistical analysis, biological assumptions, or the number and type of parameters in the model. The suitability index developed by Soniat and Brody (1988) correlates significantly with "normalized oyster density" (log density adjusted to a 0 to 1 scale) on non-harvested reef sites in Galveston Bay. However, the correlation was insignificant when harvested reefs were included in the analysis (Soniat and Brody 1988). Soniat and Brody stressed that the index should be tested against an independently collected data set. The most updated version of the model, which is presented on Gulf Oyster Watch, has yet to be field tested.

Preliminary testing of the HSI model was performed; however, the relatively poor performance of the model in comparison to a data-based regression modeling approach in predicting oyster reef condition, and the available resources for the current task precluded an in-depth validation report of the HSI model.

3.0 Assessment of Available Data

A preliminary component to developing an oyster condition index and related suitability criterion regression based model for Matagorda Bay was to locate suitable data for these tasks. It was first necessary to determine the type of data ideally suited for describing the oyster condition and their responses as a function of salinity and temperature, and then to find and evaluate potential data sources. This section describes these issues with respect to data availability and coverage; specifically addressing types of data needed to describe oyster habitat and oyster populations, and appropriate spatial scales, temporal scales, and geographic boundaries for possible data sources.

3.1 Description of Data Search Goals

Ideally, the data used to develop oyster suitability criterion models would come from long-term concurrent monitoring of physical (habitat) conditions and oyster population conditions. Frequently, however, these are performed under separate monitoring programs. Oyster condition measures can include density of different life stages, average size or size structure of the population, dermo infection indices, and oyster physiological condition (i.e., length-weight or flesh condition data). Habitat physical measures include temperature and salinity.

Spatial scale is also an important consideration in searching for data. Relationships between the physical and biological properties of estuarine habitats should be made on spatial scales equivalent to those of oyster reefs. Scales larger than oyster reefs will lose information about relationships between oyster condition and temperature and salinity patterns specific to each reef location.

Temporal consistency is also important for development of the suitability criterion models. It is preferable to examine relationships between current oyster conditions and past trends in physical conditions on time scales of months, seasons and years. Such analyses require both a spatial link at the reef level and a consistent and frequent temporal sampling pattern.

For species with large geographic ranges, responses to environmental conditions are typically adapted to local climactic variations. Therefore, the geographic origin of data is an important consideration. The American oyster has a vast geographic range, including an enormous latitudinal gradient. In order to develop suitability criterion models that most accurately predict oyster condition within Matagorda Bay, data from the bay should be used; however, if additional data from oyster reefs in close geographic proximity and similar conditions to Matagorda Bay exist, these data should be evaluated for use.

3.2 Evaluation and Use of Available Data

3.2.1 DermoWatch Online Database

The DermoWatch program and DermoWatch online database (dermowatch.org) have been developed to track dermo infestation levels in established reefs throughout the Gulf of Mexico, although the most data exist for Galveston and surrounding bays, where the program was initiated. Salinity, temperature, dermo prevalence and dermo intensity in juvenile and commercial-sized

oysters are recorded for specific reefs on a monthly basis (although months are sometimes skipped) in Galveston and Matagorda Bays, and less frequently in other bays. The DermoWatch data base is the single best source of Matagorda Bay and Gulf of Mexico dermo infestation data.

Dermo prevalence is the percent or proportion of oysters with any level of dermo infestation; a standard parasitological metric. Parasite intensity indices vary depending on the parasite type and methods used to detect and quantify the parasite. The dermo intensity metric used in DermoWatch is Ray's Fluid thioglycollate media (RFTM) culture assay. The assay is used to visualize *P. marinus* infestation in oyster tissue on a semi-quantitative 0– 5 scale (0 = no observed parasites, 5 = all oyster tissue infested with parasites); http://www.tdi-bi.com/analytical_services/environmental/NOAA_methods/s&tmethod-dermo.pdf. The DermoWatch database records the average of dermo intensity index for 12 randomly-collected oysters per reef site. Oysters at infestation levels 4 and 5 are uncommon, probably because they do not survive long, and average dermo intensities above level 3 are extremely rare.

Population metrics for the oysters, such as oyster density and average length, are not recorded for the DermoWatch program; consequently, the DermoWatch data had to be linked to other data collection programs for suitability criterion model development.

Previous use of the DermoWatch database for the MBHE project examined data from the three Matagorda Bay reefs (MBHE 2005). In the interest of having a larger database and a wider range of reef salinity regimes for this study, data from Galveston, Lavaca, and San Antonio Bays were included for oyster suitability criterion model development. Lavaca Bay is connected with Matagorda Bay, and the other two bays are immediately adjacent to Matagorda Bay. Thus, data from these locations should be reasonably representative of processes in Matagorda Bay.

3.2.2 TPWD's Coastal Fisheries Data

TPWD coastal fisheries oyster dredge data are available for Matagorda, Lavaca, Galveston, and San Antonio bays. The data set includes counts of both live and dead oysters, spat (newly settled juvenile) counts on up to five live and five dead shells, total length of up to 19 live oysters, water temperature, and salinity. However, the TPWD monitoring programs do not include assessments of dermo prevalence, oyster weight or other oyster physiological indicators.

TPWD does not systematically resample a fixed set of oyster reef locations at a fixed time interval. Instead, for each sampling time (approximately once per month), a subset of locations are randomly chosen within a predetermined set of reef stations. A survey of data for seven Matagorda Bay stations sampled between 1999 and 2003 revealed that each station was sampled between two and eight times per year with the months varying randomly. These stations were sampled on average 4.9 times per year. This level of temporal coverage is insufficient for development of an oyster suitability criterion model. However, by combining TPWD sampling stations located on the same reef a more complete temporal coverage is possible.

3.2.3 Other Data Sources

Other oyster data sources referenced in the 2005 MBHE Data Inventory and Acquisition Final Report (MBHE 2005b) were evaluated, but none had the level of spatial and temporal coverage and resolution of the DermoWatch and TPWD databases. Additional data sources may be sought for future model modification and validation efforts.

3.3 Summary of Data Evaluation

No single data set provided dermo, oyster population, temperature, and salinity data. Hence, the approach for obtaining a suitable data set to develop an oyster suitability criterion model was to combine DermoWatch data and TPWD coastal fisheries oyster dredge data using the reef based spatial scale defined by the reefs sampled in DermoWatch program. This data aggregation accomplished two goals: it combined oyster population data with dermo data and it ameliorated the temporal gap problem inherent in TPWD randomized sampling by combining data from multiple stations.

TPWD and DermoWatch data were utilized and combined from Matagorda Bay, Lavaca Bay Galveston Bay, and San Antonio Bay. It was assumed that the geographic range was such that there would be no difference in oyster and dermo response to salinity and temperature among these bays, hence, their data could be combined to create a more robust data set. Although oyster reefs exist in East Matagorda Bay, no DermoWatch stations are located there, and TPWD oyster dredge sampling in this bay ceased in 1991. As a result, oyster suitability criterion model development did not include data from East Matagorda Bay even though the biological linkage task to the hydrodynamic/salinity model includes this bay. It is assumed that a model developed from data from the surrounding bays will be sufficient to characterize the expected oyster condition in East Matagorda Bay.

4.0 Data Processing and Aggregation

Two data sources were used for development of oyster condition indices and suitability criterion models. Temperature, salinity, and oyster population data were obtained from TPWD's coastal fisheries oyster dredge database. Dermo data, plus additional temperature and salinity data, were acquired from the DermoWatch monitoring program. This section describes the pre-processing and aggregation of those data that occurred before undertaking condition index construction and suitability criterion model development.

4.1 TPWD Summary Statistics Development

The TPWD oyster dredge data required pre-processing in order to derive sample summary statistics. Each TPWD oyster dredge sample resulted in between 1 and 26 rows/records containing oyster data in the database. The species code "9300" denoted a record with oyster data. A separate code denoted samples where no oysters were captured during dredging. Single records were either observations for individual live oysters, individual dead oysters, groups of live oysters or groups of dead oysters. Additionally, records with single live or dead oysters might or might not contain counts of attached spat (newly settled juvenile oysters, < 25 mm long). Records of live oysters were indicated with a "1" in a User Defined field; those of dead oysters were indicated with a "2" in this field. For each dredge sample, up to 19 individual live oysters ≥ 25 mm long were measured for length, the rest were only counted. For example, if 27 live oysters were caught, there were 19 records, reflecting individual oysters, with lengths recorded and with "1" in the organism number field. The remaining 8 were recorded without length information as a single record indicating "8" in the organism number column. If fewer than 19 live oysters were collected, the total number of records with live oysters equaled the number of individuals collected.

Up to five live oyster shells and five dead oyster shells were examined for attached spat for a given sample. The number of spat on each shell was recorded in three adjacent fields; each holding a single digit. To obtain total spat count the three fields must be concatenated; then average spat count per shell estimated and multiplied by the total number of live and dead shells in the sample. The five dead shells examined for spat were each recorded on a separate record. If more than five dead shells were collected then the remaining number were recorded in a single record.

In order to determine sample summary statistics such as total live oyster count, total commercial-sized oysters, mean oyster length, and total spat count, a program was developed to analyze the TPWD oyster dredge database. From this work, summary statistics are currently available for all TPWD oyster dredge samples taken in Matagorda, East Matagorda, Lavaca, San Antonio, and Galveston/Trinity Bays for 1986 through spring 2006. This program and summary database is available for future applications utilizing TPWD oyster dredge data.

4.2 Data Aggregation

TPWD and DermoWatch stations were grouped to improve temporal continuity of data. Typically multiple TPWD stations per DermoWatch reef existed. A combination of map sources and station statistic comparisons were used to group TPWD stations with each other and with DermoWatch

stations in Matagorda , Lavaca , Galveston, and San Antonio Bays. In Matagorda, Lavaca, and San Antonio Bays, additional groups of stations in non-DW locations were chosen because they formed coherent spatial groups and had similar average statistics. In all, data from 97 TPWD sample stations and 13 DermoWatch reef stations were combined to create data sets for 20 reef locations; 13 based on established DermoWatch locations (Table 1). Figures 2a – 2d illustrate the oyster sampling locations and reef locations within San Antonio Bay, Matagorda Bay, and Trinity and Galveston Bays.

Table 1. Summary of the TPWD oyster dredge stations and DermoWatch stations combined to create reef locations.

Stations are indicated by their TPWD grid number in each bay (numbers may be repeated in different bays), and "DW" indicates a station from the DermoWatch database. The number of months that were not sampled for each reef location during the years 2000 – 2005 is also indicated.

Reef Location #	Major Bay Area	Reef Location Name*	Stations in Reef Location	# of Stations	Dermo Watch Site	# Missing Months 2000-2005
1	Matagorda	Sammy's Reef	240, 280, DW	3	Yes	15
2	Matagorda	Mad Island Reef	203, 243, 244, DW	4	Yes	9
3	Matagorda	Shell Island Reef	205, DW	2	Yes	22
4	Matagorda	Charancahua Bay	88, 89, 116, 117, 118, 148	6	No	3
5	Matagorda	Tres Palacios Bay	74, 93, 94, 95, 124, 158	5**	No	1
6	Matagorda	Oyster Lake Point	316, 317, 347, 348, 349, 379	6	No	2
7	Lavaca	Indian Point	332, 364, DW	3	Yes	17
8	Lavaca	Gallinipper Point	297, 298, 254, 255, DW	5	Yes	7
9	Lavaca	Upper Lavaca Bay	44, 45, 46, 60, 61	4***	No	6
10	Lavaca	Rt 35 Bridge	107, 108, 136, 137	4	No	7
11	Galveston	Fisher's Reef	112, 113, 114, 133, 134, DW	6	Yes	8
12	Galveston	Frenchy's Reef	326, 327, 358, 359, DW	5	Yes	16
13	Galveston	Redfish Reef	343, 344, 345, 346, 370, 371, 372, 373, DW	9	Yes	1
14	Galveston	Hanna's Reef	376, 377, 378, 379, 402, 403, 404, 405, 406, DW	10	Yes	4
15	Galveston	Confederate Reef	562, 563, 564, 574, 575, 576, 577, 578, DW	9	Yes	3
16	San Antonio	V Reef	102, 103, 104, 120, 121, 122, DW	7	Yes	7
17	San Antonio	2nd Chain Reef	165, 177, 178, 188, DW	5	Yes	14
18	San Antonio	1st Chain Reef	99, 281, 282, 111, 112, DW	6	Yes	11
19	San Antonio	Port O'Connor	211, 212, 217, 218, DW	4	No	13
20	San Antonio	Espiritu Santo Bay	262, 263, 274, 275, 276	5	No	7

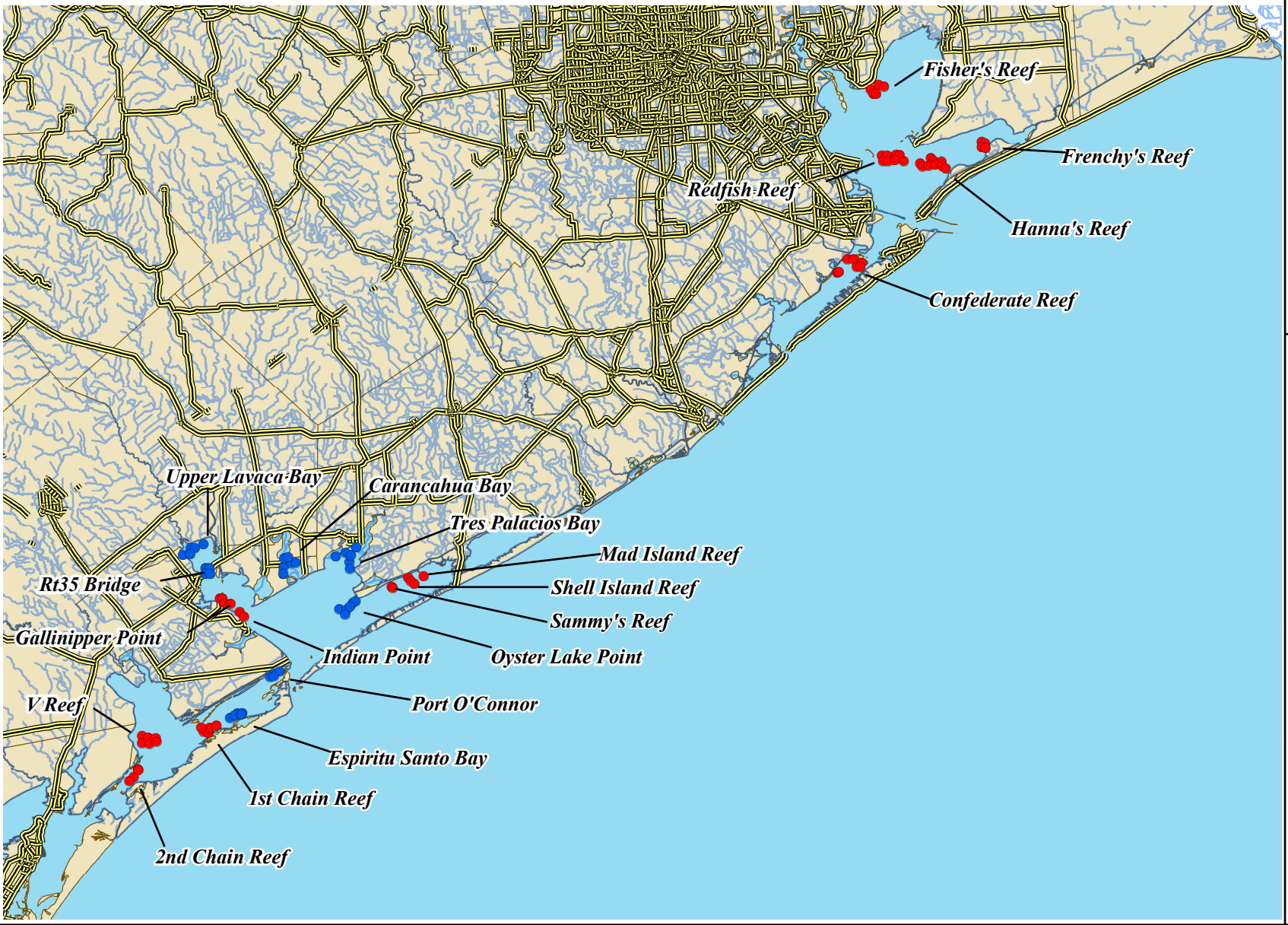
Reef Location #	Major Bay Area	Reef Location Name*	Stations in Reef Location	# of Stations	Dermo Watch Site	# Missing Months 2000-2005

**Reef location names were taken from the DermoWatch database for DW locations, and reef locations were named for local geographic features otherwise.*

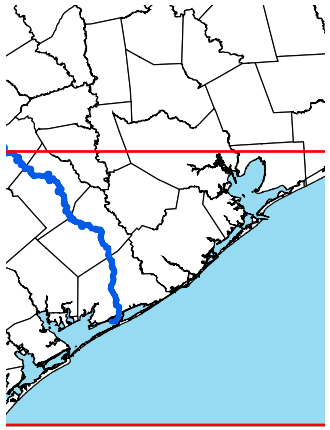
***station 94 had only one sample.*

****station 60 had only 2 samples.*

Oyster Reef Locations



LOCATION OF TEXAS BAYS



Legend

- Roads and Highways
- NHD Hydrology
- Counties
- Water
- Dermo Watch site
- non-Dermo Watch site

Figure 2-a.

Oyster Sampling Locations.

Station locations are the average latitude and longitude of each station recorded in the TPWD Coastal Fisheries Oyster Dredge Database.

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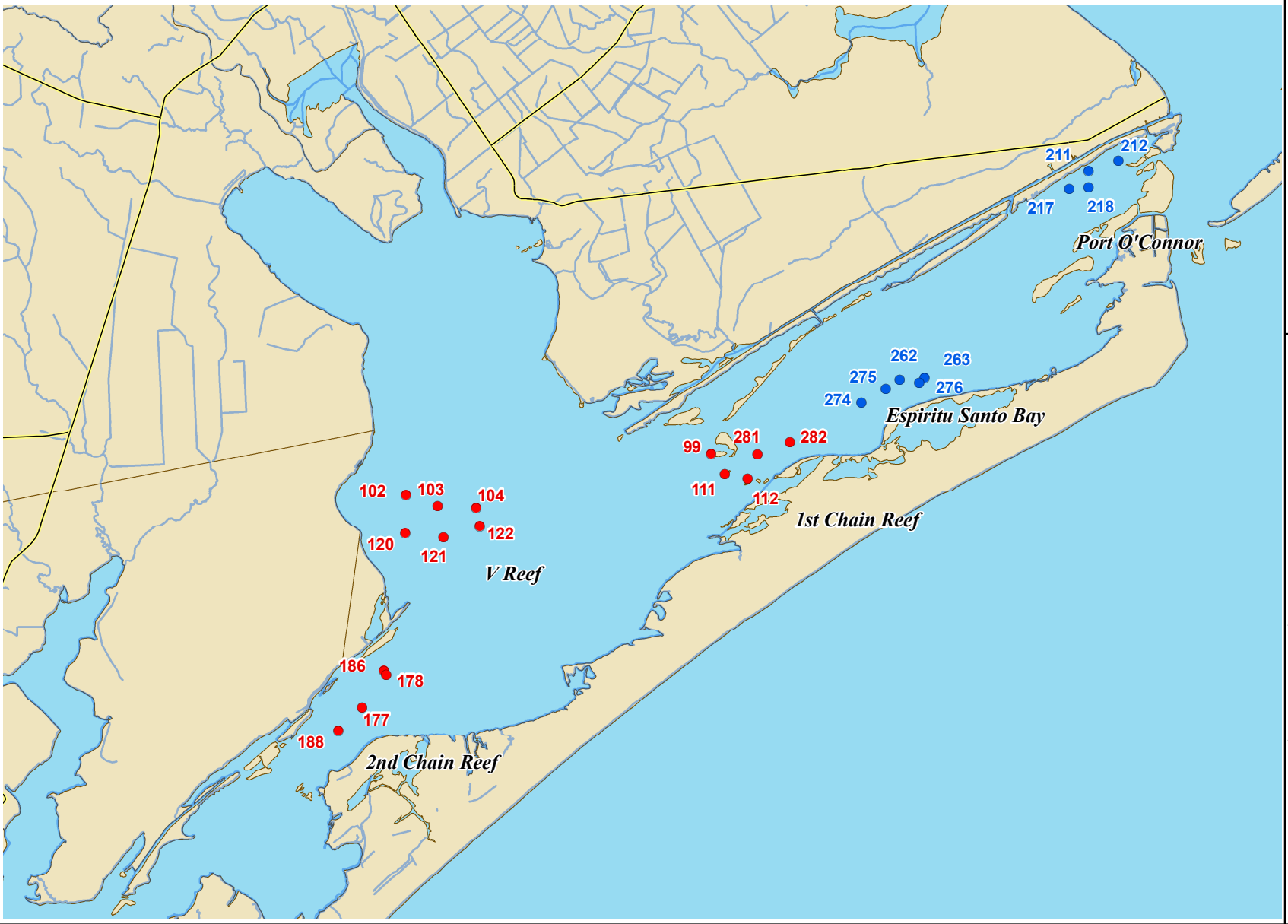
SCALE BAR

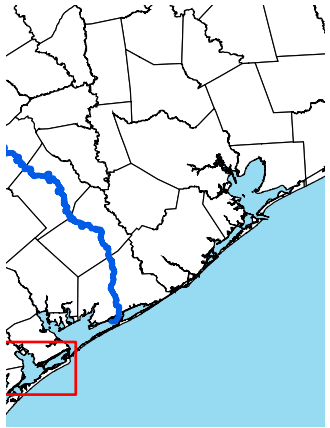
0 12.5 25 50 75 KM

"oyster_data.pdf"/ August 31, 2006 / QEA, LLC / Henna Chou /
Texas State Plane, Central Zone 5376, NAD83, (U.S. survey ft.) Lambert Conformal Conic projection

Oyster Reef Locations



LOCATION OF TEXAS BAYS



Legend

- Roads and Highways
- NHD Hydrology
- Counties
- Water
- non-Dermo Watch site
- Dermo Watch site

Figure 2-b.

San Antonio Bay

Station locations are the average latitude and longitude of each station recorded in the TPWD Coastal Fisheries Oyster Dredge Database.

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SCALE BAR

0 1.25 2.5 5 7.5 10 Kilometers

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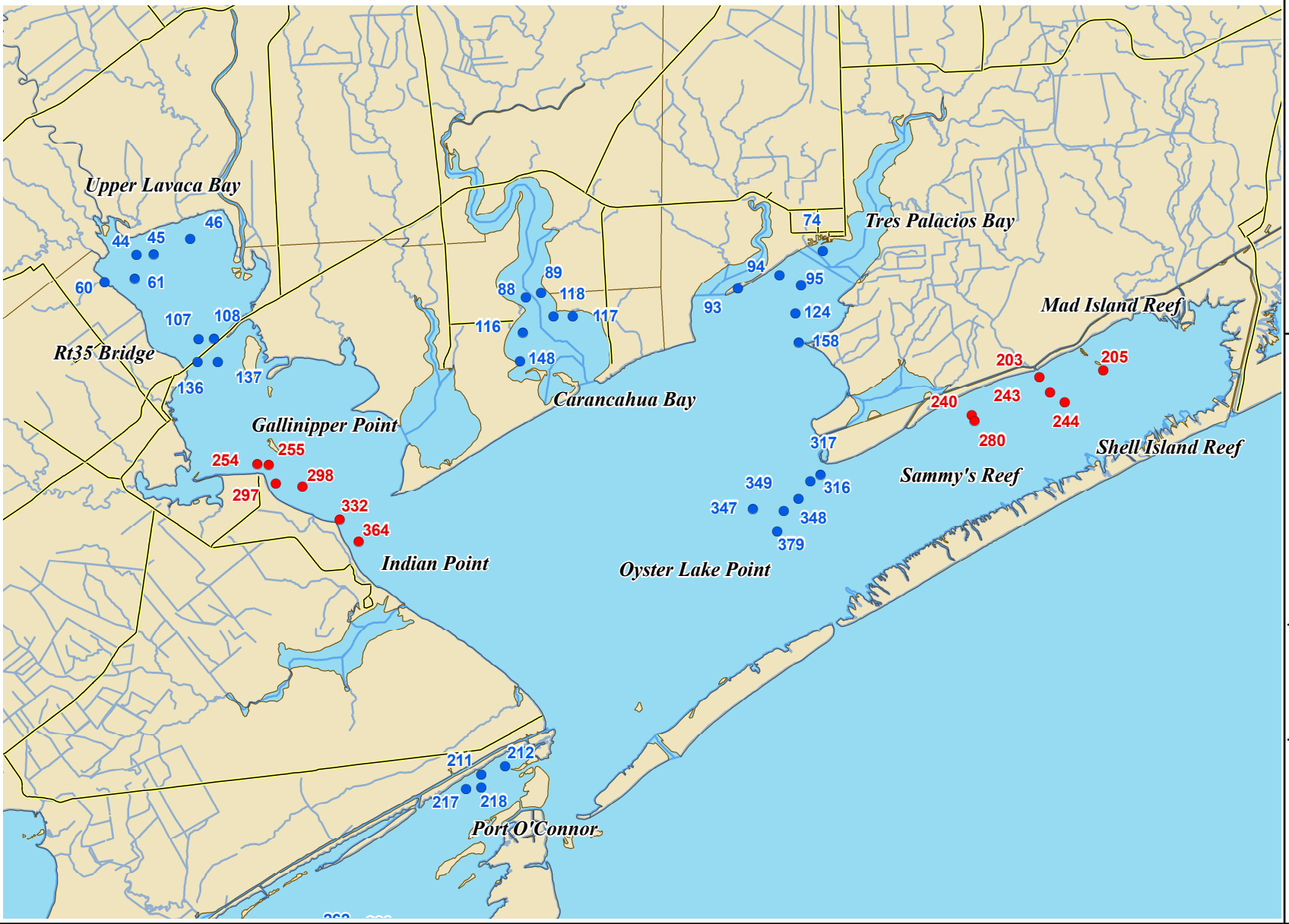
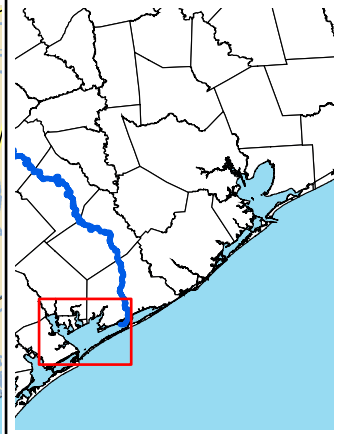
Texas State Plane, Central Zone 5376, NAD83, (U.S. survey ft.) Lambert Conformal Conic projection

Oyster Reef Locations



LOCATION OF TEXAS BAYS



Legend

- Roads and Highways
- NHD Hydrology
- Counties
- Water
- non-Dermo Watch site
- Dermo Watch site

Figure 2-c.

Matagorda Bay

Station locations are the average latitude and longitude of each station recorded in the TPWD Coastal Fisheries Oyster Dredge Database.

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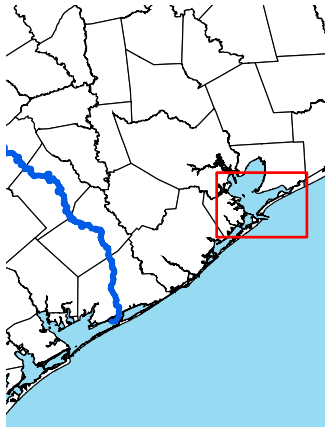
SCALE BAR

0 1.5 3 6 9 12 Kilometers

"oyster_data.pdf"/ August 31, 2006 / QEA, LLC / Henna Chou /
Texas State Plane, Central Zone 5376, NAD83, (U.S. survey ft.) Lambert Conformal Conic projection

Oyster Reef Locations

LOCATION OF TEXAS BAYS



Legend

- Roads and Highways
- NHD Hydrology
- Counties
- Water
- non-Dermo Watch site
- Dermo Watch site

Figure 2-d.

Trinity and Galveston Bays

Station locations are the average latitude and longitude of each station recorded in the TPWD Coastal Fisheries Oyster Dredge Database.

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SCALE BAR

0 1.5 3 6 9 12 Kilometers

"oyster_data.pdf"/ August 31, 2006 / QEA, LLC / Henna Chou /
Texas State Plane, Central Zone 5376, NAD83, (U.S. survey ft.) Lambert Conformal Conic projection

The number of TPWD and DermoWatch stations combined for each reef location ranged from 3 to 10 due to reef size and whether they were DermoWatch locations. The number of months with missing temperature and salinity data from 2000 through 2005 declined as the number of stations per reef location increased (Figure 3), demonstrating the efficacy of combining stations to improve temporal continuity in the data.

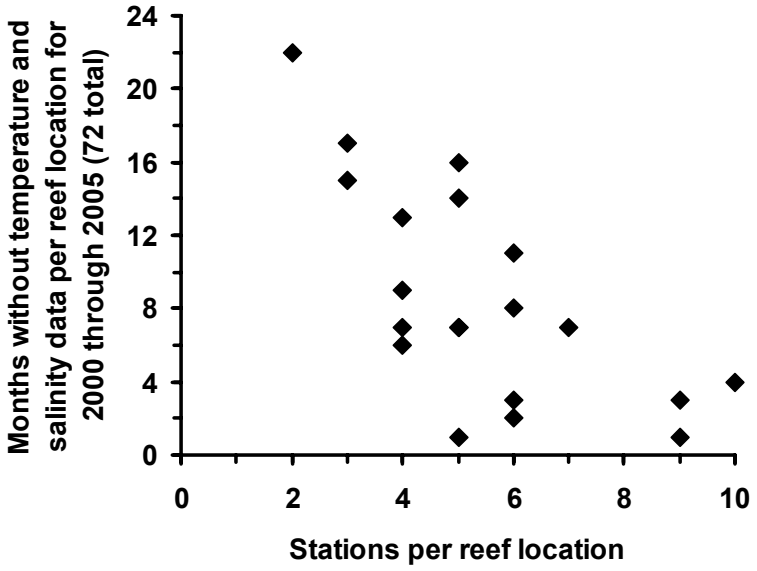

Figure 3. Monthly availability of temperature and salinity based on stations per reef.

Temperature, salinity, and oyster count data were available starting from 1986 for most TPWD stations. Because the oyster analysis involves interpretation of data 10 years prior to the oyster population sampling date, this enabled analysis of relationships between oyster population data from 1996 onward. DermoWatch data were only available from the late 1990s or early 2000s depending on the location, and were restricted to fewer reef locations. Therefore, incorporation of dermo into suitability criterion models was performed with a more restricted data set.

Calendar months (January through December) were chosen as the basic temporal subunit for the combined data set because there was rarely more than one day of sampling per month per reef location (multiple stations at a reef location were often sampled, but usually all on the same day). Once the DermoWatch program began, two sample days per month per reef location were more common.

Both physical data (temperature and salinity) and biological data (oyster counts, dermo) were aggregated on a monthly scale. The four oyster condition indices (defined in section 5.2) were also calculated for each month where the relevant oyster and dermo data were available. Multiple station samples on the same day at a reef location were treated as repeated measures of the same site and were averaged to get a daily average. Then, if there were multiple sample days per month, these were averaged to obtain the monthly average for a reef location.

Table 2 summarizes the averages of the available monthly values for 1996 through 2005 for each reef location.

Where temperature and salinity data were available, the monthly average dermo division rate, dermo r, was calculated using the equation from Hofmann et al. (1995):

For salinity > 10 ppt:

$$dermo\ r = 0.555e^{0.06931(T-20)}$$

where:

T = temperature in ˚C

Or

For salinity ≤ 10 ppt:

$$dermo\ r = rd(_{To,So})*(S/10)e^{0.06931(T-20)}$$

where: rd ($_{To,So}$) = dermo r at reference temperature and salinity (20˚C and 20 ppt).

S = salinity in ppt

T = temperature in ˚C.

Table 2. Average parameters for reef locations.

Temperature, salinity, total oyster count, commercial oyster count, dermo intensity, Dermo Condition Index (DCI), Oyster Condition Index 1 (OCI 1), OCI 2, and ODCI have been calculated from all available monthly averages for each reef location. Number of months with a particular data type for each location are indicated by 'Temp and Salinity N', 'Oyster Count N', and 'Dermo N'. As this is a ten year period, the maximum N would be 120. N for the condition indices will be equal to Oyster Count N for OCI 1 and OCI 2, equal to Dermo N for DCI, and for ODCI will be the number of months that have both oyster count and dermo data (slightly lower than Dermo N).

Major Bay Area	Reef Location Name	Temperature	Salinity	Temp and Salinity N	Total Oyster Count	Commercial Oyster Count	Oyster N	Dermo Intensity Index	Dermo N	DCI	OCI_1	ODCI	OCI_2
Matagorda	Sammy's Reef	23.14	18.50	87	20.14	4.52	75	1.18	35	0.46	0.38	0.41	0.57
Matagorda	Mad Island Reef	23.32	17.23	105	20.36	5.07	102	0.54	23	0.70	0.40	0.50	0.57
Matagorda	Shell Island Reef	22.88	16.63	71	29.80	4.87	56	0.14	16	0.91	0.39	0.56	0.64
Matagorda	Charancahua Bay	23.13	18.71	116	19.81	7.00	116				0.46		0.57
Matagorda	Tres Palacios Bay	22.66	20.53	118	20.16	5.20	118				0.40		0.57
Matagorda	Oyster Lake Point	22.20	23.09	112	0.34	0.12	112				0.03		0.05
Average for bay		**22.89**	**19.11**	**101.5**	**18.44**	**4.46**	**96.5**	**0.62**	**24.67**	**0.69**	**0.34**	**0.49**	**0.50**
Lavaca	Indian Point	22.73	20.77	87	17.44	3.14	79	0.74	19	0.62	0.31	0.41	0.54
Lavaca	Gallinipper Point	22.36	19.15	105	39.17	4.79	101	0.83	21	0.58	0.39	0.45	0.69
Lavaca	Upper Lavaca Bay	22.02	13.15	108	7.99	1.58	108				0.21		0.41
Lavaca	Rt 35 Bridge	22.40	15.98	108	21.07	2.62	108				0.29		0.58
Average for bay		**22.38**	**17.26**	**102**	**21.42**	**3.03**	**99**	**0.78**	**20**	**0.60**	**0.30**	**0.43**	**0.56**
Galveston	Fisher's Reef	20.72	13.13	104	25.01	5.80	93	0.15	44	0.90	0.43	0.58	0.61
Galveston	Frenchy's Reef	20.65	15.65	91	17.69	5.68	68	0.65	53	0.65	0.42	0.50	0.55
Galveston	Redfish Reef	21.36	16.26	118	28.81	6.95	111	1.13	71	0.48	0.46	0.47	0.63
Galveston	Hanna's Reef	21.31	16.79	113	32.43	6.84	109	0.95	65	0.54	0.46	0.48	0.66
Galveston	Confederate Reef	22.95	24.16	111	9.56	2.36	105	1.92	78	0.26	0.27	0.27	0.44

Major Bay Area	Reef Location Name	Temperature	Salinity	Temp and Salinity N	Total Oyster Count	Commercial Oyster Count	Oyster N	Dermo Intensity Index	Dermo N	DCI	OCI_1	ODCI	OCI_2
Average for bay		**21.40**	**17.20**	**107.4**	**22.70**	**5.53**	**97.2**	**0.96**	**62.2**	**0.57**	**0.41**	**0.42**	**0.58**
San Antonio	V Reef	22.17	11.80	107	12.81	2.75	106	0.01	9	0.99	0.29	0.52	0.49
San Antonio	2nd Chain Reef	23.02	14.50	91	24.83	5.09	79	0.86	40	0.57	0.40	0.46	0.61
San Antonio	1st Chain Reef	22.59	20.00	104	20.64	3.71	100	1.07	36	0.50	0.34	0.39	0.57
San Antonio	Port O'Connor	23.63	25.42	98	9.35	1.78	98				0.23		0.44
San Antonio	Espiritu Santo Bay	22.73	23.79	107	10.63	1.81	107				0.23		0.46
Average for bay		**22.83**	**19.10**	**101.4**	**15.65**	**3.03**	**98**	**0.65**	**28.33**	**0.69**	**0.30**	**0.46**	**0.51**
Range of Reef Location Averages:													
	Minimum:	20.65	11.80	71.00	0.34	0.12	56.00	0.01	9.00	0.26	0.03	0.27	0.05
	Maximum:	23.63	25.42	118.00	39.17	7.00	118.00	1.92	78.00	0.99	0.46	0.58	0.69

4.3 Development of Temperature and Salinity Terms on Different Temporal Scales

Oyster reef condition may be dependent on temperature and salinity forcing functions operating on a variety of temporal scales, including seasonal, annual, and multi-annual. The approach for suitability criterion model development compared oyster condition to temperature and salinity in terms of different temporal scales in order to provide the best predictive model. Occurrence of extreme salinity events such as freshwater inundations was also considered. Table 3 describes temperature and salinity terms that were evaluated as predictors in the oyster suitability criterion regression model, and how they were hypothesized to relate to oyster and dermo population dynamics. This section describes the protocol used to calculate these terms for each reef location for all months ranging from 1996 to 2005; that is, 10-year averages may include data from as far back as 1986 (for months in 1996). This data set is available upon request.

Table 3. Terms considered for oyster suitability criterion model development.

Temporal Scale	Term	Predicted impact, rationale
Immediate or short term annual averages	1 or 2 year salinity average	Effects of single or multi-year droughts or other types of short term climactic extremes. Oysters take 1-2 years to grow to commercial size, so reefs usually take 2-3 years to recover from catastrophic or extreme events in the Gulf.
	1 or 2 year temperature average	
Long term or 'historic' annual averages	5 or 10 year salinity average	Long-term suitability of a reef location – annual extremes should not have a large impact on these terms. Long-term salinity will vary substantially with location of the reefs, but long term temperature average is unlikely to vary much among years or locations in the small region being considered in this study
	5 or 10 year temperature average	
Short term averages	Average winter, spring, summer and/or fall salinities of preceding year	Short-term population growth responses of both oysters and dermo.
	Average winter, spring, summer and/or fall temperatures of preceding year	Determine which seasons have the largest shot-term impact on oyster condition.
	Average salinity of the current 3-month season	
	Average temperature of the current 3-month season	
	Average dermo division rate (Hofmann et al. 1995) of the current 3-month season	
Long term seasonal averages	5 or 10 year salinity average for winter, spring, summer or fall	Important if particular seasons have a larger impact than other seasons on reef location and condition.
	5 or 10 year temperature average for winter, spring, summer or fall	
Extremes—short term*	Weeks or months since a killing flood (≤ 2 ppt salinity)	Short term oyster population loss and recovery from freshwater die-off

Temporal Scale	Term	Predicted impact, rationale
	Weeks or months since "dermo-cleansing" level of salinity (≤ 10 ppt salinity)	Short term dermo population reduction and recovery from intense infection for oysters.
	Weeks or months of high salinity duration (≥ 25 ppt salinity)	Physiologically stressful for oysters and allows predator and parasite levels to continuously increase.
	Weeks or months of high temperature duration (> 25 ˚C)	Physiologically stressful for oysters and allows for a very high dermo division rate.
Extremes—long term	Frequency of killing floods (<= 2 ppt salinity)	Frequency of lethal freshwater inflows will determine suitability of location for reef

**Impacts of short-term extremes were not investigated in the2006 suitability criterion modeling effort, but may be incorporated into the 2007 model revision and validation effort.*

Temperature and salinity data were first grouped by season. Seasons were defined as follows: winter was designated to be December – February; spring: March – May; summer: June – August; and fall: September – November. Seasonal averages were constructed for temperature, salinity, dermo intensity, total oyster counts, and commercial oyster counts. The four oyster condition indices (defined in section 5.2) were also calculated for each season. Season averages were calculated for each reef location from monthly averages from spring 1986 through fall 2005 where data were available. The number of months used for the average (which ranged from 0 to 3 depending on available data) was also retained in the database. If there were no monthly data for a data type during a season (season_n = 0), then the season average field was left blank for that data type.

Temperature and salinity data were then grouped in one-year and multiple-year averages by combining consecutive seasonal averages. For one-year and two-year averages, if one or more of the composite seasons had a season_n < 2, the average was not calculated and was left as a missing data point. This helped ensure that the season averages were not skewed by very small sample sizes in a given season.

For five-year and 10-year averages, minimum sample size restriction per season was relaxed so that only one month of data per season was needed in all of the seasons combined for the average. This was done because as the number of years increased, the likelihood of having a season with less than two months data was very high and too many fields were left blank. Fortunately, any skewing due to an increased number of missing months would be ameliorated by the longer time span.

The seasons used to obtain a yearly temperature or salinity average depended on the month and year of biological data to which the physical data were being compared. If the month of the biological data was one of the final months of a season (February, May, August, or November), then the yearly average started with that season and worked backward three more seasons. If the month was not the final month of the season, then the yearly average started with the previous season and worked back three more seasons. Additional years back in time all had the same seasonal starting place.

Spring, summer, fall, and winter temperature and salinity averages from the preceding year were calculated in the following way. For the last months of a season, that year's 'preceding' value for the season the month belonged to was actually the current season. In all other cases, a value from an earlier season was used. At least two months of the season must contain data for the specific

seasonal average to be calculated; otherwise, the field was left blank. Spring, summer, fall, and winter averages for temperature and salinity were also constructed for two, five, and 10 years working backward in time from the first year's average. At least two months per season for each season had to have data for the two-year average and at least one month per season for all seasons had to have data for the five-year and 10-year averages.

A specific term in the Cake and Soniat HSI model, the frequency of killing floods (FKF), also necessitates a long data period for calculation. While the HSI model is not explicitly tested in this report, the effect of flood frequency on oyster condition was tested as a potential term in the suitability criterion models. The duration of the time series used to calculate flood frequency is not specified by Cake (1983) or Soniat and Brody (1988), but was decided for this study to utilize five-year and 10-year spans as with the long-term temperature and salinity averages.

Gulf Oyster Watch defines a killing flood as at least three weeks of salinity ≤ 2 ppt at a reef site. The level of temporal resolution available in the data used here did not allow for determination of flood duration. As a proxy, it was decided that any month where average salinity at a reef location was ≤ 2 ppt would be designated a "killing flood" event. FKF was the average time in years between killing floods and was calculated based on the number of killing flood events in either a five-year or 10-year span.

5.0 Oyster Reef Condition Index Development

A prerequisite to developing oyster suitability criterion models was the definition and development of an index to describe oyster reef condition. A number of various metrics can be considered when describing an "oyster reef condition"; such as, production of harvestable oysters, dermo infection intensity, fecundity/reproductive effort, and annual biomass production. The choice in this work was restricted by available data and focused by the project goals. This section explains the choice and development of four oyster condition indices, and provides mathematical and distributional descriptions of those indices.

5.1 Choosing Metrics of Oyster Condition

The oyster condition metric predicted by Cake and Soniat and Brody's HSI model is total oyster density (Cake 1983, Soniat and Brody 1988). However, while oyster density will be used as one indicator of oyster reef condition to be predicted by the suitability criterion models in this work, it will not be the only criterion used. The main reason for this is that density alone may not adequately describe oyster reef condition, especially given the tendency for oyster size within high-density patches to be stunted due to resource competition (Hofmann et al 1992, 1995). Stunted oyster populations result in limited commercial value and poor reproductive effort. To improve indication of oyster population quality, oyster reef condition should also include size-class specific information such as adult or legal-sized oyster density (Soniat 2005).

TPWD oyster dredge data included counts of all live oysters collected in one dredge pull and lengths of a subset of those oysters. These data provide a source of both abundance and size structure data. It is assumed that dredge pull protocol has not changed from 1996 to present, so that the count data are comparable among samples. Count data were not converted to density data, but this can be done at a future time without changing the results of the analyses in this report.

Two categories of count data were used for the development of the MHBE oyster condition indices. *Total oyster count* was defined as the total live oyster count. *Commercial oyster count* was the total oyster count multiplied by the proportion of measured oysters that were ≥ 76 mm, the current legal size for oysters in the state of Texas. Commercial counts were considered preferable for index construction because they represented the production of marketable oysters, and the presence of large numbers of small oysters (which would lead to a high total count) do not necessarily indicate a healthy reef.

Also included in oyster condition index development was an indicator of the impact of the major oyster parasite dermo, which severely impacts oyster populations in the Gulf of Mexico. The presence and intensity of dermo infections can affect reproduction and survival of adult oysters as well as reduce the quality of oyster meat, hence reducing market values of harvested oysters. For both commercial and juvenile oysters, the DermoWatch database includes prevalence (% of oysters infested) and average intensity of dermo infestation per oyster. Because prevalence has an upper limit of 100%, it does not convey as clear a picture of parasite infestation as intensity. This occurs because a 100% infested population (prevalence = 1.0) may range from light to severe dermo intensity in each oyster. Intensity of infection can and did continue to increase after prevalence of infected individuals maxed out at 100%. Therefore, it was decided that intensity was a better

indicator of parasite levels on the oyster reefs and only *dermo intensity* was used to construct oyster condition indices for Matagorda Bay.

Physical descriptors such as length-weight ratio or flesh condition of oysters (which deteriorates as a result of dermo) could also be good indicators of reef condition, but there did not appear to be suitable data sources (in terms of duration and geographic range) for these metrics.

5.2 Condition Index Definition and Explanation

Four oyster reef condition indices based on commercially-sized oyster abundance, total oyster abundance, dermo infection intensity in commercially-sized oysters, and a combination of dermo infection and commercial oyster abundance were constructed from monthly oyster and dermo data. The index most useful to an investigator will depend on types of available input data as well as the goal of the investigation.

Oyster Condition Index 1 (OCI 1) is an index of commercial oyster abundance normalized to a 0 to 1 scale:

$$OCI\ 1 = \frac{Log_{10}(CommercialOysterCount + 1)}{Log_{10}(MaxOC + 1)}$$

This index relies upon a maximum commercial oyster count (MaxOC). The maximum observed commercial oyster count in the data set used here was 80, but higher counts are possible. A value of 90 was used here for MaxOC. MaxOC was chosen, after examining the data set, as a best judgment of a value that was not likely to be exceeded while not going too far above the maximum observed value in the data. Thresholds for the other indices were chosen similarly. Future model refinement efforts may include development of a more formal statistical protocol for cutoff choice. Note OCI 1 can only be calculated in cases where oyster count data and size data are available. For cases where oysters are present and all below the commercial size threshold, OCI 1 equals 0.

Oyster Condition Index 2 (OCI 2) is an index of total oyster abundance normalized to a 0 to 1 scale:

$$OCI\ 2 = \frac{Log_{10}(TotalOysterCount + 1)}{Log_{10}(MaxTO + 1)}$$

Maximum total oyster count (MaxTO) in the data set was 200, but higher counts could occur during model validation and a cutoff of 210 was therefore used for MaxTO. OCI 2 was developed because cases may arise where oyster abundance data are not accompanied by size data, in which case OCI 1 cannot be calculated. However OCI 1 is recommended over OCI 2 for the MBHE project.

Dermo Condition Index (DCI) is an index of dermo infection intensity in commercially-sized oysters normalized to a 0 to 1 scale. DCI decreases as dermo intensity increases because higher dermo indicates poorer condition.

$$DCI = \frac{1 - Log_{10}(Dermo\ Intensity + 1)}{Log_{10}(MaxInt + 1)}$$

Maximum dermo intensity (MaxInt) in the data set used here was 3.2, but higher counts could occur during model validation and a cutoff of 3.25 was therefore used for MaxInt. It is important to

recognize that a higher DCI indicates a more parasite-free oyster population, hence a better condition. This index can only be calculated for times when dermo was measured, which is a small subset of the total data set.

Oyster-Dermo Condition Index (ODCI) combines the indices for dermo intensity and commercial oyster counts, hence combining the abundance and parasite-related health of the commercial oyster population into one index.

$$ODCI=2/3*OCI1+1/3*DCI$$

The weighting of the two component indices is arbitrary and may be changed to better reflect the relative importance of these variables with regard to reef condition in future model refinement efforts. The current unequal weighting was chosen because the amount of commercially-sized oysters caught was thought to be more important than the quality of their meat, because dermo intensities high enough to render meat unmarketable (4 or 5) would be rare, and because moderately infested oysters can still spawn (although to a lesser degree than unparasitized oysters). Therefore, because a dermo-infested commercial oyster population was better than none at all, oyster abundance was deemed worthy of a higher weighting than dermo infestation in the combined index.

ODCI can only be calculated when dermo intensity, oyster abundance, and oyster size data are available at a reef location. For the current project, it is therefore the most limited index in terms of sample size. An investigator who does not wish to use the combined index, but still wishes to predict dermo intensity and oyster abundance can use the suitability criterion models for DCI and OCI 1 or OCI 2 separately (section 5).

5.3 Distributional Properties of the Condition Indices

The condition indices, based on oyster abundance, OCI 1 and OCI 2, had a high frequency of zero values, and were highly heterogeneous through time at each reef site. This temporal heterogeneity was likely due to high spatial heterogeneity in abundance (typical of benthic organisms) and the necessary variability in dredge pull locations. To decrease the temporal heterogeneity of these indices (which initial regression analysis found subsequently improved the predictive ability of suitability criterion regression models), indices were averaged for each season (3-month averages), and these seasonal index values were used for suitability criterion model development rather than the monthly values.

OCI 1 and OCI 2 had many zero counts even after aggregating them to seasonal averages (Figure 4). OCI 1 unfortunately had very little representation of high values in the data set used for this work. DCI had a relatively uniform distribution, slightly skewed toward higher values (lower parasite levels; Figure 4). When DCI and OCI 1 were combined to create ODCI, the result was a normal distribution for the condition index, with no zero values (Figure 4). The better distributional properties of this index in comparison to its component indices may improve the statistical robustness and reliability of its suitability criterion model, especially in comparison to OCI 1. In some cases ODCI was derived solely from DCI because OCI 1 was zero. This is a legitimate situation because while oysters were below the detection limit of dredge pulls, they still had to be present at the site for parasite data to be collected.

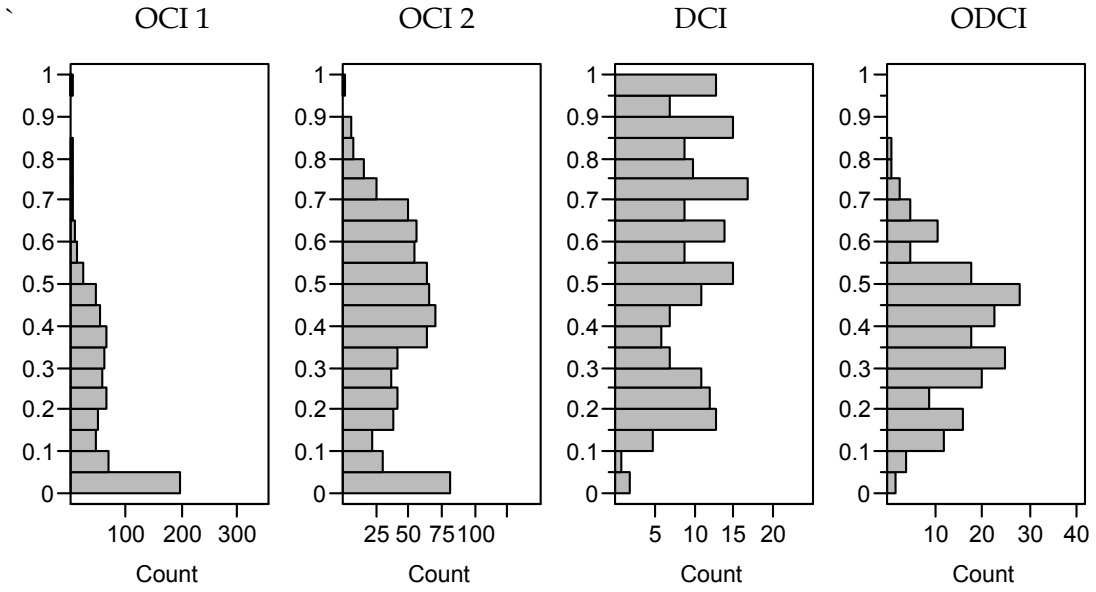

Figure 4. Frequency distribution of seasonal averages of the four oyster condition indices from 1996 through 2005 for all reef locations combined.

6.0 Suitability Criterion Models

6.1 Model Development Overview

This section describes the development of the oyster suitability criterion models based on statistical regression modeling. Multiple regression model-building techniques were used to explore the predictive ability of a wide range of temperature and salinity parameters, both alone and in combination. The objective of these analyses was to develop relatively simple models (few terms) correlating temperature and salinity to oyster health that have high predictive power as well as biological plausibility.

Four indices of oyster condition have been developed for this report, each providing a different indicator of the health of a reef population. The indices represent commercial oyster population abundance, total oyster population abundance, level of dermo parasitism, and a combination of commercial population abundance and parasitism. Separate analyses were performed for all four indices to determine the best predictive regression model for each index. These best models were the designated suitability criterion models for oyster reef condition in Matagorda Bay.

6.2 Two Regression Approaches Based on Temporal and Spatial Extent Variations

Two regression approaches were used for the development of suitability criterion models. These approaches differed in the temporal aggregation of dependent and independent model terms. For Approach 1, seasonal condition index values (3-month averages) were calculated from all reef locations and were then pooled and regressed against temperature and salinity terms for their reef location and date. Terms tested for prediction of condition indices ranged in time scale from current condition index season averages of temperature and salinity to 10-year temperature and salinity averages prior to the condition index date.

Average statistics for each reef location, which were calculated from monthly averages from 1996 through 2005 (Table 2), showed a relatively wide range of salinity, oyster density, and dermo intensity among the reef locations. In consideration of this range, a second regression approach (Approach 2) was used to determine how well long term averages of oyster conditions at reef locations could be predicted by long term averages of temperature and salinity parameters at those locations.

As a result of only considering 10-year averages, Approach 2 lost the temporal resolution and the extremes that Approach 1 contained, but also reduced the variability in the oyster population data. A limitation of Approach 1 was that the extreme heterogeneity in 3-month averages of oyster count data limited the predictive ability (percent of oyster condition variation explained) of the suitability criterion models. Approach 2 had less ability to be mechanistically explanatory, especially of short term effects on oyster condition, but because of the reduced variability, was potentially more predictive for long-term expectations. A second limitation of Approach 2 was small sample size as there were only 20 total reef locations and 13 DermoWatch reef locations.

6.2.1 Calculating Seasonal Condition Indices for Approach 1

Where data were available, seasonal averages of OCI 1 and OCI 2 (four values per year – spring, summer, fall, and winter) were calculated from monthly oyster data at each reef location from 1996 through 2005. Where data were available, seasonal averages of DCI and ODCI were calculated from monthly dermo and oyster data from 1998 (the earliest year of DermoWatch data) through 2005. Temperature and salinity data for each reef location from 1986 (the earliest year of the TPWD oyster dredge database) through 2005, a 20-year period, were used to construct the rolling temperature and salinity terms of the various time periods to be tested as potential predictors in the suitability criterion models.

There were several reasons for developing the condition index values for data beginning in 1996, but not earlier. First, the use of some oyster data prior to 1996 would confound modelling efforts because of changes in sampling protocols (Smith, Personal Communication). Second, the intention of the project was to characterize current conditions in Matagorda Bay in order to place potential LSWP effects within the framework of these conditions. Data collected during the past decade were considered sufficient and reasonable to characterize current conditions. Third, as the earliest temperature and salinity data were from 1986, 10-year temperature and salinity parameters could not have been constructed for comparison to oyster data from earlier than 1996.

6.2.2 Analysis Results for Approach 1

Modeling Procedure for Approach 1

Each of the four condition indices was first regressed separately against all of the suitability criterion model potential terms to find the best single-term predictors for that index, to determine whether temperature or salinity was the dominant predictor of that index, and to elucidate the dominant time scale(s) for a given index. Seasonal averages of each condition index were regressed against:

- current seasonal averages of either temperature or salinity;
- current seasonal averages of dermo growth rate (based on temperature and salinity; Hofmann et al. 1995);
- one-year, two-year, five-year or 10-year temperature and salinity averages (for the whole year);
- one-year, two-year, five-year or 10-year spring, summer, fall and winter temperature and salinity averages; and
- five-year and 10-year FKF.

Subsequent modeling steps were informed by the single regression results and by biological knowledge, such as the fact that oysters should have an optimum at intermediate salinity values.

Models were primarily judged by comparing R^2 and partial- R^2 values. As R^2 describes the percent of variance in the data accounted for by the model, it is indicative of the predictive value of a model. Additionally, given the large sample size (as high as 789 for the seasonal terms and greater than 500 for longer-period terms), P values were typically <0.001 even for very poor R^2 values and hence of little or no use in choosing the best suitability criterion models.

Approach 1: OCI 1 and OCI 2 Suitability Criterion Models

The commercial oyster abundance index, OCI 1, was not predicted well by any single temperature or salinity term. Two-, five-, and 10-year salinity terms yielded the highest correlations, with R^2 ranging from 0.025 to 0.040. The majority of the remaining terms had R^2 <0.009: essentially no predictive power. Ten-year summer salinity had the highest R^2 at 0.046.

The total oyster abundance index, OCI 2, was predicted even more poorly than OCI 1 by single temperature and salinity terms, with all $R^2 \leq 0.030$. The one exception was the 10-year FKF with $R^2 = 0.073$.

Given that no single term predicted OCI 1 and OCI 2 well and that oysters exhibit intermediate estuarine salinity optima, OCI 1 and OCI 2 were next regressed against two-factor polynomials of all salinity terms, including FKF.

For OCI 1, the majority of R^2 values for two-factor polynomials of salinity terms were > 0.060. The best polynomial predictors of OCI 1 were 10-year FKF, $R^2 = 0.143$, and multi-year salinity averages: two-year salinity, $R^2 = 0.132$; five-year salinity, $R^2 = 0.121$; and 10-year salinity, $R^2 = 0.099$. For OCI 2, 10-year FKF was also the best predictor among the two-factor polynomials of salinity terms, with $R^2 = 0.167$. Multi-year salinity terms were also the next best predictors: 10-year salinity, $R^2 = 0.127$; five-year salinity, $R^2 = 0.103$; and two-year salinity, $R^2 = 0.095$.

Figures 5 and 7 show the large variance in OCI 1 and OCI 2 around their respective trend lines, including occurrences of OCI = 0.0 (oyster counts = 0) at all salinities and flood frequencies. This inherent high variability, likely due to spatial variance in oyster density, precluded achieving a highly predictive suitability criterion model for oyster abundance indices. Nonetheless, it can be seen from the figures that the general trend of higher oyster condition indices in intermediate salinity conditions was captured by the 2-factor polynomial models.

In contrast to longer time periods, the two-factor polynomial of one-year salinity was a particularly poor predictor, with $R^2 = 0.059$ for OCI 1 and $R^2 = 0.005$ for OCI 2. In the Gulf of Mexico, oysters require two or more years to reach commercial size, such that a one-year salinity term does not completely capture the forcing term for these indices. Seasonal salinity terms (spring, summer, winter, fall averages) were poorer predictors than the whole-year terms, likely because oysters can be impacted by salinity regime at any time of year and a whole-year term is a better descriptor of those impacts.

The two-factor polynomial of five-year FKF likewise was not a good predictor ($R^2 = 0.040$ for OCI 1, $R^2 = 0.084$ for OCI 2) because situations with longer intervals between floods were better numerically described if there was a longer base time period. For example, in five years, the five-year FKF = 5, for one or zero flood events, the next lowest number, FKF = 2.5 for two flood events in five years, then 1.25, etc. There is more flexibility to describe flood frequencies between one and three years with a longer time period (Figures 5 and 7).

For the next step in OCI 1 and OCI 2 suitability criterion model building, starting with the two-factor polynomial models for 10-year FKF, which were the best predictive terms for both OCI 1 and OCI 2, all remaining terms were then entered into the regression models to look for the best improvement in OCI prediction. For both OCI 1 and OCI 2, the best third terms in the regression models were the salinity terms that had had the second best R^2 values for those indices as single terms: two-year salinity average for OCI 1 and 10-year salinity average for OCI 2. Furthermore, the

best fourth terms in both regression models were the squares of those salinity terms (Figures 6 and 8; OCI 1 model $R^2 = 0.265$, OCI 2 model $R^2 = 0.258$).

Residuals from the resulting best four-term models were then regressed against all remaining potential temperature and salinity model terms to determine if any additional terms could improve the model. For both OCI 1 and OCI 2 the most predictive fifth model term was two-year winter temperature, which was positively related to the four-term model residuals in both cases, indicating that higher winter temperatures led to better OCI (Figures 6 and 8). Possible reasons for winter temperatures having the most predictive power are discussed below.

Final model R^2 values were 0.304 for OCI 1 and 0.289 for OCI 2. While the effect of the winter temperature term makes biological sense and it has a significant relationship with OCI 1 and OCI 2 within the five-term model, the improvement in model R^2 value is slight enough (0.039 and 0.031 for OCI 1 and OCI 2 respectively) that a four-term model using only the salinity terms may be preferable. No additional terms provided significant improvement to the regression models.

The five-term suitability criterion models for OCI 1 and OCI 2 are given as follows:

OCI 1 = -0.553 + 0.08493(10YR Killing Flood Frequency) – 0.00783(10YR Killing Flood Frequency^2) + 0.0490(2YR Salinity) – 0.00156(2YR Salinity^2) + 0.02280(2YR Winter Temperature).

OCI 2 = -1.44 + 0.0871(10YR Killing Flood Frequency) – 0.00870(10YR Killing Flood Frequency^2) + 0.167 (10YR Salinity) – 0.00459(10YR Salinity^2) + 0.0204(2YR Winter Temperature).

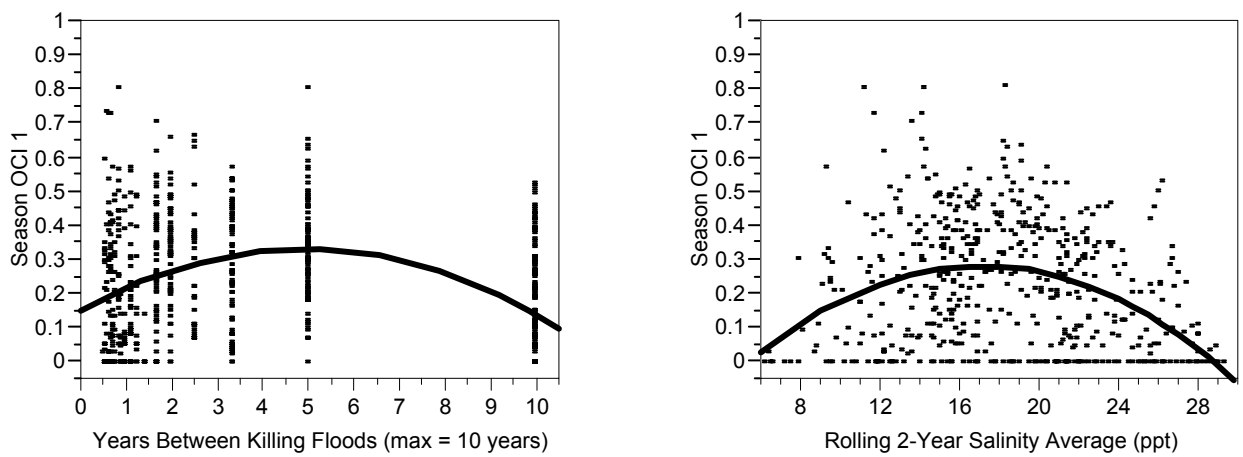

Figure 5. Two-factor polynomial relationships between OCI 1 and the two most predictive salinity terms.

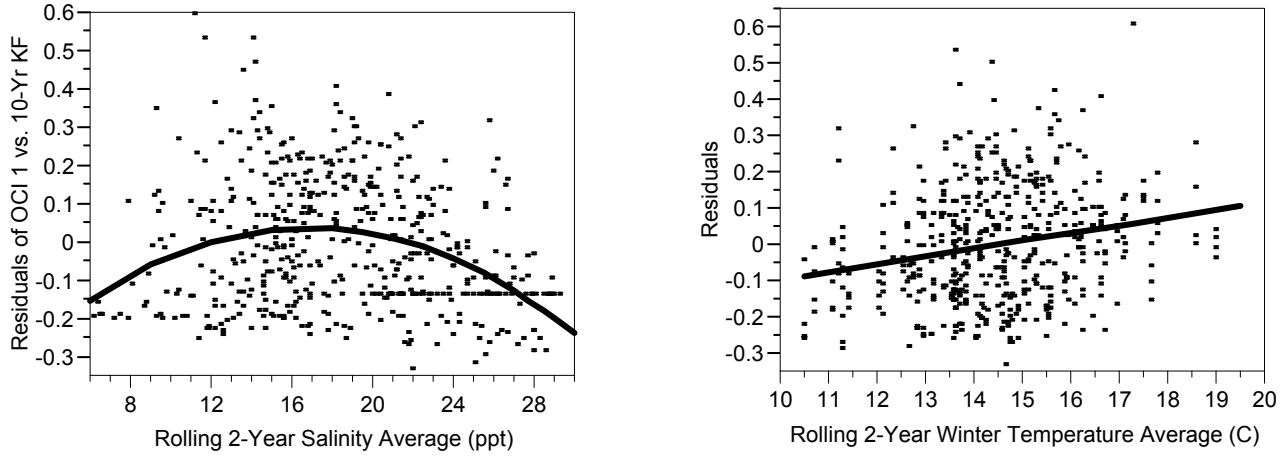

Figure 6. Remainder of Regression Model for OCI 1.

Left: two-factor polynomial of two-year salinity regressed against residuals from OCI 1 vs. two-factor polynomial regression of 10-year FKF. Right: Residuals from right panel plotted against two-year winter temperature

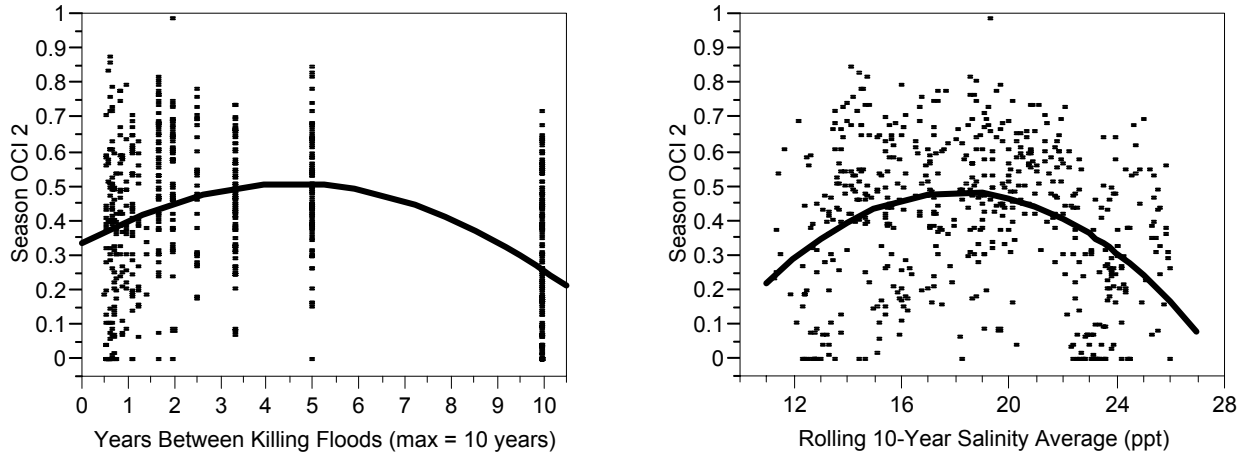

Figure 7. Two-factor polynomial relationships between season OCI 2 and the two most predictive salinity terms.

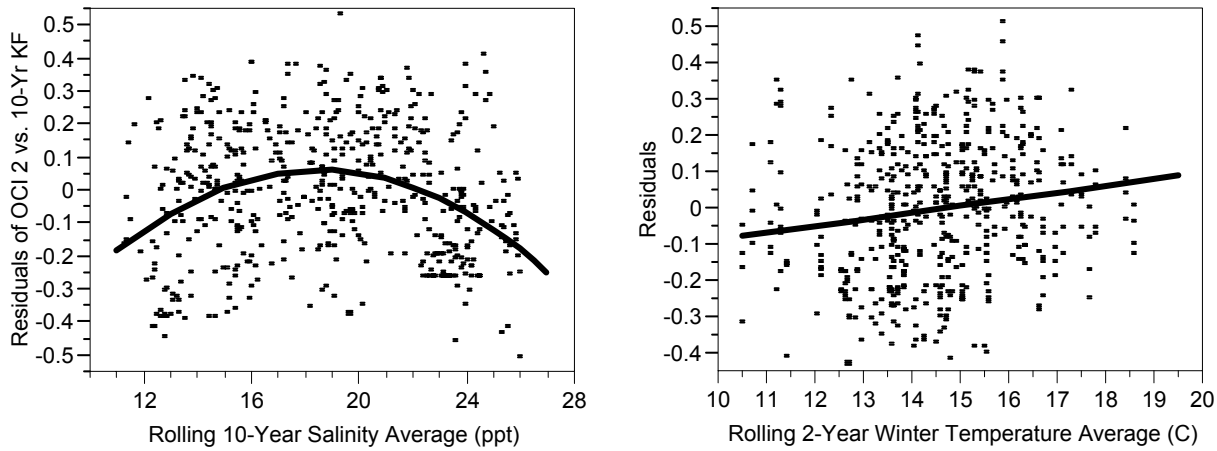

Figure 8. Remainder of regression model for OCI 2.

Left: two-factor polynomial of 10-year salinity regressed against residuals from OCI 2 vs. two-factor polynomial regression of 10-year FKF. Right: Residuals from right panel plotted against two-year winter temperature.

Approach 1: DCI Suitability Criterion Model

The dermo intensity index, DCI, usually had much stronger relationships to single temperature and salinity terms than OCI 1 and OCI 2. Salinity terms all had linear, negative relationships with DCI (dermo intensity increased with higher temperature and salinity), with all R^2 values > 0.100. The best single predictor of DCI was current season salinity, R^2 = 0.374 (Figure 9). The negative relationship with salinity indicated that higher salinity leads to higher dermo levels in oysters (lower condition index values indicate poorer oyster condition, which is higher dermo intensity).

Temperature terms also generally had negative relationships with DCI, which was expected as lower temperatures would lead to lower dermo growth rate. However, with the exception of one-year and two-year winter temperatures, R^2 = 0.173 and 0.151 respectively, all R^2 were < 0.118 and the majority had R^2 < 0.080. The current season average of dermo division rate, calculated from temperature and salinity, also predicted DCI relatively well with R^2 = 0.234.

All remaining possible model terms were then tested with current season salinity to find the best two-term suitability criterion model for DCI. The most predictive second terms were again salinity terms, which had negative relationships to residuals of the DCI-season salinity regression. The best two-term model included two-year salinity average (Figure 9) to bring the model R^2 to 0.516. Slightly better R^2 values were obtained with five-year summer salinity (model R^2 = 0.525) and 10-year fall salinity (model R^2 = 0.537), but the residuals were not as uniform and it was also reasoned that, unless there was a compelling biological reason to add specific seasonal terms, they should be avoided.

The most predictive third term in the DCI suitability criterion model was the one-year winter temperature, which had a negative relationship to the residuals of the two-term model (Figure 9), indicating that higher winter temperatures led to higher dermo intensity in oysters (model R^2 = 0.564). As with OCI 1 and OCI 2, the temperature term only contributed minimally to the explanatory power of the suitability criterion model, with a partial R^2 = 0.048, such that a two-term

model using only the salinity terms may be preferable. No additional terms provided significant improvement to the regression model.

The best three-term suitability criterion model for DCI is therefore as follows:

DCI = 1.78 – 0.0144(Season Salinity) – 0.0254(2YR Salinity) – 0.0367(1YR Winter Temperature)

All of the terms in the DCI are from short time scales, which may be reflective of the short development time of the parasite.

Again, as with OCI 1 and OCI 2, the only temperature term in the model is a winter term. From a biological standpoint, both oysters and their parasites should be most affected by temperature extremes, which would occur in either winter or summer. However the temperature range in summer is relatively small, while the temperature range in winter is much larger (Figure 10), giving winter temperatures more leverage to affect oyster condition than summer temperatures. Whole-year temperature averages also have a small range compared to winter, spring, and fall temperatures, so whole-year values likewise would not have a great deal of leverage to predict condition indices.

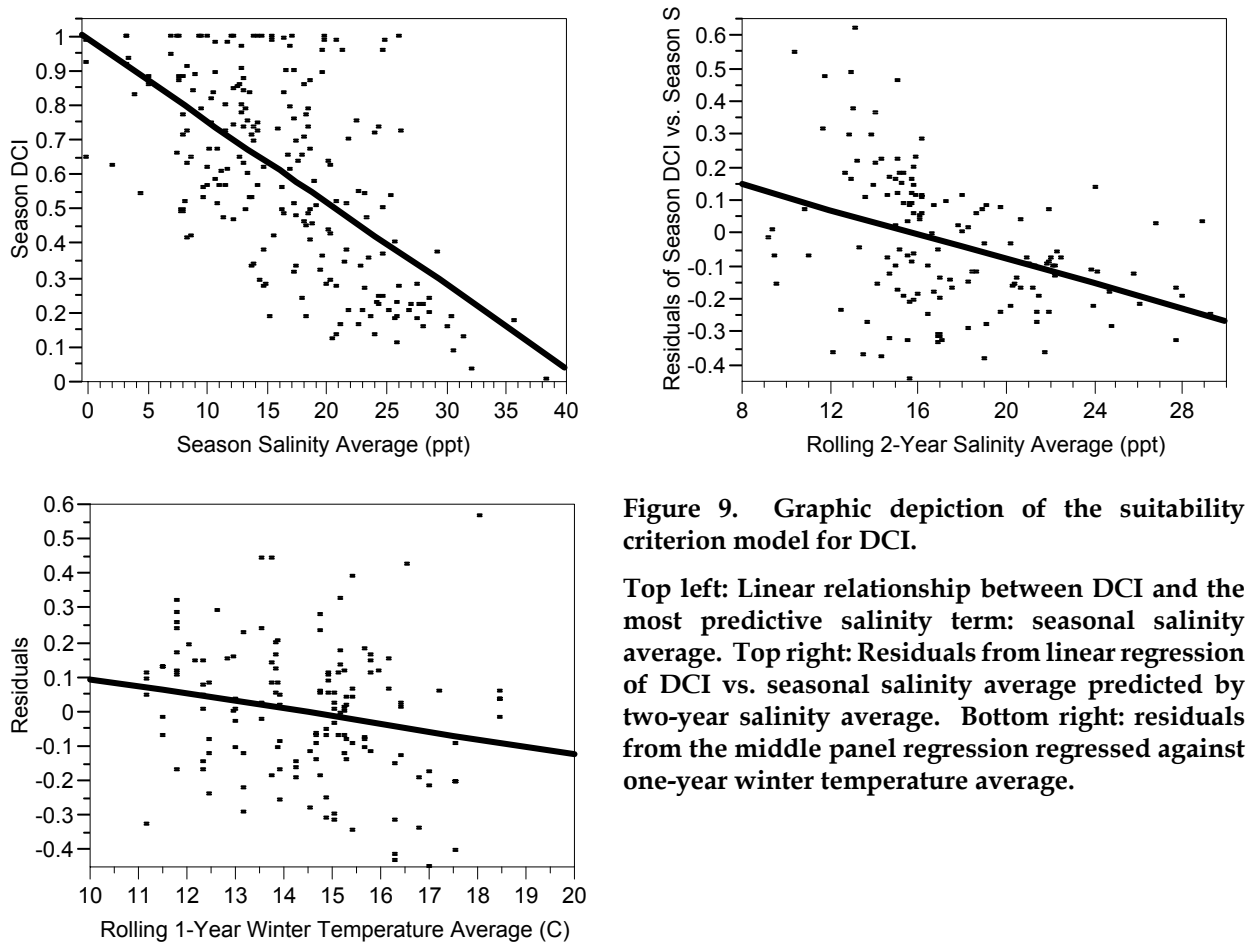

Figure 9. Graphic depiction of the suitability criterion model for DCI.

Top left: Linear relationship between DCI and the most predictive salinity term: seasonal salinity average. Top right: Residuals from linear regression of DCI vs. seasonal salinity average predicted by two-year salinity average. Bottom right: residuals from the middle panel regression regressed against one-year winter temperature average.

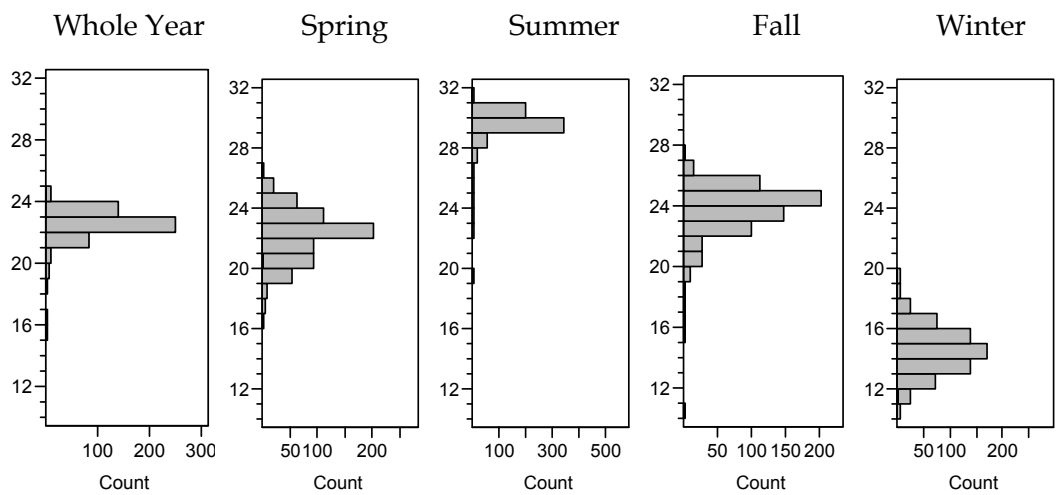

Figure 10. Frequency distributions of rolling two-year temperature averages for 1996 through 2005 for all reef locations.

Approach 1: ODCI Suitability Criterion Model

As with DCI, the commercial oyster abundance and dermo infestation index, ODCI, had linear, negative relationships with salinity terms in single-term regression models and these relationships were better than the others evaluated, with all $R^2 > 0.100$ and almost all > 0.200. Again, all temperature terms were poor single predictors of ODCI, with the majority of $R^2 < 0.060$. The best single predictor of ODCI was the 10-year salinity average, $R^2 = 0.383$ (Figure 11).

All remaining possible model terms were tested with 10-year salinity to find the best two-term model. The most predictive second terms were again salinity terms with negative relationships to residuals of the ODCI vs.10-year salinity regression. The best two-term model added two-year salinity average to bring the model R^2 to 0.496 (Figure 11). No additional terms contributed meaningfully to the model, resulting in a suitability criterion model without a temperature term.

The Suitability Criterion model for ODCI is therefore as follows:

ODCI = 0.890 – 0.0188(10YR Salinity) – 0.0103(2YR Salinity)

Although the dermo part of the ODCI is only given one third of the weight in the index, the main relationship of ODCI with estuarine salinities, a linear decline, resembles the response of DCI to salinity rather than the parabolic response of OCI 1 and OCI 2 to salinity. This indicates that although salinity is a driver of both oyster abundance and dermo abundance, that dermo has a stronger direct response to salinity than oyster abundance in the data set used to develop this model.

Both OCI 2 and ODCI include 10-year salinity averages in their suitability criterion models, but it is unlikely, given the development times of dermo and oysters, that the target organisms are affected by the entire 10 prior years of salinity. The 10-year salinity average may be a good predictor for these indices simply because it has less random variability than terms from shorter temporal periods.

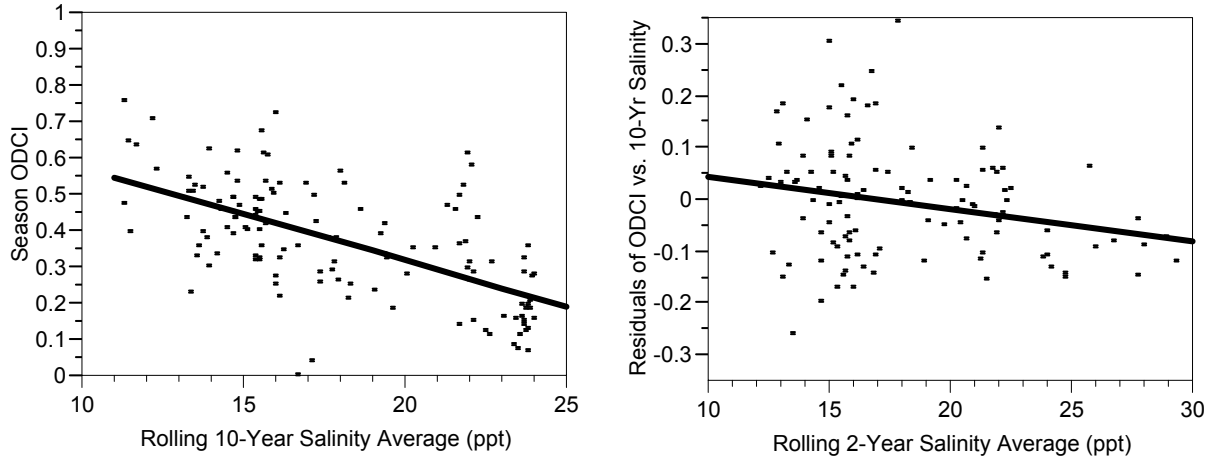

Figure 11. Graphic depiction of suitability criterion model for ODCI.

Left: Linear relationship between ODCI and the most predictive salinity term: 10-year seasonal salinity average. Right: Residuals from the top panel were best predicted by the two-year seasonal salinity average.

6.2.3 Analysis Results for Approach 2

Suitability Criterion models for regression Approach 2

As described above, in addition to developing suitability criterion models from the pooled seasonal averages from all reef locations, models were derived based on comparing long-term average conditions at each reef location – regression Approach 2. The resulting models are referred to as 10-year suitability criterion models in this report. Average long-term condition indices were calculated for the 20 reef locations based on 10-year average oyster counts, and on average dermo intensity for the entire period of DermoWatch sampling at each location (Table 2).

The same general model building approach was taken as described for the pooled reef location data. Potential predictive terms for these long-term condition indices were the 10-year averages of the following: salinity (Table 2); spring, summer, fall and winter salinity; temperature (Table 2); spring, summer, fall, and winter temperature, and frequency of killing floods at each location.

Oyster Lake Point was excluded as an outlier as it had exceptionally low oyster abundances for the entire 10-year span (Table 2), and was not considered a well-established reef. This exclusion brought the sample size of reef locations for oyster abundance indices to 19, but substantially improved the fit of the 10-year suitability criterion models.

Salinity was the strongest driver in each model, and over 50% of the variation in all four 10-year condition indices was explained by whole-year salinity alone (Figure 12; 2-factor polynomial R^2 = 0.531 and 0.593 for OCI 1 and OCI 2 respectively, linear regression R^2 = 0.581 and 0.719 for DCI and ODCI). These relationships with salinity followed the same general patterns as seen for the pooled reef locations in regression Approach 1 (Figures 5, 7, 9 and 11): there was an intermediate salinity optimum for commercial and total oyster abundance indices (OCI 1 and OCI 2), and a strong negative relationship between salinity and the dermo condition index (DCI). When DCI and OCI 1 were combined to create oyster-dermo index (ODCI), the result was a decline in oyster reef condition with salinity, but not as sharp a decline than if dermo alone was considered (Figure 12).

This 10-year ODCI response to salinity also followed the same pattern as seen for pooled reef locations in Approach 1.

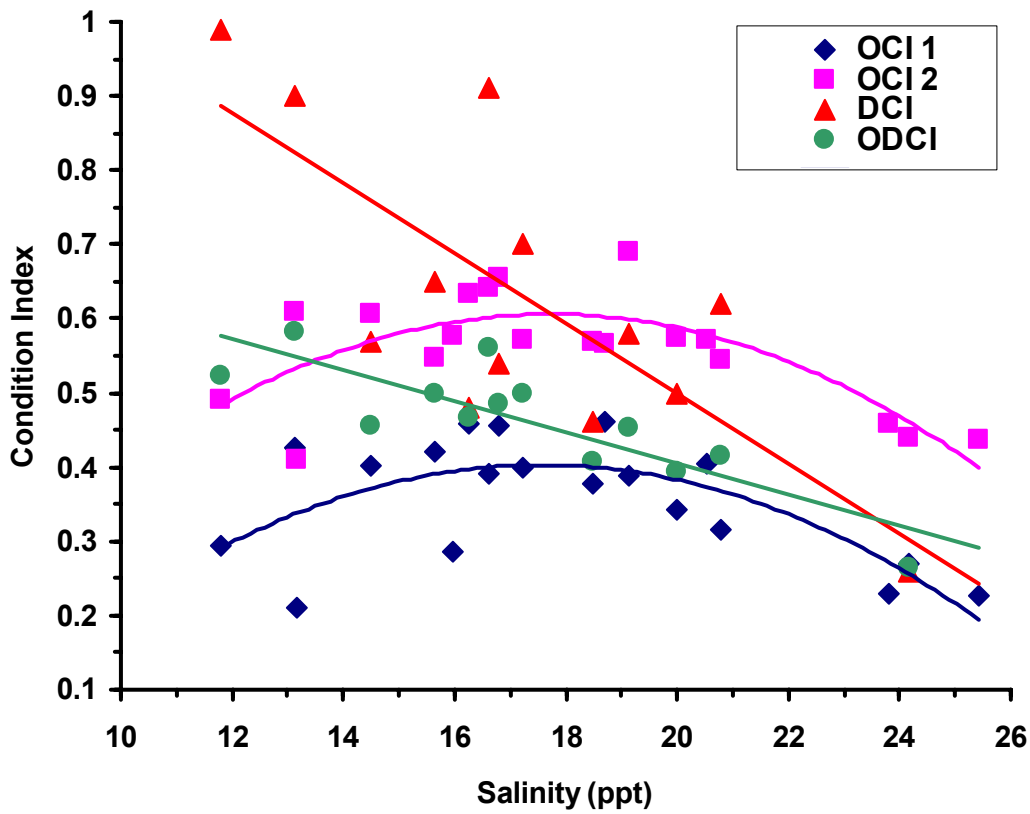

Figure 12. Average salinity from 1996 through 2005 at the reef locations vs. 10-year condition indices for those locations (Table 2). Regression lines are for either linear or two-factor polynomial regressions.

The best suitability criterion models for 10-year average reef conditions are as follows:

Oyster Condition Index 1 (OCI 1)

OCI 1 was the only one of the four indices where temperature was included in the 10-year suitability criterion model. Warmer fall temperatures correlated with lower index values and fall temperature substantially improved the R^2 value of the suitability criterion model.

With no temperature term:

$$OCI\ 1\text{-}10YR = -0.6375 + 0.11845(Salinity) - 0.003372(Salinity^2)$$

where:

Model $R^2 = 0.532$

N = 19 reef locations

Or, with a temperature term:

$$OCI\ 1\text{-}10YR = -1.8747 - 0.09288(Fall\ Temperature) + 0.03880(Salinity) - 0.001449(Salinity^2)$$

where

Model $R^2 = 0.674$

N = 19 reef locations

Fall temperatures among the reef locations ranged from 19.85 to 25.05˚C. As this range is not likely to directly affect the oysters it may be that the negative effect of higher fall temperatures is an indirect result of promoting a longer period of high dermo growth.

Oyster Condition Index 2 (OCI 2)

Unlike OCI 1, temperature terms did not improve the 10-year suitability criterion model for OCI 2. This supports the above speculation that the temperature effect on OCI 1 is primarily an indirect one, through dermo propagation. This is because total oyster abundance is primarily driven by juvenile abundance, and dermo intensity and dermo-mediated mortality are typically much lower in juvenile oysters than in adult oysters.

$$OCI\ 2\text{-}10YR = -0.4938 + 0.1241(Salinity) - 0.003499(Salinity^2)$$

where:

Model $R^2 = 0.593$

N = 19 reef locations

Dermo Condition Index (DCI)

$$DCI\text{-}10YR = 1.7127 - 0.1535(Salinity) + 0.09655(Spring\ Salinity)$$

where:

Model $R^2 = 0.811$

N = 13 reef locations

It is perhaps surprising that DCI responds only to salinity and not to temperature, considering how dependent dermo division rate is on temperature. However, the lack of temperature response is likely due to the lack of range in long-term temperature averages among reef locations in this study rather than lack of importance of temperature to dermo growth.

Oyster-Dermo Condition Index (ODCI)

$$ODCI\text{-}10YR = 0.8240 - 0.02095(Salinity)$$

where:

Model $R^2 = 0.719$

N = 13 reef locations

As with Approach 1, when oyster count and dermo intensity terms were combined, the resulting response to salinity more closely resembled the response of dermo to salinity (negative slope) rather than the response of oyster abundance to salinity (polynomial). This, especially in spite of the heavier weighting of oyster abundance than dermo intensity in the index, indicated that dermo intensity is much more strongly affected by salinity changes than oyster abundance.

6.3 Suitability criterion models – Interactive calculation tool

An interactive calculation tool is under development with the suitability criterion models (Approach 1) and 10-year suitability criterion models (Approach 2) for all condition indices.

7.0 Summary and Recommendations

7.1 Comparison of Approach 1 vs. Approach 2 for Suitability Criterion Models

The suitability criterion regression models had a varying range of success in predicting the four oyster condition indices, but in all cases the variance in the condition indices explained by the models (i.e. model R^2 values) were higher for regression Approach 2 than for regression Approach 1.

The seasonal oyster abundance indices (OCI 1 and OCI 2) had high variability, likely due to inherent heterogeneity resulting from the distribution and sampling methods of oysters, and these indices were consequently the most poorly predicted. The suitability criterion model for the commercial oyster abundance index, OCI 1, had a model R^2 of 0.304 and the suitability criterion model for the total oyster abundance index, OCI 2, had a model R^2 of 0.289. Both oyster abundance indices were substantially better predicted using the 10-year averages – regression Approach 2. Suitability criterion model R^2 for 10-year condition indices were 0.674 for 10-Year OCI 1 and 0.593 for 10-Year OCI 2.

In contrast to OCI 1 and OCI 2, the dermo intensity index, DCI, was relatively well predicted by regression Approach 1, with a model R^2 of 0.564. This improvement was likely because measurements of dermo intensity were not affected by as much natural and measurement variance as local oyster abundance. The dermo transmission process has a broadcast nature - all infected oysters release infectious dermo propagules and the reef oyster population is exposed to the same pool of these propagules, which are then transmitted via oyster filter feeding. This indirect transmission likely results in low heterogeneity of dermo intensity among oysters in a reef (as opposed to if there were direct, host to host transmission). There is also a less uncertain sampling method for dermo – the parasites are searched for within hosts rather than within reefs. Interestingly, given the short generation time of these parasites and the resulting expectation that they would respond most strongly to short-term environmental forcing, DCI is also better predicted using the 10-year averages of regression Approach 2: model R^2 for 10-Year DCI = 0.812.

As a combination of OCI 1 and DCI, it was unsurprising that ODCI was also better explained by regression Approach 2 and that the amount of variance explained was intermediate between its component indices. Suitability criterion model R^2 for ODCI = 0.496 and model R^2 for 10-Year ODCI = 0.719.

7.2 Salinity and Temperature in Suitability Criterion Models

All four types of condition indices responded more strongly to salinity terms than to temperature terms. All suitability criterion models had at least one, and up to four salinity terms, while all models had either 0 or 1 temperature terms, and temperature terms always had the least significant contribution of all the terms in the models. The lack of strong response to temperature does not necessarily imply that temperature is not important to oyster reef condition; more likely it is due to

the low degree of variability in temperature among the reef locations used to develop these models. This low variability was deliberate, as one of the primary goals in choosing data to develop models for Matagorda Bay was to avoid variability due to oyster adaptations to other climactic regions. All reef locations occurred within a relatively small geographic range – either within Matagorda/Lavaca Bay itself or within one of the adjacent bays. Given that there is no temperature output from the hydrodynamic/salinity model (to which the suitability criterion models are to provide biological linkage for oyster condition) the lack of strong temperature responses may prove convenient.

7.3 Recommendations for choice of Approach 1 or Approach 2 Suitability Criterion Models

Approach 2 can be recommended for biological linkage to the hydrodynamic/salinity model for several reasons. Most importantly, more variance in oyster condition indices is predicted by regression Approach 2. Additionally Approach 2 model terms are simpler to calculate as they are simply long term averages, and the models are less dependent on temperature terms, which will make them easier to link to the hydrodynamic/salinity model output.

A caveat to the use of Approach 2 is that, because these models were developed from a small sample size of reef locations and because 10-year averages will generally have a smaller range in salinity than actual bay conditions considered on a monthly or annual basis, the Approach 2 models do not handle or predict extremes well. Hence, if the inflow regimes being modeled for Matagorda Bay result in salinities outside the ranges of the long term averages, it is advisable to use Approach 1 suitability criterion models over Approach 2 models.

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www.PortofBayCity.com

Port of Bay City Authority

Home / Description

The Port of Bay City Authority is a county navigation district created by Texas law in 1960, and charged with working with the U.S. Army Corps of Engineers in maintaining the navigability of the Colorado River and regulating certain port facilities on the Colorado River and Intracoastal Waterway in Matagorda County, Texas. It is governed by a six-member board of commissioners who are elected by Matagorda County residents for stagered six-year terms.

The Port of Bay City Authority maintains a port facility on the Colorado River located 15 miles upriver from the locks at the Intracoastal Waterway. It accommodates barge traffic including off-loading and loading facilities for various products. Storage facilities are also available.

The Port of Bay City terminal

4/16/07

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The Nature Conservancy
Protecting nature. Preserving life.™

Clive Runnells Family Mad Island Marsh Preserve

A haven for native and migratory birds

Clive Runnells Family Mad Island Marsh is part of an expansive coastal wetlands system which, 60 years ago, stretched nearly unbroken along the mid- and upper-Texas Gulf Coast. It lies at the terminus of the Central Flyway, one of four principal North American migratory bird routes. The preserve's upland prairies represents a portion of the remaining 2 percent of the original tallgrass coastal prairies once found across Texas.

The 7,063–acre preserve is home to marshy wetlands habitat dominated by a variety of aquatic and water tolerant species, including various cordgrasses, glassworts, rushes and cattails. The preserve's upland prairies display different grasses such as bluestem, plains bristlegrass and Texas wintergrass.

Nearly 250 species of birds—including migrating and resident songbirds, shorebirds, colonial nesting birds, and wading birds—use the area for feeding, resting and roosting. The preserve is especially important to waterfowl including 16 species of ducks and 4 species of geese. Sandhill cranes and various wading birds also inhabit the Mad Island Marsh Preserve at some point during the year. The annual Mad Island Christmas Bird Count has ranked in the top five national counts since its inception in 1993.

The marsh area provides habitat for many different marine organisms, such as red drum, blue crabs, brown shrimp, southern flounder and speckled trout. Mad Island Lake and its surrounding wetlands provide a critical nursery for a variety of marine life from adjacent Matagorda Bay. Other animals also found on the preserve include alligators, bobcats, armadillos, rattlesnakes, white-tailed deer and coyotes.

This area provides unique habitat for a diversity of wildlife, but its fragile ecosystem has degraded over the years. Through a unique land swap, The Nature Conservancy received 5,700 acres of wetlands and coastal prairies that it turned over to the Texas Parks and Wildlife Department which became the Mad Island Wildlife Management Area. Then in 1989, Clive Runnells donated 3,148 acres of coastal wetlands and upland prairies adjacent to Mad Island Marsh to The Nature Conservancy.

Location

The preserve is located in Matagorda County, on West Matagorda Bay.

Download Fact Sheet

Gulf Coast Prairies and Marshes Ecoregion (PDF)

Agriculture and Conservation

Meet Derril Franzen, our partner in conservation at Clive Runnells Family Mad Island Marsh Preserve.

In 1993 the Conservancy acquired an additional 3,900 acres with more than $1 million from the North American Wetlands Conservation Council. The Nature Conservancy of Texas, National Fish and Wildlife Foundation, Dow Chemical, US EPA, Trull Foundation and Communities Foundation of Texas partnered to raise another $2.5 million for the project.

In 1990, The Nature Conservancy forged a partnership with Ducks Unlimited to restore the wetlands and tallgrass coastal prairies through four habitat management programs:

The Clive Runnells Family Mad Island Marsh Restoration Program increases freshwater inflows to enhance and recreate marsh habitat through water management, salinity monitoring and other measures. The Ricefield Enhancement Program

improves the ricefields as feeding and roosting areas for waterfowl primarily through winter flooding. Over a 10-day period in 1990, Mad Island ricefields fed more than 200,000 waterfowl, the largest number of along the Texas Coast.

The Palustrine Marsh Enhancement Program restores key freshwater wetlands lost to past drainage projects. The Uplands Enhancement Program includes controlled grazing and burning to restore the coastal prairies on the preserve. This creates winter foraging areas for geese and sandhill cranes and nesting cover for game and nongame species in upland prairies. By the end of 2001, 650 acres of freshwater wetlands were either created or enhanced, and over 3,000 acres of coastal prairie have been restored using prescribed fire, exotic brush control, and sustainable cattle grazing. In addition, more than 2,522 acres of tidal wetlands and 1,200 acres of ricefield habitat have been enhanced.

The preserve is located off F.M. 1095 in Matagorda County, southeast of Collegeport. Visitation is open only for volunteer workdays; an appointment is needed otherwise. For more information, contact the Clive Runnells Family Mad Island Marsh Preserve, P.O. Box 163, Collegeport, TX, 77428-0163, phone: (361) 972-2559, fax: (361) 972-6426.

To learn about educational and visitation opportunities at the preserve, please see our Field Trips and Events section.

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2005

THE TEXAS PARKS AND WILDLIFE DEPARTMENT

LAND *and* WATER RESOURCES

CONSERVATION AND RECREATION PLAN

TEXAS PARKS & WILDLIFE

REVISED AND APPROVED JANUARY 2005

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Executive Summary

The Texas Parks and Wildlife Department's conservation and recreation mandate is complex and requires long-term strategic planning and implementation. The *Land and Water Resources Conservation and Recreation Plan* was written to guide the Department in conserving the state's natural and historic heritage and in providing public access to the outdoors. The Plan specifically addresses conservation of land and water resources and recreation on land and water. It was developed with significant input from the public, state leadership, staff and other experts. TPWD held two constituent meetings to identify concerns and preliminary ideas and eight subsequent public meetings across the state for final input and comments. In preparing for the 2005 revisions, the agency convened 10 river-basin focus groups of staff and several external reviews by constituents.

LAND CONSERVATION

Texas is a large and ecologically complex state where conservation of game and other wildlife species depends upon landowners who manage the majority of the important habitats. The Plan establishes priority habitat types and ecoregions based on the conserved status, threat and biological value. For example, the Plan identifies the Blackland Prairies, the Gulf Coast Prairies and Marshes and the South Texas Plains as priorities to enhance TPWD's conservation efforts and its work with landowners. It also establishes priority wildlife species to focus TPWD's management efforts.

LAND RECREATION

Demand for outdoor recreation is changing as the population becomes increasingly diverse and urban. The Plan evaluates all existing state parks, wildlife management areas, and historic sites to determine whether the sites need additional resources to meet the demands of its constituency or if the sites would be better managed by another entity. TPWD will focus its efforts to acquire additional land to improve access, recreational experience, wildlife habitat and resource protection on priority state parks and wildlife management areas. It will also strive to fully interpret, protect and appropriately market all priority historic sites.

The Plan identifies the need for more state parks to serve major urban areas. It sets goals for the Department to provide large, accessible state parks near areas experiencing significant population growth. The Plan also identifies the importance of continued support for local park development through TPWD's grant programs. In addition, the Plan directs TPWD to work with landowners interested in increasing public access to their lands.

WATER CONSERVATION

It is imperative that Texas maintain freshwater in its river and coastal systems. Sufficient, good quality freshwater runoff into springs, rivers, reservoirs and bays is critical to conserve quality of life and healthy natural systems. Without regulatory authority, however, the Department must rely on providing the best scientific information available about the needs of fish and wildlife to be considered in statewide water policy decisions. The Plan identifies instream flow study needs to improve river basin conservation and identifies the priority bays to focus TPWD conservation efforts. The Plan also identifies steps to improve water resources by providing technical assistance to private landowners to enhance range management.

WATER RECREATION

Water is also the basis for a significant recreational resource that includes boating, fishing, swimming, sailing, diving, bird watching and paddle sports. Over the last two decades, however, participation in recreational fishing has decreased due to limited access, the aging of anglers, time constraints, fishing equipment costs and competing interests for leisure time. The Plan develops strategies to increase angler participation and sets a goal of maintaining current fishing license sales

MAJOR GOALS

This Plan sets forth eight fundamental goals to meet the numerous conservation and recreation needs identified:

Goal 1: Improve access to the outdoors.

Goal 2: Conserve, manage, operate, and promote agency sites for recreational opportunities, biodiversity, and the cultural heritage of Texas.

Goal 3: Assist landowners in managing their lands for sustainable wildlife habitat consistent with their goals.

Goal 4: Increase participation in hunting, fishing, boating and outdoor recreation.
Revised Goal 5: Enhance the quality of hunting, fishing, boating and outdoor recreation.

Goal 6: Improve science, data collection and information dissemination to make informed management decisions.

Goal 7: Maintain or improve water quality and quantity to support the needs of fish, wildlife and recreation.

Goal 8: Continuously improve TPWD business management systems, business practices and work culture.

The window of opportunity for conservation of natural resources and providing adequate access to the outdoors is gradually closing. In order to meet the goals outlined in this Plan, TPWD must foster new approaches, build partnerships and identify new public and private resources. It will require a renewed effort and commitment from the Department, state leaders, conservation and recreation organizations, the private sector and citizens alike.

Introduction

LAND AND WATER RESOURCES CONSERVATION AND RECREATION PLAN

The Texas Parks and Wildlife Department's (TPWD or Department) primary functions are management and conservation of Texas' natural resources, provision of outdoor recreational opportunities and management of historic sites. It also acts as a catalyst for private sector activity to increase conservation and outdoor recreational opportunities in the state.

The Department performs a number of important functions to protect natural resources, including regulating possession or transport of nongame species, regulating the take of game species and enforcing those regulations. These functions require that the Department conduct surveys of fish and game populations, create harvest estimates, educate the public about regulations and investigate potential violations. It is also required to promote public safety on Texas waterways as well as the safe operation and use of recreational boating and other watercraft. The Department's regulation and enforcement authority is straightforward, but providing for conservation and recreation needs is a broader and more complex mandate that requires strategic planning and implementation.

Over the years, TPWD has acquired parks, historic sites and wildlife management areas to provide public access to the outdoors and to conserve important natural and cultural resources. It has developed programs for habitat conservation on private lands and has promoted water conservation to support the needs of fish and wildlife. Yet the Department has never completed a comprehensive analysis of natural, historic and recreation needs in Texas, and it has never developed a strategic plan to meet these needs. Without a comprehensive plan, TPWD has been limited in making strategic or long-term decisions.

Many studies of land and wildlife conservation, public recreation and historic preservation have been conducted recently on behalf of, or in partnership with, the Department. The prevalent theme emerging from these studies is the need for a comprehensive plan to guide TPWD conservation programs and development of outdoor recreational opportunities.

In addition, the National Park Service requires each state's park agency to update a Statewide Comprehensive Outdoor Recreation Plan every five years to be eligible for Land and Water Conservation Funds. Eligibility for this program allows the Department to receive matching grants for land acquisition and construction of recreational facilities on state and local parks. The *Land and Water Resources Conservation and Recreation Plan* will serve as Texas' comprehensive plan and meet the National Park Services' eligibility requirements.

SUNSET BILL REQUIREMENTS

In 1999, Texas Parks and Wildlife Department underwent the Sunset evaluation process that culminated with the passage of Senate Bill 305, 77th Legislature, directing the Department to develop a comprehensive and strategic *Land and Water Resources Conservation and Recreation Plan*. According to the bill, conservation includes historic, natural, recreational and wildlife resources. The bill requires the Department to inventory land and water resources associated with all historic, natural, recreational and wildlife resources in the state owned by governmental entities or nonprofit entities offering public access. Using the inventory, TPWD is required to create a permanent database and develop a plan that:

1. analyzes the state's existing and future land and water conservation and recreation needs;
2. identifies threatened land and water resources in this state; and
3. establishes the relative importance of conserving the resources listed in the inventory.

The plan must include criteria for determining how to meet the state's conservation and recreation needs. Furthermore, the Department is required to use the criteria to guide its decisions on the acquisition of new resources, grant funding to local parks, its work with private landowners and divestiture of Department-owned resources.

AD HOC STRATEGIC LAND AND WATER COMMITTEE

In November 2001, the Chairman of the Texas Parks and Wildlife Commission appointed an ad hoc Strategic Land and Water Committee to guide the development of the Plan. Members of the ad hoc committee included four Texas Parks and Wildlife Commissioners: Chairman Katharine Armstrong, Alvin Henry, Philip Montgomery and Donato D. Ramos; and three advisors: Chairman Emeritus Lee Bass, Dealey Herndon and Barry Miller. The ad hoc committee functioned as a working group and made decisions related to the scope and content of this document. The group's first priority was to clearly describe the Department's role in providing recreational opportunities and conserving natural resources in Texas. Secondly, it was to determine and describe particular threats to resources, including land fragmentation, population growth and increasing demands on water resources. Finally, the committee was to develop processes and standards that would determine recreation and conservation priority needs and to set objectives for meeting the needs over the next ten years.

List of Previous Studies

Texas Historic Sites: A Study Conducted for the Texas Historical Commission and the Texas Parks and Wildlife Department, KPMG Peat Marwick (1997)

Texas Historic Sites: TPW's Response to the Report by KPMG Peat Marwick, Texas Parks and Wildlife Department (1997)

Texas Cultural Heritage Plan, Texas Historical Comm. (1999)

Wildlife Management Area Strategic Plan, Saski et. al (1997)

Texas Outdoors: A Vision for the Future, Texas A&M University (1998)

Texas Parks and Wildlife Department Staff Report 2000, Sunset Advisory Commission (2000)

Taking Care of Texas: A Report from the Governor's Task Force on Conservation (2000)

Texas Parks and Wildlife for the 21st Century, Texas Tech University (2001)

Introduction

THE PLAN

> ✻ Conservation and recreation are inextricably linked; without adequate conservation of the natural and cultural resources, there will be few opportunities for public outdoor recreation.

This is reflected within the Texas Parks and Wildlife Department's mission, organization and the constituencies it serves. For example, without clean and abundant waters in rivers and lakes, Texas would not rank second in the nation in the number of angler days and dollars spent on fishing annually. Texas' exceptional hunting tradition could not be sustained without proper habitat management on private land. Moreover, the public must have access to lands and waters so that they can appreciate and support their conservation.

Likewise, TPWD recognizes the inherent relationship between land and water. For example, improper land management practices can cause poor water quality in streams and rivers that negatively impacts aquatic habitats, freshwater fishing and ultimately coastal resources.

This plan is organized into four parts: 1) the role of the Texas Parks and Wildlife Department; 2) land conservation and recreation; 3) water conservation and recreation; and 4) goals and conclusions. Although the land and water sections are organized individually, both discuss conservation threats and priorities, recreational threats and priorities and the strategies that TPWD will use to address them.

INVENTORY

As required by S.B. 305, the Department gathered information from local, state, federal and nonprofit entities using a geographic information system. This information was used in a number of analyses in this document, including the Outdoor Recreation Analysis, the Local Park Analysis and components of both the land and water conservation analyses. The following lists the categories of data collected:

- Federal Lands
  - National Park Service
  - National Forest Service
  - Fish and Wildlife Service
  - U.S. Army Corps of Engineers
  - Bureau of Land Management
  - Bureau of Reclamation
  - National Oceanographic and Atmospheric Administration
- Texas Parks and Wildlife Department Lands
- Other State Lands
  - General Land Office
  - Texas State Forests
- River Authority Lands
- County Parks and Preserves
- City Parks and Preserves
- Non-Profit Organizations
- U.S. Census Bureau Census Tracts 2000
- Texas Lakes and Bays from Texas Commission on Environmental Quality and Texas Department of Transportation (TxDOT)
- City Limits from TxDOT
- Texas County Lines from Texas Natural Resources Information System (TNRIS)
- Rivers and Streams from TPWD, TxDOT, Texas Water Development Board and TNRIS
- Ecoregions and Sub-Regions
- Texas Historical Commission Historic Site Atlas database

The inventory was based on existing data wherever possible. A large part of the data was gathered from official web sites, vectorized paper maps and geo-referenced digital raster maps. TPWD also collected information through direct contacts with federal agencies, river authorities, cities over 20,000 in population, nonprofit entities, councils of government and county appraisal districts.

Department Roles

The Department's primary commitment is to the people of Texas. The Texas Legislature has charged it with protecting the state's fish and wildlife resources and to manage a system of parks, wildlife management areas and historic sites across the state for people to use and enjoy. The Department depends on hunters, anglers, boaters, campers and other visitors to state parks and historic sites for support and revenue. TPWD works with other governmental agencies, nonprofits, the private sector and private landowners to conserve important natural resources and to provide recreational access to their lands. The Department also reaches out to Texans who have not had opportunities to access the outdoors through numerous programs for youth, women, urbanites and other groups.

THE ROLE OF STATE PARKS AND WILDLIFE MANAGEMENT AREAS IN TEXAS

State parks are part of a larger system of parks within Texas that includes national parks, refuges and forests, as well as city, county and other public parks. State parks serve as natural classrooms and provide opportunities for visitors to enjoy large natural areas. Visitors can participate in recreational activities like mountain biking, hunting, horseback riding and experiencing the state's cultural heritage that are typically not available in local parks and may not be available on national parks or wildlife refuges.

State parks must balance recreation and conservation. Recreational use must therefore be maximized in ways that do not degrade the resources through incompatible use or overuse. State parks do not pay for all their own operation or maintenance, but they have direct and indirect economic benefits locally and statewide. In many communities, state parks are a significant economic engine for tourism and service-related businesses. State parks also provide other intangible quality-of-life benefits, such as opportunities for physical fitness and a healthy environment.

✻ Government Canyon lies 16 miles from downtown San Antonio. It fulfills three major TPWD goals: It protects significant water and wildlife resources; it establishes a recreation area easily accessible by an urban population; and it embodies the partnership of state agencies, city government, other public entities and the private sector.

Wildlife management areas (WMA) are also an important public resource where visitors can experience, learn about and enjoy Texas' natural heritage. Given that private landowners own most of the state's wildlife habitat and that wildlife management is a growing land use, WMAs provide essential research and demonstrate sound wildlife and habitat management techniques. Wildlife management areas are also important for wildlife and habitat conservation, public hunting and other outdoor recreational opportunities.

TPWD'S ROLE IN DEVELOPING, MAINTAINING AND INTERPRETING HISTORIC SITES

In 1967, the Texas Legislature passed the Historic Sites and Structures Act, which required TPWD to manage a statewide system of historic sites that exemplify the history and culture of the state. Since then, the Department has acquired, restored, preserved, interpreted, maintained and operated historic sites in order to preserve important elements of Texas' heritage. TPWD currently manages 36 designated historic sites of cultural and historic significance that represent major components of the state's history and culture rather than a comprehensive collection. Historic sites provide opportunities for visitors to learn, understand and appreciate history and foster a sense of stewardship of a shared past. Other government agencies and private organizations also manage many of the state's important historic resources. Within TPWD's holdings are state parks and wildlife management areas that may also have significant archeological or historic resources.

Using sound management practices, architectural, archeological and historic expertise, modern interpretive and educational methods and ongoing evaluation, TPWD strives to develop and maintain appreciation of these important historic resources for Texans and visitors to the state now and in the future.

TPWD'S ROLE IN WORKING WITH PRIVATE LANDOWNERS

TEXANS' QUALITY OF LIFE DEPENDS ON SOUND LAND MANAGEMENT ON PRIVATE LANDS.

Landowners provide recreational opportunities and maintain water quality and wildlife diversity. TPWD cannot succeed in its responsibilities to protect fish and wildlife resources without good partnerships with private landowners. The Department also cannot serve the public's demand for outdoor recreation without the efforts of private landowners. The Department recognizes both the intrinsic and the economic value of good stewardship on land and supports landowners who assume this responsibility.

Texas leads the nation in the actual number of hunters, the overwhelming majority of which hunt on private lands. TPWD encourages and assists landowners who wish to provide this and other recreational opportunities. It also helps facilitate good conservation decisions that landowners make on their lands through its programs and by producing a wide array of educational materials.

Current programs and tools include the Technical Guidance Program, Landowner Incentive Program, Wildlife Management Tax Valuation assistance, information on private land trusts and the Lone Star Land Steward Awards. The Department coordinates federal programs that provide conservation incentives to landowners and facilitates the development of private wildlife management associations and land trusts.

Department Roles

TPWD'S ROLE IN PROVIDING LOCAL PARK GRANTS

Local parks are the "frontline" in the nationwide system of parks. Most communities do not have enough funds to acquire and develop parks to meet the demands of their expanding populations or their growing interest in land and water conservation. To assist in this work, the Texas Legislature funds the Texas Recreation and Parks Account that is administered by TPWD. The Department also receives federal funding, including Land and Water Conservation Funds from the National Park Service, that can be used to provide matching grants to help meet the need for local parks in Texas.

TPWD'S ROLE IN ENSURING WATER FOR FISH, WILDLIFE AND RECREATION

The Department's role in protecting fish and wildlife resources will become increasingly important as the demand for water increases and water availability decreases statewide. It has regulatory responsibility for recreational fishing in Texas' waters and regulates commercial fishing along the Gulf coast. It is also designated as the state trustee for aquatic resources, but has no regulatory authority to ensure water quality and quantity for fish, wildlife and recreational resources. TPWD's key role in water is to provide accurate scientific data on the water needs of fish and wildlife.

The Department focuses on maintaining and restoring sustainable aquatic life and maintaining fishable and swimmable designations in the state's waterways. An important component of this work is integration of data on aquatic communities, on physical, chemical and habitat parameters and on adjacent land uses. TPWD works with regional and state water planning stakeholders and works closely with regulatory agencies in an advisory capacity to protect and enhance water quality and to assure adequate instream flows for rivers and freshwater inflows for bays and estuaries. It is critical that the Department be successful in its efforts to conserve adequate water for fish and wildlife in order to reduce future economic and quality of life costs to governments, industries and citizens.

Conservation and Recreation Priorities on Land

A recent survey of public attitudes towards natural resources, conducted for Texas Tech University's *Texas Parks and Wildlife for the 21st Century* report, found that Texans strongly value natural resources and opportunities to participate in outdoor recreation. For instance, 97 percent felt it was important to know that wildlife exists in Texas, while 98 percent of the general population felt that it was important that people have the opportunity to visit state parks in Texas.

PRIORITIES FOR CONSERVATION ON LAND IN TEXAS

CONSERVATION THREATS ON LAND

There are many threats to wildlife habitat and plant communities in the state; some are specific to particular geographic regions, while some occur statewide. The following list describes the general threats to natural resources statewide. Specific threats in each ecoregion are described in the Ecoregion Priority Analysis.

Changing Demands on Land Resources

Projected population growth and fragmentation, or the division of single ownership properties into two or more parcels, have had profound effects on the landscape. Land conversion changes natural habitats, which can threaten the viability of those habitats and sustainability of wildlife population. For example, Texas A&M's *Fragmented Lands* report found that the conversion of rural land to urban uses in Texas exceeded 2.6 million acres from 1982 to 1997. Such changes will increase pressures on natural resources throughout the state especially near growing metropolitan areas.

Introduced Species in Terrestrial Environments

Non-native plant and animal species introduced into the state can displace native species, threaten habitat integrity and can profoundly alter the landscape. For example, Chinese tallow has invaded woodlands and coastal prairies and, left unchecked, changes these diverse habitats into virtual monocultures. Introduced grass species can create monocultures devoid of quality wildlife forage and of limited use for young ground nesting birds. For some ground dwelling birds like quail, these dense turf-type grasses cannot be traversed, which fragments their habitats. Imported red fire ants in eastern Texas have profound, but as yet not fully understood, adverse impacts on many wildlife species.

Overgrazing and Fire Suppression
Overgrazing and fire suppression have contributed to a drastic alteration of the historic landscape. For example, overgrazing results in less diversity in forage and poorer cover for nesting and other needs of wildlife. In addition, fire suppression has caused native grasslands, savannahs and open woodlands to become overgrown with thickets of woody species.

Limited Understanding of Complex Natural Systems
Research is a critical component of natural resource conservation. Without reliable knowledge and rigorous scientific inquiry, scientists cannot make informed conservation decisions. For instance, some principles of wildlife ecology, such as the early research on edge effects on wildlife, have since been found to be inaccurate. The decision making process at TPWD must remain based on the best science available to assure that policy development, regulatory action and resource management are accurate and effective.

ECOREGION PRIORITY ANALYSIS

According to NatureServe's *2002 States of the Union: Ranking America's Biodiversity*, Texas ranks second to California in terms of overall biodiversity nationwide. It has the highest number of bird and reptile species and second highest number of plants and mammals. It also has the third highest rate of endemism (species unique to Texas) and has the fourth highest number of extinct species in the United States.

Texas is a large and ecologically complex state with deserts, mountains, hills, prairies, forests, karst, caves, springs, rivers, wetlands and coastal habitats. One of the first challenges in addressing the conservation priorities was to determine what scale to use when describing the diversity found in the state. The scale could range from species-level to population, community, habitat or ecoregion level analysis. Ecologists typically divide the state into ecoregions that categorize the complex, dynamic system of vegetation, climate, geology and soils into a broad and comprehensible form. Given the complexity, the range in scale of the data inputs and the goals, TPWD chose the ecoregion scale as most appropriate for this analysis.

> 'Occupying a central position along the nation's southern border, this vast state overlaps several major ecological regions, including the southwestern deserts, the Great Plains, the humid Gulf Coast and, at the State's southern tip, the Mexican subtropics. As a result, many species reach distributional limits in Texas, and a strange blend of eastern and western species commingle within the state.' (NatureServe 2002)

Methodology

Primary Inputs
The conserved status in each ecoregion was determined by using the percent of publicly owned land, land owned by nongovernmental conservation organizations and large local parkland designated for conservation [Map 1] as well as the percent of the region operated under TPWD wildlife management plans [Map 2]. This evaluation considered the probability of private and public lands being conserved into the future. The analysis assumes that all public lands are protected into perpetuity and that the conservation value of private lands managed under wildlife management plans is currently stable. However, TPWD recognizes that public and private lands can be sold or converted to other purposes and

the conservation value of both depends on the quality of management.

The percent of land converted to urban or agricultural use [Map 3], fragmentation [Map 4] and population growth projections [Map 5] were used to determine the primary level of threat of each ecoregion. TPWD recognizes that both agriculture and urban lands [Maps 6, 7] can provide limited habitat for some species, though many native wildlife habitats have been negatively impacted by these conversions.

The biological value was determined by the total vertebrate species richness [Map 8], or actual number of species, as well as the vascular plant species richness [Map 9] occurring within the ecoregion.

Secondary Inputs

In determining a final ranking for the ten ecoregions, a number of secondary factors were also considered.

- The conservation value of Conservation Reserve Program lands (CRP) [Map 10], pasturelands, commercial timberlands and rangelands fall between that of undisturbed, natural habitats and crop and urban lands. The percentage of land under each of these human managed systems in each ecoregion was considered as a secondary input in the analysis.

- This evaluation considered miles of roads per acre in each ecoregion as a secondary indicator of land fragmentation [Map 11].

- The evaluation also considered the percentage of vertebrate species of concern (e.g., threatened, endangered, candidate and other species) as well as the number of rare plants in each ecoregion [Map 12]. Though rarity is a natural aspect of the biology of some species, TPWD recognizes that it is an appropriate value to use for broad generalizations about threats and vulnerability.

TPWD weighted the conserved status, primary level of threat and biological value equally and used these values to rank the ecoregions. [Table 1] Considering the secondary inputs, TPWD categorized the ecoregions of the state into three tiers: high, secondary and tertiary ecoregions [Map 13]. Within each tier, the ecoregions are listed in alphabetical order.

FOR DETAILED VIEW, SEE MAP 13 ON PAGE 94.

The Department will continue its existing efforts in the secondary and tertiary ecoregions, but will focus more resources to increase the number of technical guidance biologists, increase lands under wildlife management plans and other conservation actions in the high priority ecoregions. In addition, the Department will evaluate other methods, such as building partnerships with local and nonprofit organizations, to improve water availability and conserve wildlife habitat in these sensitive ecoregions.

TPWD also identified high priority habitat types that occur across all ecoregions, which are described in detail following the Priority Ecoregions for TPWD Conservation Efforts. The Department will focus its efforts to conserve, restore or enhance these habitats over the next ten years through acquisitions, partnerships with other entities, wildlife management plans, education and other TPWD programs.

PRIORITY ECOREGIONS FOR CONSERVATION EFFORTS

Tier I – High Priority Ecoregions for TPWD Efforts

Blackland Prairie

Percent of Ecoregion under Wildlife Management Plans 5.77

Percent of Ecoregion in Public and Nonprofit Conserved Land 1.52

Conserved Status: This ecoregion ranked medium in conserved status because there is only a small percentage of public and non-profit conservation land and private property operated under wildlife management plans.

Threats: This is the most severely altered of Texas' ecoregions, since most blackland prairie has been converted to crops or development. Only an estimated 5,000 acres remain in their historic condition in terms of plant species. All habitats in this ecoregion are threatened by rapid population growth in most of the ecoregion and accompanying conversion to urban and pasture, fragmentation and decreasing land parcel size.

Rare Plants and Communities: This ecoregion ranks lowest in number of rare plant species and seventh in number of endemics, but all four native blackland prairie grass communities are rare.

Rare Animals: Many tall grass prairie birds have declined drastically due to land conversion and fragmentation. This region is important stopover habitat for migrant songbirds and wintering raptors.

Priorities: Protection and restoration of remnant prairies is a high priority.

Gulf Coast Prairies and Marshes

Percent of Ecoregion under Wildlife Management Plans 8.93

Percent of Ecoregion in Public and Nonprofit Conserved Land. 5.69

Conserved Status: Overall, this ecoregion ranked relatively high in conserved status second only to the Trans-Pecos ecoregion, although conservation efforts are not evenly distributed across the region. The coastal marshes and barrier islands are relatively well

conserved, whereas the inland prairies, coastal woodlands and some beach habitats are not.

Threats: All factors considered, this is among the most threatened of the ten ecoregions and the more threatened of the two high diversity ecoregions. The high population growth and associated development along the coast have fragmented land, converted prairies, changed river flows, decreased water quality and increased sediment loads and pollutants on marshes and estuaries. Projections indicate continued high growth and increasing fragmentation in most parts of this ecoregion.

Rare Plants and Communities: The region ranked high in rare plant species and endemism including five rare plant communities. All of the region's 24 rare plants occur inland where the conserved status is lowest.

Rare Animals: Attwater's prairie chicken, whooping crane, aplomado falcon, white-tailed hawk, Gulf Coast hog-nosed and eastern spotted skunks are all in need of attention, as are many of bird species that depend on this important migratory stopover area.

Priorities: Protection efforts should focus on inland prairies and coastal woodlands. Many beach areas and mud flats need additional protection.

South Texas Plains

Percent of Ecoregion under Wildlife Management Plans 13.6

Percent of Ecoregion in Public and Nonprofit Conserved Land 0.51

Conserved Status: This ecoregion ranked relatively high in conserved status overall. The South Texas Plains consists mostly of level to rolling terrain characterized by dense brush. Little of the brush country is conserved on public lands, but a relatively high percent is in large stable ownerships and operated under wildlife management plans. Much of the high quality brush habitat that still exists in the Lower Rio Grande Valley (LRGV) is in public ownership, but it is insufficient to sustain many of the region's threatened plants, animals and communities.

Threats: Overall, this region ranked relatively high. Threats are concentrated in the LRGV due to the expanding human population, fragmentation, conversion to croplands, urban development, insufficient river flow and introduction of exotic plants.

Rare Plants and Communities: Rare plant communities include the Texas ebony-anacua, Texas palmetto and Texas ebony-snake-eyes assemblages. Rare species include Walker's manioc, star cactus, Texas ayenia and Zapata bladderpod.

Rare Animals: The LRGV has particularly rich bird and butterfly faunas, as well as the endangered ocelot and jaguarundi.

Priorities: The remaining fragments of brush in the LRGV should be protected and corridors between these habitats should be protected and restored.

Tier II – Secondary Priority Ecoregions for TPWD Efforts

Cross Timbers and Prairies

Percent of Ecoregion under Wildlife Management Plans 5.03

Percent of Ecoregion in Public and Nonprofit Conserved Land 1.73%

Conserved Status: This ecoregion and the High Plains ecoregion rank the lowest in conserved status. There is little public land, few private preserves and a low percentage of private land under wildlife management plans.

Conservation and Recreation Priorities on Land

Threats: This ecoregion ranked medium in terms of land conversion, but the potential for rapid conversion and fragmentation in the future is suggested by high projected population growth. Threats in the region include fragmentation and land conversion of prairies, forests and savannahs; mesquite invasion of degraded grasslands, and proliferation of exotic grasses. Rivers and streams have been altered by an extensive reservoir system. Hundreds of miles of riparian, or river, forests have been inundated and downstream flows reduced. Most ground nesting birds, grassland mammals, amphibians and egg-laying reptiles are also threatened by fire ant invasion.

Rare Plants and Communities: This ecoregion harbors only one rare plant and has relatively low endemism. Patches of blackland prairie grasslands within the Cross Timbers are made up of threatened communities similar to those described for other ecoregions.

Rare Animals: The region provides nesting habitat for the federally endangered black-capped vireo and the golden cheeked warbler.

Priorities: Protecting the ecoregion's prairies, woodlands and remaining river corridors should be a priority.

Edwards Plateau

Percent of Ecoregion under Wildlife Management Plans 9.58

Percent of Ecoregion in Public and Nonprofit Conserved Land 0.51

Conserved Status: Despite a small amount of public and non-profit conservation land, the region ranked medium due to the relatively high percentage of private land managed under wildlife management plans.

Threats: Land conversion values for the ecoregion, overall, were relatively low. However, projected population growth and subdivisions of large tracts of land are high, particularly in the eastern portion where intense development and fragmentation threatens the biodiversity and the region's unique hydrology.

Rare Plants and Communities: The Edwards Plateau is internationally recognized for its unique flora associated with karst (limestone, cave, spring, stream systems). It has the highest number of plant endemism of any ecoregion in the state and ranks third in number of rare plants. Of the 29 plant communities found here, three occur nowhere else in Texas and two are found nowhere else in the world.

Rare Animals: Karst habitats support many species of salamanders and cave insects, many of which are restricted to only a few sites. This is the most important ecoregion for herpetological and invertebrate species due to high endemism, sensitive habitats and intense threats. Black-capped vireos and golden-cheeked warblers are the two bird species of greatest concern.

Conservation and Recreation Priorities on Land

Priorities: The sheltered canyons, springs, caves and river systems are home to most of the biological diversity and should be priorities for public and private conservation efforts. Conserving relatively intact grasslands and maintaining sufficient old growth juniper habitat for the golden-cheeked warbler, especially in the western hill country, are also a priority.

High Plains

Percent of ecoregion under Wildlife Management Plans. 2.6

Percent of Ecoregion in Public and Nonprofit Conserved Land 0.56

Conserved Status: This ecoregion is the least conserved because there is a low percentage of public and non-profit conserved land and wildlife management plans.

Threats: This ecoregion experienced a high rate of conversion to crops, but a considerable portion of it is now enrolled in the USDA's Conservation Reserve Program that has higher conservation value than cropland. Threats include fragmentation and land management practices that are harmful to species such as lesser prairie chickens. Other threats include the damming of springs, streams and rivers, the draining and conversion of playa lakes and surface mining.

Rare Plants and Communities: Plant endemism is low, but there are two rare species, five endemics and several distinct plant communities

Rare Animals: Birds of concern in this region include ferruginous and Swainson's hawks, burrowing owls, mountain plovers and lesser prairie chickens. The black-tailed prairie dog, swift fox and pronghorn antelope need conservation attention.

Priorities: Increasing the percentage of conserved land to support several important game species and threatened animals is a priority.

Pineywoods

Percent of Ecoregion under Wildlife Management Plans 2.81

Percent of Ecoregion in Public and Nonprofit Conserved Land. 6.72

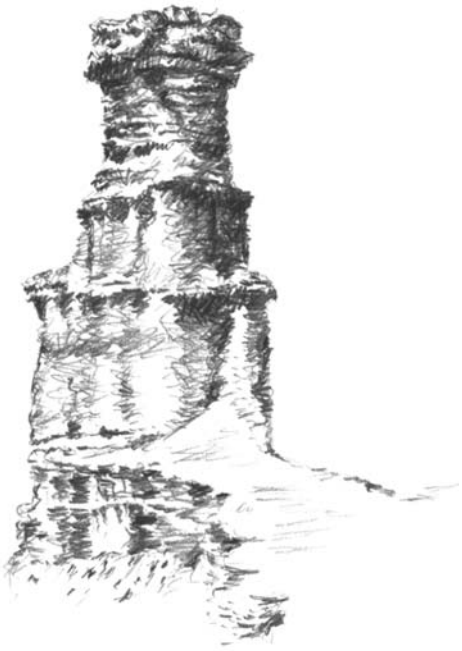
Conserved Status: This ecoregion ranked medium in conserved status because of the relatively high percentage of publicly owned land and medium percentage of land under wildlife management plans. The northern half of the ecoregion is not well conserved and has unique habitats and rare species of plants and reptiles.

Threats: The Pineywoods ranked relatively low in terms of land conversion, but high in terms of projected population growth. Much of the longleaf pine and hardwood forests habitats have been converted to loblolly plantations, which have limited conservation value. The primary threats are fragmentation and land conversion, for instance the consolidation of timber interests around the country has led to sales of large timber tracts in east Texas which may be converted to other uses. Fire suppression, fire ant and Chinese tallow invasion are also threats. Much of the best remaining bottomland hardwood habitat is threatened by potential reservoir construction.

Rare Plants and Communities: Plant endemism ranks relatively low, though the region supports 22 rare species and 27 endemics. The longleaf pine savannahs have been reduced from approximately 1.5 million acres historically to 50,000 acres today. Many of the acid seeps and pitcher plant bogs have been converted to other uses.

Rare Animals: The Pineywoods and the Gulf Coast ecoregions share one of the world's most diverse, highly threatened mussel populations. Reptiles of concern include the Louisiana pinesnake, alligator snapping turtle and timber rattlesnake. Amphibians are declining generally. Birds of concern are the red-cockaded woodpecker, Bachman's sparrow and other grassland savannah nesters and winterers. The endangered Louisiana black bear may be attempting to naturally recolonize and the conservation of bottomland forests is critical to their return.

Priorities: Longleaf pine savannahs and other unique plant communities, including bogs, hardwood slope forests and baygalls should be preserved and restored where possible. Conservation and restoration of remaining bottomland hardwood habitat is also important for many wildlife species.



TIER III –Tertiary Priority Ecoregions for TPWD Efforts

Post Oak Savannah

Percent of land under Wildlife Management Plans. II.18

Percent of Ecoregion in Public and Nonprofit Conserved Land I.13

Conserved Status: This ecoregion ranked medium in conserved status because only a small percentage is public or non-profit conservation land.

Threats: The Post Oak Savannah ranked relatively low in threats overall. The primary threats are fragmentation and land conversion, especially from the damming of springs, streams and rivers. Other threats include fire ant infestation and fire suppression in both oak savannahs and pitcher plant bogs.

Rare Plants and Communities: Endemism in the plants of this ecoregion ranks lower than in others, though the area supports 17 rare species and 65 endemics. Many highly specialized plant habitats such as blow-out sandhills, clay-pan savannahs, pitcher plant bogs, Catahoula and Oakville sandstone outcrops, chalk glades and limestone prairies support numerous rare plants, which are not found on public land.

Rare Animals: There are several species of concern in the region including loggerhead shrikes, painted buntings, spotted skunks, the Brazos water snake and the Houston toad.

Priorities: Conservation efforts in this region should focus on areas that support many of the region's unique species and communities such as mesic hardwood woodlands, bogs, sandhills and bottomland hardwoods.

Conservation and Recreation Priorities on Land

Rolling Plains

Percent of Ecoregion under Wildlife Management Plans 6.51

Percent of Ecoregion in Public and Nonprofit Conserved Land 0.49

Conserved Status: The ecoregion ranked low in conserved status with a relatively small amount of public and non-profit conservation land and a medium percentage of land under wildlife management plans.

Threats: This region ranked medium in threats including land fragmentation and conversion. Exotic species such as saltcedar exist along many miles of riverbank.

Rare Plants and Communities: The only rare plant endemic to this region, the Texas poppy-mallow, is associated with the mesquite grasslands and Havard shin oak communities.

Rare Animals: Low forests on limestone out-pockets are important habitat for the endangered black-capped vireo. Both the federally listed Concho and Brazos water snakes occur. The state listed Texas kangaroo rat also survives in this region.

Priorities: This region is a prime candidate for restoration efforts and many species would benefit from restoration of grasslands and riparian forests. Protection of the Texas poppy-mallow and high quality examples of communities such as Havard oak-tallgrass, sandsage-midgrass, cottonwood-tallgrass, types of grasslands and woodlands is also important.

Trans-Pecos

Percent of Ecoregion under Wildlife Management Plans 8.74

Percent of Ecoregion in Public and Nonprofit Conserved Land 7.56

Conserved Status: This ecoregion is the most conserved of all ecoregions, but the conserved lands are not evenly distributed across the region. The desert grasslands of the region are poorly conserved, as are much of the forests along the Rio Grande and plant communities around springs.

Threats: Threats in this region are the lowest of any ecoregion but include persistent drought and groundwater withdrawals that have damaged many existing spring-associated communities. Expansion of human activities in the El Paso region will negatively impact habitats in the surrounding region.

Rare Plants and Communities: The region is one of Texas' botanically richest and most unique. Approximately one of every 12 plant species occur nowhere else in Texas. The Trans-Pecos supports three times the number of rare plants than any other region. Much of the banks of the Rio Grande are choked with saltcedar, making the protection of the rare patches of cottonwood-willow and velvet ash-willow communities important. Many springs and their associated cienegas and creeks contained numerous rare plants, but most have dried out. Of the few springs that remain, only three are permanently conserved.

Rare Animals: This region has the highest percentage of vertebrate species of concern. The bird, mammal and insect faunas are rich and unique. Rare birds include the golden eagle, the common black hawk,

elf and flammulated owls, peregrine falcon, Montezuma quail and others. Mammals include the black-tailed prairie dog, kit fox, desert bighorn, pronghorn antelope, Mexican black bear and the hooded skunk. This is by far the most herpetologically diverse ecoregion. Species of concern include the Chihuahuan mud turtle and the dunes sagebrush lizard.

Priorities: The high desert grasslands, spring communities and riparian woodlands along the Rio Grande need additional conservation action.

HIGH PRIORITY HABITATS FOR TPWD EFFORTS

Despite the many positives associated with the ecoregion scale, the very real and often critical conservation needs of some habitats, communities and species can be missed by this approach. Every ecoregion in Texas is home to important game species, threatened and endangered species, significant habitats and communities. The Priority Ecoregion Analysis showed that native prairies and grasslands, riparian habitats that cross ecoregion boundaries are the most important wildlife habitats, contain the highest numbers of rare species and are often the most threatened. These habitat types will be a priority for the Department in the future.

Native Prairie and Grassland Habitats

Native prairies and grasslands once covered Texas from the shortgrass prairies in the Panhandle; to the coastal marshes of the Gulf; to the desert and montane grasslands of the west; and even to small openings within the Pineywoods. These habitats supported a vast array of species including bison, prairie dogs, eastern meadowlarks, northern bobwhites, big bluestem and Indiangrass. Without native prairies and grasslands, cattle ranching and cotton production would not have been successful in the state, but relatively little native habitat remains today. Even those patches of prairies and grasslands that have not been altered or converted to other uses often support fewer species due to fragmentation, fire suppression, overgrazing and woody plant invasion. Nevertheless, with proper management, native prairie and grassland habitats are resilient and many can be restored.

Riparian Habitats

Riparian habitats include vegetation found along the banks and on the floodplains of rivers, creeks and streams. Riparian forests that cover broad floodplains are often referred to as bottomland hardwood forests. In arid regions and in times of drought, riparian corridors are often the only place where trees and wildlife species are able to survive. These corridors support highly diverse wildlife because they are critical feeding areas and serve as valuable refuges. Riparian forests improve water quality and quantity and provide important nutrients to the streams and rivers. Riparian vegetation also holds water by slowing the rate at which water moves from the land into streams and shaded waterways lose much less water to evaporation.

PRIORITIES FOR RECREATION ON LAND IN TEXAS

THREATS TO PUBLIC OUTDOOR RECREATION

Changing Needs

Outdoor recreation needs in the state are changing as the population becomes increasingly diverse and grows older. For instance, Texas A & M's *Texas Outdoors a Vision for the Future* indicates that older adults and minorities choose to participate in traditional TPWD programs and services, such as visiting state parks and recreational fishing, at lower levels than other population groups. In addition, the population is now predominantly urban; more than 80 percent of all Texans live in urban areas and approximately half live in four major population centers including Dallas, Fort Worth, Houston and San Antonio. These shifts in the general makeup of the population will change TPWD's historic constituent base and the demand for traditional services and opportunities.

Access to Public Lands

By the turn of the 20th century, most of the state's 266,807 square miles were already privately owned. Gradually, over the following 100 years, it has become predominately urban and most rural lands surrounding metropolitan areas have been converted to residential and other uses. With a growing urban population and limited public lands, access to the outdoor recreation is becoming more limited for most Texans.

QUALITATIVE TEXAS PARKS AND WILDLIFE DEPARTMENT RECREATION SITE EVALUATION

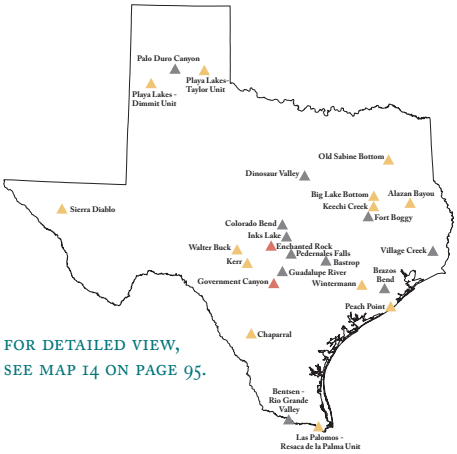
The Department evaluated all state parks and wildlife management areas to determine whether the sites need additional resources to meet the demands of its changing constituency. It is much more cost effective to add land to existing parks and wildlife management areas rather than to develop infrastructure and add staff to entirely new sites. Management input, recreation and resource value, location and visitation all factored into this evaluation [**Tables 2, 3**].

State parks and wildlife management areas were also analyzed to determine whether TPWD was the appropriate manager of the sites. The criteria were

used to determine whether the sites served more as local parks, if they had little recreational or resource value or would be more appropriately managed by another agency or organization.

Priority Sites

Priority state parks and wildlife management areas are relatively large and have significant natural resource or recreation value. In the next ten years, TPWD will focus its efforts on expanding these sites where possible to improve access, recreation experience, wildlife habitat and resource protection. TPWD will evaluate each site to determine whether they also warrant improved or expanded public facilities, staffing or educational and interpretive programs [Map 14].



FOR DETAILED VIEW, SEE MAP 14 ON PAGE 95.

State Parks

The priority state parks are within 90-minutes of the I-35/I-10/I-45 triangle, the Lower Rio Grande Valley or are destination parks – places where people are willing to travel greater distances and spend one or more nights. Some state parks may operate at or near capacity for part of the year and relatively undeveloped lands still exist adjacent to the sites.

Criteria Used for Priority State Parks

- Location – Proximity to urban population centers
- Natural Resource Value – Significant geographic, wildlife, plant resources present
- Recreational Value – Water features; visitation; accessibility; available activities
- Ability to Expand – Undeveloped adjacent lands
- Current Size of State Park
- Destinations

PRIORITY STATE PARKS FOR EXPANSION
Bastrop/Buesher
Bentsen-Rio Grande
Brazos Bend
Colorado Bend
Dinosaur Valley
Enchanted Rock
Fort Boggy
Government Canyon
Guadalupe River
Palo Duro
Pedernales Falls
Resaca de la Palma
Village Creek
Inks Lake

Conservation and Recreation Priorities on Land

Other sites in TPWD's inventory fit many of these criteria, but are either small, are not within a 90-minute drive or do not have significant natural resource or recreation value, but would be a secondary priority for expansion.

State parks like Cedar Hill or Garner may also be operating at capacity for much of the year, but there are few opportunities to expand the sites. These sites represent an opportunity for TPWD to reach many people and likely need additional educational or interpretive staff and programming to improve the visitor experience.

Wildlife Management Areas

Priority wildlife management areas for expansion have high natural and recreational value, can be expanded because relatively undeveloped adjacent lands still exist and increasing the sites will enable TPWD to conduct high-quality research and demonstrate good wildlife management practices.

Criteria Used for Priority Wildlife Management Areas

- Natural Resource Value – Significant wildlife habitat, plant resources present
- Recreational Value – Water feature; accessibility; available activities
- Ability to Expand – Undeveloped adjacent lands
- Current Size of Wildlife Management Area – Sustainable research and demonstration capacity

PRIORITY WILDLIFE MANAGEMENT AREAS FOR EXPANSION
Alazan Bayou
Big Lake Bottom
Chaparral
Keechi Creek
Kerr
Old Sabine Bottom
Peach Point
Playa Lakes
Sierra Diablo
Walter Buck
Wintermann

Sites such as Gus Engeling WMA in the Post Oak Savannah ecoregion and Black Gap WMA in the Trans-Pecos ecoregion may need additional resources to continue outstanding research and demonstration efforts and other programming.

Sites Eligible for Transfer

Sites on these lists do not fit the Department's role defined in this Plan. In some cases, these sites have high recreational or resource value, but another entity could more appropriately manage them. State parks may function more like a local parks and many of the wildlife management areas are adjacent to land managed by the U.S. Fish and Wildlife Service.

House Bill 2108, 76th Legislature, allows the Department to transfer state parks to local or regional governments for operation and maintenance. TPWD can award grants to the local or regional governments who are willing to assume this

responsibility. In the next ten years, TPWD will consider transferring or selling these sites if the opportunity arises. The Department may need to place restrictions on these lands to protect recreational or natural resource integrity prior to sale or transfer.

Criteria used to Determine State Parks Eligible for Transfer

- Site functions more as a local park – developed for local use (e.g., baseball fields, swimming pools; golf courses); serves a single community (e.g., completely surrounded by a single community)
- Size – site is small with little opportunity for expansion
- Site has not been developed – underutilized; future development is not funded
- Site is adjacent to other recreation or conservation organization land that could better manage the site

In addition, TPWD leases many sites from other governmental entities. When these lease agreements expire or if an opportunity to terminate the lease arises, TPWD will return management responsibility of the site. TPWD will evaluate leased state parks on lakes to determine whether the entire lake should be managed by TPWD or another entity to avoid redundancy and duplication of efforts.

State Parks Eligible for Transfer

State Park	Acres	County	Potential Transfer
Big Spring	381.99	Howard	Local Management
Boca Chica	1,054.92	Cameron	Transfer to USFWS
Copano Bay	5.92	Aransas	Local Management
Davis Hill	1,737.34	Liberty	Transfer to USFWS
Eagle Mountain Lake	400.71	Tarrant	Local Management or Sale
Kerrville-Schreiner	517.20	Kerr	Local Management
Lake Arrowhead	524.00	Clay	Local Management
Lockhart	263.74	Caldwell	Local Management
McKinney Falls	744.40	Travis	Local Management

Leased State Parks Eligible for Transfer

State Park	Acres	County	Leasor
Atlanta	1,475.00	Cass	COE
Lake Casa Blanca International	371.00	Webb	Webb County
Lake Colorado City	500.00	Mitchell	TE
Lake Somerville & Trailway	5,520.00	Burleson/Lee	COE
Lake Tawakoni	376.29	Hunt	SRA
Lake Texana	575.00	Jackson	LNRA
Lake Whitney	1,280.70	Hill	COE
Martin Creek Lake	286.86	Rusk	TX Utilities

Conservation and Recreation Priorities on Land

All of the Department's wildlife management areas have moderate to high resource value for wildlife habitat. However, some would be better managed by another entity.

Criteria used to Determine Wildlife Management Areas Eligible for Transfer

- Adjacent to other conservation organization lands
- Size – site is too small for appropriate research and demonstration
- Management – isolated site may be more appropriately managed by other conservation organizations

Wildlife Management Areas Eligible for Transfer

WMA	Acres	County	Potential Transfer
Atkinson Island	151.96	Harris	Transfer or Sale
Las Palomas/Ocotillo	2,082.14	Presidio	Transfer or Sale
Las Palomas/Kelly	46.00	Hidalgo	Transfer to USFWS
Las Palomas/Kiskadee	14.00	Hidalgo	Transfer to USFWS
Las Palomas/LaGrulla	136.00	Starr	Transfer to USFWS
Las Palomas/McManus	56.00	Hidalgo	Transfer to USFWS
Las Palomas/Prieta	164.00	Starr	Transfer to USFWS
Las Palomas/Voshell	67.86	Cameron	Transfer to USFWS
Redhead Pond	36.93	Nueces	Local Management

Leased WMAs Eligible for Transfer

State Park	Acres	County	Leasor
Lake Somerville WMA	3,180.00	Burleson/Lee	COE
Lake Tawakoni WMA	1,562.00	Hunt/Van Zandt	SRA

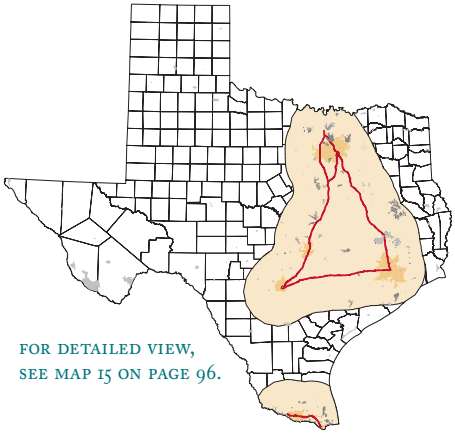
OUTDOOR RECREATION ANALYSIS

> ‘*Texas Parks and Wildlife for the 21st Century* surveys of park visitors illustrate that the majority of park visitors typically travel two hours or less to visit a state park for day use...’

New state parks should be accessible to major population centers, especially those areas that are experiencing significant population growth. Ideally, users should be able to travel to these sites and home in one day. However, due to their high recreational or resource value, some state parks and wildlife management areas are destinations – places where people are willing to travel greater distances and spend one or more nights. *Texas Parks and Wildlife for the 21st Century* surveys of park visitors illustrate that the majority, or 59 percent, of park visitors typically travel two hours or less to visit a state park for day use – the majority of visitors staying overnight at state parks, or 66 percent, travel two hours or more.

Most of the larger wildlife management areas and state parks are located far from the bulk of Texas' urban population. Seventy-five percent of the population lives within 60 miles of the I-35/I-45/I-10 corridor and the Lower Rio Grande Valley, whereas only 27 percent of the available acres of TPWD sites are located within these areas [**Map 15**]. The U.S. Census Bureau projects that these areas will also experience the most rapid growth over the next ten years.

State parks provide high quality outdoor recreational opportunities, but many are too small to manage as sustainable natural areas and are often too small to meet the increasing need for public access. TPWD recognizes five thousand acres as the minimal size requirement for optimal wildlife habitat and is the minimum acreage necessary for a high quality outdoor experience. Ideally, more than a single 5,000-acre state park or wildlife management area should serve each major population center for recreation.



FOR DETAILED VIEW, SEE MAP 15 ON PAGE 96.

- Almost all Texans believe that it is important to have the opportunity to visit a state park.
- 70% of Texans believe that it is important for TPWD to continue to manage and preserve places to experience and enjoy nature.
- Texans believe it is important that TPWD expand its efforts to provide high quality outdoor recreational opportunities.
- Texans are very interested in participating in resource-based recreation, including hiking and wildlife viewing.
- The majority of Texans say they are willing to pay for more public access and natural resources conservation.

-Texas Parks and Wildlife for the 21st Century, 2001

Conservation and Recreation Priorities on Land

An acre-per-capita standard is the most widely accepted measure for providing public recreation land by state parks agencies around the country. This standard, however, does not measure more significant factors such as the quality of the user experience, availability of activities and convenience of access in a state as populous and as large as Texas.

In addition to the supply of recreational opportunities, it is important to consider the demand for a variety of outdoor recreational activities. In 2001, a Texas Tech University survey showed that 33 percent of Texans visited a state park at least once in the last twelve months. Of those who had not participated in outdoor activities at least once in the last twelve months, 37 percent said that they would be interested in visiting a state park.

Percent of Texas Population Participating in Outdoor Recreation Activities at least once in the last 12 months

Picnicking	45%
Visit historic sites	41%
Swimming in natural waters	39%
Fishing	38%
Visit park or natural area within 1 mile of home	35%
Trips or outing to view wildlife	34%
Visit Texas State Park	33%
Motorboating (excluding jetskis)	30%
Camping	27%
Bicycling	20%
Hiking	19%
Hunting	16%
Jetskiing	12%
Canoeing/Kayaking	6%
Mountain biking	5%
Rock climbing	5%
Sailing	4%

– Texas Parks and Wildlife for the 21st Century, 2001

Another survey in 1998 from Texas A&M's *Texas Outdoors: A Vision for the Future*, described constraints to user participation close to and away from home.

- Most outdoor recreation participation occurs close to home.
- The most desired activities among Texans who experienced activity constraints close to home included fishing (21%), trail activities (17%) and boating and other water-related activities (13%).
- The most desired activities among Texans who experienced activity constraints away from home included fishing (18%), camping and active outdoor recreation activities (16%), hunting (14%) and trail activities (26%).

Methodolgy

TPWD evaluated outdoor recreational opportunities available to the 25 most populous cities in Texas, which make up approximately three-quarters of the state's population. TPWD gathered data on the types of activities available at each state park, wildlife management area, national park, national forest, national wildlife refuge and other recreation areas owned by the federal government. The activities measured included hiking, biking and equestrian trail miles, campsites, acres available for hunting and sites where fishing or other water access is available.

This analysis used data from the 2,000 U.S. Census, which breaks the state into geographic units known as census tracts, averaging between 1,500 – 8,000 people. The Department created city units by aggregating adjacent suburban communities into larger cities and by only using census tracts that met the U.S. Census Bureau's criteria for urban areas. For instance, Mesquite and Plano are within the Dallas city unit, while La Porte and Pasadena are part of Houston.

Conservation and Recreation Priorities on Land

Using computer software that calculates actual drive times, TPWD established a 90-minute service area radius from the headquarters or entrance station of each state park, wildlife management area, federal wildlife refuge, national park, and other recreation areas. The Department used 90 minutes as the longest distance people are willing to drive to a park or wildlife area for the day and still be able to return home in the evening [**Map 16**]. Outdoor recreational opportunities for each city unit were compared and ranked and the total population within each property's service area was calculated. City units were compared by the number of acres available per 1,000 people and by activities available including camping, biking, hiking, hunting and horseback riding.

The Outdoor Recreation Analysis did not take into account trail miles, campsites, fishing opportunities and other activities that are open to the public at local parks because this data was not readily available for all cities and counties. Local and private parks can provide these important recreational opportunities for communities across the state, but it is also important that state and national parks provide these activities close to urban areas. Opportunities to access local parks is developed in the Local Parks Analysis below.

Findings and Priorities

TPWD underserves major population centers, especially those that will experience the most growth in the future [Graph 1].

- TPWD provides four of the largest 25 cities in Texas with more acres per capita than the statewide average of 52-acres per 1,000 population.
- TPWD underserves the most populous cities with Houston at 40.3 acres per 1,000 population followed by El Paso, Austin, Dallas, Fort Worth and San Antonio with 9.9 acres per 1,000 population.
- Houston is better served than the rest of the most populous cities, but like the other big cities, it is projected to grow dramatically in comparison with the rest of the state.
- To best serve the populations of Texas, a priority for TPWD is to focus acquisition efforts within 90-minute drives of San Antonio, Fort Worth, Dallas, Austin and the Valley areas, all of which are underserved.

Even when combined with federal parks, forests and refuges, most large cities in Texas do not have enough large land holdings open to the public for a high quality outdoor experience [Graph 2].

- Combining the outdoor recreational opportunities available on federal and TPWD lands, the level of opportunities measured by acres available generally increases for all cities.
- Of the 25 most populous cities, the best served include Corpus Christi with 278.1 acres per 1,000 population followed by Bryan-College Station and Longview.
- Of the 25 most populous cities, the least served include Abilene with 7.4 acres per 1,000 population followed by Lubbock and Wichita Falls.
- Houston has the most opportunities of the largest cities, while San Antonio and El Paso do not increase significantly.
- Including federal lands significantly increases the apparent level of service to the Valley communities.

Conservation and Recreation Priorities on Land

90-Minute Service Area - Public Recreation and Conservation Acreage by City

City Unit	Population	TPWD & Federal Acres Per 1,000	TPWD Acres Per 1,000	Federal Acres Per 1,000
Greater Houston	3,899,400	52.6	40.3	12.3
Greater Dallas	3,094,075	18.3	15.9	2.4
Greater Fort Worth	1,531,517	16.7	13.6	3.1
Greater San Antonio	1,347,728	10.4	9.9	0.5
Greater Austin	951,234	21.1	17.5	3.6
El Paso	625,539	36.9	36.8	0.1
Greater McAllen	487,388	41.7	6.0	35.7
Greater Corpus Christi	278,017	278.1	33.9	244.2
Greater Beaumont - Port Arthur	267,431	96.1	63.9	32.2
Lubbock	216,488	4.5	0.3	4.2
Temple - Belton - Killeen	194,353	23.3	18.3	5.0
Midland - Odessa	188,031	13.7	13.7	0.0
Amarillo	181,989	85.2	49.1	36.1
Laredo	168,032	59.7	59.7	0.0
Greater Brownsville	163,975	42.2	6.8	35.4
Greater Waco	158,343	18.2	12.6	5.6
Bryan - College Station	138,166	97.5	62.6	34.9
Greater Galveston	121,647	32.7	11.4	21.3
Abilene	117,415	7.4	4.4	3.0
Wichita Falls	116,802	3.5	3.5	0.0
Tyler	103,377	95.9	39.4	56.5
Greater Harlingen	100,310	44.1	7.7	36.4
San Angelo	90,041	80.3	51.3	29.0
Longview	89,254	96.4	82.3	14.1
Greater Denison - Sherman	67,669	43.7	35.0	8.7

- TPWD Outdoor Recreation Service Analysis, 2002

Conservation and Recreation Priorities on Land

Acres per capita only measures what is available, not the quality, quantity or type of activities available for outdoor recreation [Graphs 3-7], [Tables 4-8].

- Specific recreational activities provided by TPWD and federal lands vary greatly between cities. The six most populous cities have relatively low levels of activities available overall. Given that the populations will increase tremendously, improving outdoor recreational opportunities to these areas is a priority for the Department.

- Houston: even though Houston has the most acres available of the most populous cities, it has the fewest campsites, hiking trail miles and biking miles per 100,000 people.
- Dallas: populations in Dallas are generally underserved and have few hiking and camping opportunities.
- Fort Worth: is above average among the most populous cities for outdoor recreational activities except for hunting and biking.
- San Antonio: ranks below average of the most populous cities for all activities. The activity analysis did not include the current development of Government Canyon State Natural Area (to open in the fall of 2003).
- Austin: is average among the most populous cities but has few opportunities for horseback riding and fishing on state or federal land.
- El Paso: of the most populous cities, El Paso ranks below average for hiking and equestrian trails and has no opportunities for public hunting.
- Lower Rio Grande Valley: despite not having many TPWD acres within a 90-minute drive, the Valley communities are relatively well served by federal lands for hunting and camping opportunities. The Valley has few opportunities for horseback riding, fishing, biking and hiking.

TPWD does not equally serve cities with single 5,000-acre recreational opportunities within a 90-minute drive [Table 9].

- Cities best served by TPWD are Dallas, Houston, San Antonio and Austin.
- The least served cities are Midland – Odessa, Brownsville, Abilene, Wichita Falls, Harlingen, Lubbock and McAllen.
- Of the most populous cities, TPWD best serves Dallas, followed by Houston, San Antonio, Austin, followed by Fort Worth and El Paso.
- The Lower Rio Grande Valley communities need at least a single 5,000-acre opportunity for recreation; they currently do not have access to a single large TPWD site.

LOCAL PARK ANALYSIS

> ‘Local parks not only serve a recreational purpose, but they also enhance the quality of life for the communities...’

State parks balance natural resource conservation with the recreational needs of the state. Local parks focus on recreational activities that are generally more intensive and often require highly developed infrastructure (e.g., ball fields, golf courses and swimming pools), though many local parks also preserve important land and water resources. Local recreation providers tend to be more involved in recreation and leisure programming to address a wider variety of public services (e.g., fitness, child development and sports programs). Local parks not only serve a recreational purpose, but they also enhance the quality of life for the communities by attracting businesses and providing positive experiences for youth. TPWD encourages all communities to provide outdoor recreational experiences for their populations through its local grants program.

Methodology

The Department recognizes that an acre-per-capita standard is an indicator of service that does not measure the activities available or the quality of the visitor experience. For this evaluation, TPWD used local park acreage in each city or town and compared acreages to the population they serve because these data were the most objective and accessible information available.

The Department collected information in a geographic database on local parks serving 388 Texas communities. Data were used from existing sources including Texas Department of Transportation digital maps and direct contacts with many communities across the state. In contrast to the recreational analysis for TPWD and federal properties, the communities were analyzed using actual city limits instead of city units. TPWD compared cities with populations below 20,000, between 20,000 and 100,000 and cities over 100,000 people [**Table 10**].

Findings

> The opportunity for Texans to access local recreational lands is dependent upon local priorities, established needs and the financial ability of the community to provide access.

Of the 388 cities in Texas reporting local parkland acreages to TPWD

- 133, or 38 percent, have less than 10 acres of local parks per 1,000 population
- 90, or 23 percent, have between 10 and 25 acres of local parks per 1,000 population
- 32, or 8 percent, have between 25 and 100 acres of local parks per 1,000 population
- 6, or 1.5 percent, have over 100 acres of local parks per 1,000 population

Cities over 100,000 have a broad range of local outdoor recreational opportunities [**Map 17**].

- The mean acres per 1,000 for cities over 100,000 population is 15.5 acres.
- Cities with the most acres per 1,000 people are Waco with over 49 acres followed by Grand Prairie, Austin, Carrollton and Fort Worth with 21 acres.
- Cities with the fewest acres per 1,000 people are Laredo with 0.9 acres followed by Pasadena, McAllen, El Paso, Abilene and San Antonio.
- Of the most populous cities, Austin has the most acres per 1,000 with 37 acres followed by Fort Worth, Dallas, Houston, El Paso and San Antonio with 7.9 acres.
- The Lower Rio Grande Valley has relatively few opportunities using this measure: Harlingen is best served with 21 acres; Brownsville with 7 acres; and McAllen with 1.2 acres per 1,000 population.

Conservation and Recreation Priorities on Land

Park Acres per 1,000 Ranked for Cities over 100,000

City	Acres per 1,000 Population	City Population	Total City Park Acres
Houston	10.30	1,953,631	20,107.83
Dallas	19.70	1,188,580	23,378.63
San Antonio	7.90	1,144,646	9,064.05
Austin	37.20	656,562	24,408.10
El Paso	5.10	563,662	2,891.98
Fort Worth	21.10	534,694	11,302.91
Arlington	10.00	332,969	3,328.46
Corpus Christi	8.00	277,454	2,210.07
Plano	15.80	222,030	3,505.86
Garland	10.00	215,768	2,153.10
Lubbock	17.80	199,564	3,546.13
Irving	9.00	191,615	1,733.15
Laredo	0.90	176,576	164.15
Amarillo	15.00	173,627	2,601.72
Pasadena	1.20	141,674	172.37
Brownsville	7.00	139,722	984.94
Grand Prairie	43.10	127,427	5,494.94
Mesquite	15.30	124,523	1,907.99
Abilene	5.80	115,930	675.81
Beaumont	20.30	113,866	2,307.38
Waco	49.10	113,726	5,586.99
Carrollton	23.10	109,576	2,532.38
McAllen	1.20	106,414	129.42
Wichita Falls	18.30	104,197	1,902.13

– TPWD Local Park Analysis, 2002

Cities with populations between 20,000 and 100,000 provide varying degrees of service across the state [Map 18].

- The mean acres per 1,000 for cities between 20,000 and 100,000 population is 11.4 acres.
- Cities with the most acres per 1,000 people are Pearland with 36.8 acres followed by Allen, Paris, Longview and Frisco.
- Cities with the fewest local park acreages per 1,000 people are Socorro with 0.1 acres followed by Pharr, Big Spring, San Juan and Benbrook.

Communities with fewer than 20,000 people also have access to varying amounts of recreational lands [Map 19].

- The mean acres per 1,000 for cities under 20,000 population is 15.6 acres.
- Communities under 20,000 people with the highest degree of service are Normangee with approximately 697 acres per 1,000 followed by Sunset Valley, Crawford, Sweetwater, Star Harbor, Spur and Bandera with 75 acres per 1,000.
- Communities with the lowest degree of service are West University Place and Bellaire with 0.2 acres per 1,000 followed by La Joya, Salado, Barrett, Sachse, Richmond and Port Neches with 0.4 acres per 1,000.

Grant Funding

TPWD provides grant assistance through the Texas Recreation and Parks Account, a legislatively dedicated fund to support local government park and recreation programs. The Department receives matching grant proposals from cities across the state. However, some communities have not submitted proposals, possibly due to insufficient local match funding or lack of information.

The demand for funds from all TPWD local grant programs are competitive; grants are awarded based on the most competitive proposals, not necessarily the greatest deficit of parklands or facilities. Grant assistance is based on a scoring system using criteria that were developed with extensive public input. The criteria help to assure that locally identified needs are met and that the grant program and criteria are consistent with the TPWD mission. The scoring and ranking criteria measure factors including:

- Performance on active and previous grants
- Local planning
- Increase in recreational diversity
- Water-related recreational opportunities
- Geographic distribution of park and recreation opportunities
- Conservation of significant natural resources through acquisition and stewardship
- Renovation of existing, obsolete park and recreation areas and facilities
- Wise use of natural resources
- Linear greenbelt linkages
- The appreciation and preservation of cultural resources
- The use of funds for park and recreation opportunities
- Opportunities for low income, minority, elderly and youth-at-risk
- Cooperation between government entities
- Partnerships between sponsors and the private sector

Conservation and Recreation Priorities on Land

TPWD compared the demand for local and regional park grants in both dollars and numbers of proposals to the amount and numbers granted. In addition, the analysis compared the amount of dollars granted per person by each county in Texas [**Maps 20, 21**].

Findings

Current financial resources are insufficient to meet the recreational needs.

- Since 1993, TPWD has received 975 local and regional grant applications and has awarded 375 grants.
- Since 1993, TPWD has received demands totaling $322 million in grant funds and has awarded the maximum funding available of $135 million.

In general, counties in Central Texas and the Coast have received the most grant dollars per person.

A number of communities in counties in the Panhandle, West Texas and South Texas have not received grant dollars.

Park Acres per 1,000 Ranked for Cities over 100,000

City	Number of Grants	Total Grants	Population	Grants/ Capita	County Average Grants/ Capita	Statewide Average Grants/ Capita
Harris	175	$41,861,680.93	3,275,630	$12.78	$32.72	$21.16
Dallas	144	$32,811,903.50	2,073,301	$15.83	$32.72	$21.16
Tarrant	141	$51,026,688.68	1,399,470	$36.46	$32.72	$21.16
Bexar	71	$8,280,295.79	1,379,147	$6.00	$32.72	$21.16
Travis	106	$19,146,591.09	734,764	$26.06	$32.72	$21.16
El Paso	21	$3,075,901.49	698,787	$4.40	$32.72	$21.16
Hidalgo	55	$11,020,326.32	542,528	$20.31	$32.72	$21.16
Collin	44	$14,564,410.59	472,109	$30.85	$32.72	$21.16
Denton	38	$11,625,008.98	413,087	$28.14	$32.72	$21.16
Fort Bend	17	$6,008,048.19	356,555	$16.85	$32.72	$21.16
Cameron	35	$8,888,880.05	324,127	$27.42	$32.72	$21.16
Nueces	46	$10,593,458.91	311,732	$33.98	$32.72	$21.16
Montgomery	32	$7,560,422.86	295,263	$25.61	$32.72	$21.16
Galveston	59	$13,383,350.82	249,898	$53.56	$32.72	$21.16
Jefferson	55	$6,023,553.00	244,812	$24.60	$32.72	$21.16
Williamson	31	$9,475,528.23	240,905	$39.33	$32.72	$21.16
Brazoria	59	$10,574,544.88	236,372	$44.74	$32.72	$21.16
Lubbock	17	$7,733,473.50	229,931	$33.63	$32.72	$21.16
Bell	24	$6,235,594.26	228,127	$27.33	$32.72	$21.16
McLennan	21	$1,475,361.96	204,609	$7.21	$32.72	$21.16

– TPWD Local Park Grants, 2001

Priorities for TPWD

The Department will continue to support local park needs through competitive grant programs. It will develop new programs as needed, refine criteria and identify additional funding for these important programs. It will also continue to provide technical guidance to communities who submit proposals and do not receive grants, as well as provide information to those communities who have not submitted proposals in the past. Further, the Department will continue to support regional park grants and small community grants programs and other programs to serve local park needs.

PRIORITIES FOR INCREASING PUBLIC RECREATION ON PRIVATE LANDS IN TEXAS

Hunting

The vast majority of hunting in Texas occurs on private land. In many parts of the state, hunting lease revenue has become the primary economic incentive for owning land. Less than two percent of the state's land is available to the public and TPWD manages less than half. By providing places for people to hunt, landowners significantly contribute to recreational opportunities available. It is difficult to quantify exactly how many acres of private land are hunted each year, but between hunting leases and family, neighbors and guests who hunt on private land, the number of private acres available for hunting is many times greater than public acres.

The Department can increase the number of acres available for public hunting through lease arrangements with landowners and by working with other public land managers to increase access for hunting. Given that hunting is a primary motivation for wildlife habitat conservation on private lands and participation has reached a plateau and may decline, recruiting hunters, especially youth, will be a priority in the next decade. The Department will also examine means to strengthen private markets for hunting in order to make hunting available to a broader spectrum of people.

Other Recreational Opportunities

A *Texas Parks and Wildlife for the 21st Century* survey of large Texas landowners, those owning 640 acres or more, found that 11 percent were very interested and 22 percent somewhat interested in opening their land to provide more outdoor recreational opportunities for the public. The survey also found that only 20 percent of large landowners were aware that the state provides liability protection for landowners that allow outdoor recreational use on their property. Further, 39 percent of large landowners agreed that if they had liability protection, they would be more likely to allow public access to their land.

Leased hunting was not a common practice in the state 40 years ago, but today it is a primary source of income for many landowners. As is the case with recreational hunting leases, landowners could significantly improve access to the outdoors if sufficient incentives were available. Given the high percentage of private land and the increasing need for more public access to the outdoors, TPWD should develop new methods to assist interested landowners and act as a catalyst for private markets to increase outdoor recreational opportunities. For example, the World Birding Center in the Lower Rio Grande Valley will provide visitors information about landowners who offer birding opportunities in the area. If successful, the Department can increase public access to the outdoors and facilitate new economic incentives for private land conservation.

PRIORITY WILDLIFE MANAGEMENT NEEDS FOR RECREATIONAL OPPORTUNITIES

✻ Conservation of game and other wildlife species in Texas depends upon landowners who manage the majority of the important habitats in the state including prairies, wetlands and river bottoms.

Management activities that benefit wildlife species require study, planning, effort and dollars. A primary motivation for landowners' active management is to improve recreational hunting on their lands. Funds from hunters support the majority of the private conservation efforts. This includes habitat management, paid for by landowners with revenue from hunting leases, as well as TPWD's Technical Guidance Programs, supported by license fees and excise taxes on hunting equipment. In addition, as the market for these services grow, landowners are increasingly providing access for birdwatching and other ecotourism.

The Department is responsible for the conservation of all wildlife resources in Texas. Therefore, it must develop priorities based on the wildlife species with the greatest need and programs that benefit the greatest number of species. Many of the species identified below are not thriving and their declines are due to changing land uses or other factors. Recovery of sustainable numbers of these species will require much more than changes in seasons or bag limits; it will require the efforts of private landowners, hunters, wildlife viewers and conservation organizations. TPWD will work with these constituents by providing technical guidance, information, demonstration and incentives where possible to increase the populations of these priority wildlife species across the state.

QUAIL

Ecoregion: Statewide

Bobwhite quail are declining in the Cross Timbers, Gulf Prairies and the Pineywoods ecoregions, and are increasing or stable in the High Plains and Rolling Plains. Scaled quail are increasing or stable in the South Texas Plains and are declining in the Edwards Plateau and the Rolling Plains. The health of quail populations is dependent upon sound land management, appropriate grazing regimes and prescribed burning. When land fragmentation separates or isolates remaining habitat, wildlife management associations can offer a solution.

Habitat deterioration and fragmentation are the primary causes of the bobwhite quail decline throughout the United States. Recent scientific information indicates quail populations may need enough contiguous habitat to support at least 800 quail (800-8,000 acres, depending on habitat quality) to prevent localized extinction. No wildlife agency anywhere in the Southeastern United States has been successful in recovering and restoring quail populations once they have been lost. The challenge for Texas is to discover methods that successfully restore quail populations where no one has succeeded before.

MULE DEER

Ecoregion: Edwards Plateau, Trans-Pecos, High Plains, Rolling Plains

Mule deer are one of the most valued game species in the state. Mule deer occupy approximately 23 million acres in the

Edwards Plateau, High Plains, Rolling Plains and Trans-Pecos ecoregions. Despite increased numbers and range expansion over the last 60 years, mule deer continue to experience significant population fluctuations. In recent years, substantial population decreases have occurred throughout west Texas. Mule deer numbers in the Trans-Pecos reached a low of 95,000 animals in 1999. Wildlife experts believe that these declines are the result of extended drought, lack of available quality forage and loss of cover. Proper habitat management is the most important factor in maintaining viable mule deer populations in Texas.

PRONGHORN ANTELOPE

Ecoregion: Trans-Pecos, High Plains, Rolling Plains

Endemic only to North America, the American pronghorn antelope once ranged the prairies and deserts west of the Mississippi River from southern Canada, across the Rocky Mountains and south to central Mexico. Original numbers are estimated between 30-40 million animals. Today, Texas antelope populations are restricted to the Trans-Pecos, Panhandle and southern Rolling Plains ecoregions. The Trans-Pecos region supports the largest populations, followed by the Panhandle and Rolling Plains.

Antelope numbers across the west are declining once again; numbers in the Trans-Pecos are at a 20-year low. A number of theories explain these declines including persistent drought, increased predation and long-term habitat deterioration resulting from depleted range resources. Threats to the remaining population include human encroachment, habitat fragmentation and an increase in fences and roads. A viable pronghorn antelope population can only be maintained through the cooperative efforts of private landowners, sportsman and government conservation efforts.

DESERT BIGHORN SHEEP

Ecoregion: Trans-Pecos

Desert bighorn sheep historically occupied most of the mountain ranges of the Trans-Pecos region. Bighorn numbers in the late 1800s were estimated as high as 1,500 animals. By the early 1900s, most Texas bighorn populations declined and the last documented sighting of a native bighorn occurred in 1958. Restoration efforts for bighorn sheep were initiated in 1954 with the development of a cooperative agreement between federal and state agencies and private conservation interests. Since 1959, desert bighorn sheep have been transplanted from several states and Mexico into Texas' mountain ranges.

The Trans-Pecos currently supports seven free-ranging populations of desert bighorn sheep. Recent surveys indicate an increasing population of 461 sheep. Desert bighorn sheep hunting was reinstated in 1988 after an 83-year interval and 32 hunting permits have been issued to date. Sheep are adapted to harsh desert environments, but water availability is considered to be the most limiting factor in the survival of the desert bighorn. Restoration and management are supported by committed partners including the Bighorn Sheep Society, but private landowner management remains the single most important factor in maintaining viable bighorn sheep populations.

LESSER PRAIRIE CHICKEN

Ecoregion: High Plains, Rolling Plains

Numerous in the Texas Panhandle at the beginning of the 20th century, lesser prairie chicken populations have suffered severe losses due to landscape changes. Overgrazing, brush control and farming have reduced the lesser prairie chicken to a tiny remnant of its historic range.

A working group of wildlife agencies and private organizations from Colorado, Kansas, New Mexico, Oklahoma and Texas was created in 1996 to respond to the declines in lesser prairie chickens. Funding from the Department's Landowner Incentive Program is available to landowners who wish to manage their land to benefit lesser prairie chicken habitat. Currently, a team of TPWD biologists is developing strategies to improve the status of lesser prairie chickens.

WHITE-TAILED DEER

Statewide

While white-tailed deer populations are abundant, their value to private landowners make it an important species upon which the success of many other game and non-game species depend. Most landowners enter into wildlife management plans (WMP) to benefit white-tailed deer habitat. Over 13 million acres statewide are currently under WMPs, which include recommendations for livestock grazing, burning and other habitat management that is critical in maintaining habitats that are used by many other species. Some of these, including rare and endangered species, thrive under deer habitat management practices. Deer hunting is economically valuable to landowners and therefore provides an incentive to create and manage habitats that otherwise would not be practical. The technical assistance that the Department provides to landowners for deer management is critical for the continued health of wildlife resources and could potentially evolve into a statewide watershed habitat management program, which would improve water quality and increase water quantity.

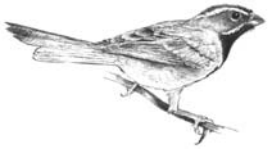
WATERFOWL

Ecoregion: Gulf Coast Prairies and Marshes, High Plains

The 1996 North American Waterfowl Management Plan identified the Gulf coast and associated grassland prairies and agriculture as one of the most important wintering areas for North America's waterfowl populations. Hundreds of thousands of waterfowl use the coast as a stopover as they migrate to Mexico and Central and South America. This area is the primary wintering range for several species of geese and is a major wintering area for every other North American duck except wood ducks, black ducks, cinnamon teal and several sea ducks. The playa lakes of the High Plains are temporary wetlands that also provide critical waterfowl habitat throughout the Southern Great Plains. In Texas alone, there are 19,000, or 65 percent of all playa lakes in the Great Plains region. These wetlands are second to the Gulf Coast as an important wintering region for waterfowl with up to 2 million waterfowl each year.

Although these regions of are significant wintering area for waterfowl, these areas are threatened by many factors, including: conversion of wetlands to agriculture use, urbanization, mineral exploration and industrialization; increased soil erosion and sedimentation; availability of water resources; degradation of water quality; saltwater intrusion and subsidence; declining rice industry; and overgrazing.

PRIORITY BIRD SPECIES



Statewide

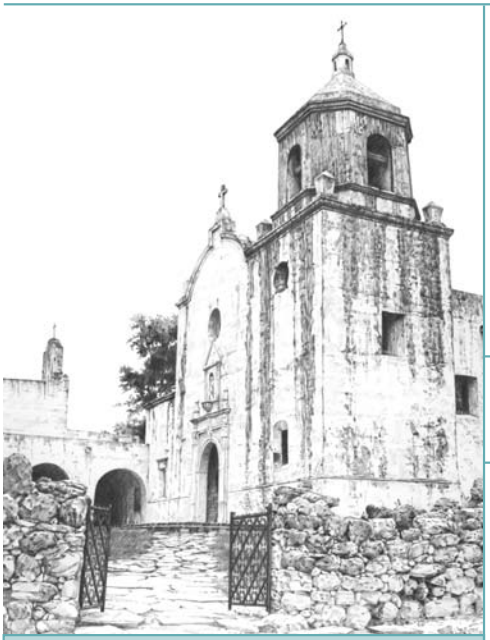
Birdwatching and nature tourism are a major draw for tourism and one of the fastest growing recreational activities nationwide. The U.S. Geological Survey Breeding Bird Survey trend data showed that over a three-decade period, 55 priority bird species, none of which is listed as threatened or endangered, have significantly declined in Texas. Factors such as habitat fragmentation, damage from feral hogs, free-ranging domestic and feral cats and pesticides are linked to the decline of many of these birds. Conservation of declining migratory and native bird species is complex and requires specific management practices and sound land stewardship to maintain viable populations.

Species like eastern meadowlark, northern bobwhite, loggerhead shrike and others thrive in grasslands comprised of native plant species. These birds typically do not occur in pastures of introduced or invasive grasses. To remain productive bird habitat, native grasslands require periodic fire or other disturbance. Depending on intensity and timing, grazing and haying can also affect these habitats. Like the grassland species, the northern mockingbird, Bell's vireo, black-throated sparrow and painted bunting require the maintenance of a healthy, dense shrub community through periodic fire or other disturbance to maintain habitat value.

Migratory shorebirds and other bird species require natural wetlands along coastal and inland waterways. Bottomland hardwood forests in the eastern third of the state require occasional flooding to maintain forest health for species like prothonotary and Swainson's warblers. Clear-cutting of large forests can negatively affect some bird species like the yellow-billed cuckoo and orchard oriole, which need dense canopy, especially along waterways, for forage and nesting. Other cavity-dwelling bird species require standing or fallen trees for cover and other habitat needs.

Since the development of the North American Waterfowl Management Plan in 1986, TPWD has supported Joint Ventures, or partnerships between the public and private sector to conserve, improve and enhance habitat on public and private lands. Several of these initiatives in Texas focused on bird habitats in specific regions of the state. The Department supports expanding Joint Ventures to all regions of the state in order to conserve all bird species and their habitats.

PRIORITIES FOR HISTORIC SITES IN TEXAS



* The Department's role for historic sites is to preserve and protect sites significant to the broad history of Texas and have great interpretive value for visitors.

The Department's collection of historic sites is strong, but not intended to be exhaustive and comprehensive. Many important historic sites are operated by private organizations and state and federal agencies, including Lubbock Lake Landmark, the Alamo in San Antonio and Fair Park in Dallas. Many non-TPWD sites hold important information on the state's history and culture; when combined with the historic sites operated by TPWD, these sites provide visitors with a scope of Texas history.

The Department evaluated 35 designated historic sites in its inventory to determine the priorities for expansion, improved interpretation or deaccession. The analysis did not include evaluation of the recently acquired Levi Jordan Plantation State Historic Site. A secondary analysis of the themes and timelines important to the state's history determined the potential gaps in the statewide inventory of historic sites and museums.

QUALITATIVE HISTORIC SITES ANALYSIS

The Department evaluated the relative significance of its existing historic sites. TPWD staff developed the criteria used for the evaluation from the Department's originating legislation, guidelines from the National Park Service and input from the Texas Historical Commission (THC). The ad hoc Strategic Land and Water Committee appointed a 12-person evaluation team including members of the TPWD's Historic Sites Advisory Committee, TPWD and THC staff, as well as other experts. The team reviewed summary information of each site that included a general description of the site, the historic context, known cultural and natural resources present, interpretive and educational opportunities and marketing potential. After reviewing the summaries, the team evaluated the historic sites using criteria developed for this analysis including, most significantly, the interpretative value of the site.

Criteria for Interpretive Value of Historic Sites

Maximum Points	Criteria
30	Possesses extraordinary value in illustrating the cultural themes of Texas or national heritage
30	Holds great potential for interpreting aspects of Texas or national history
20	Retains a high degree of integrity as an accurate example of the resource
20	Is an outstanding example of a particular type of resource
15	Is a place where events occurred that represent an important aspect of the [prehistoric or historic] cultural, political, economic, military, or social history of Texas or the nation
15	Is significantly associated with the lives of outstanding historic persons or with an important event that represents a great ideal or idea
15	Embodies distinguishing characteristics of an architectural type, exceptionally valuable for study of a period, style, or method of construction
15	Contributes significantly to the understanding of aboriginal man in Texas or the nation
15	Is a resource that has yielded or may likely yield information of major scientific importance by revealing new cultures, or by shedding light upon periods of occupation over large areas of Texas or the nation
10	Offers superlative opportunities for education, or for public use and enjoyment
10	Requires direct TPWD management instead of protection by some other government agency or by the private sector
5	Is located within a two-hour drive of a major metropolitan area

– TPWD Historic Sites Evaluation, 2002

Conservation and Recreation Priorities on Land

After the scores were tallied, four categories emerged. Within each category, sites are listed in alphabetical order. The TPWD Historic Sites Advisory Committee reviewed the process and results and validated the analysis.

Visitation and net revenue information can be indicators of public interest, demand and the quality of experience. These figures can be affected by the site's location, especially its proximity to population centers. Therefore, visitation and net revenue data for each site were collected and considered, but ultimately not used in this evaluation. TPWD will work to integrate this important data into the evaluation matrix, balancing the historic and cultural value of the properties with the cost to the state and the public benefit as measured by annual attendance.

Texas Parks and Wildlife Department Historic Site Priorities

Low	Medium	High	Highest
Acton	Casa Navarro	Admiral Nimitz	Battleship Texas
Confederate Reunion Grounds	Eisenhower Birthplace	Fannin Battleground	Caddoan Mounds
Lipantitlán	Fort Leaton	Fort Griffin	Fanthorp Inn
Starr Family Home	Landmark Inn	Fort Lancaster	Fort McKavett
	Monument Hill	Fort Richardson	Hueco Tanks
	Sabine Pass Battleground	Fulton Mansion	Mission Espiritu Santo
	Sebastopol	Kreische Brewery	San Jacinto Battleground
	Zaragoza Birthplace	Lyndon B. Johnson	Seminole Canyon
		Magoffin Home	Washington-on-the-Brazos
		Mission Rosario	
		Port Isabel Lighthouse	
		Sam Bell Maxey House	
		San Felipe	
		Varner-Hogg Plantation	

– TPWD Historic Sites Evaluation, 2002

Highest Priority Sites

It is of utmost importance to interpret fully and accurately tell the story of these premier sites within the context of Texas history. San Jacinto Battleground and Battleship Texas already have extensive restoration efforts funded with voter-approved bonds. Other sites such as Mission Espiritu Santo and Hueco Tanks also warrant special attention and additional resources. Texas Parks and Wildlife Department will work closely with its Historic Sites Advisory Committee and the Texas Historical Commission as it focuses its efforts to ensure that all sites are fully interpreted, protected and appropriately marketed to increase visitation and support.

Low Priority Sites

The lowest priority sites do not fit within the Department's role for operating historic sites stated in this Plan. These sites also may not meet the standard of statewide significance that TPWD and THC are currently developing. The Department will work closely with its partners to assess the feasibility of garnering local support for deaccession by transferring these sites to other entities, identifying adaptive uses or selling the property with appropriate restrictions. Texas Parks and Wildlife Department will manage and maintain all low priority sites until an appropriate owner is identified.

Gaps in the Statewide Inventory of Historic Sites and Museums

TPWD based the thematic contexts for Texas on the National Park Service's Thematic Framework for History and Prehistory. The Department acknowledges that this is a preliminary list of contexts and that it should be periodically reviewed and improved.

TPWD strives to interpret sites where a significant person lived, where an important event occurred or which provide great interpretive value to the state's history. The Department recognizes that museums throughout the state help fill a need by interpreting important people or themes in Texas history. For this reason, this analysis did not limit its scope to TPWD historic sites alone, but also considered information on historical sites and museums from the Texas State History Museum's Destination Texas Database and other sources.

Using the thematic contexts developed by TPWD, the statewide gaps in the contexts were determined with input from Texas Historical Commission. It is clear from this evaluation that several significant components in Texas history are missing from the inventory of historic sites and museums open to the public.

THEMATIC CONTEXTS FOR TEXAS HISTORY

Peopling Places

- Military
- Natural Resources
- Politics/Government
- Transportation
- Communication
- Immigration
- Settlement

Creating Social Institutions and Movements

- Educational Institutions
- Veterans Organizations
- Fraternal Organizations
- Transportation
- Civil Rights
- Women
- Labor
- Places of Worship

Conservation and Recreation Priorities on Land

Expressing Cultural Values

- Educational Institutions
- Art Museums
- Performing Arts Centers
- Folklore/Folk Art
- Prehistoric Art
- Architecture
- Texas Cultures
- Sports
- Libraries
- Newspaper, Radio, Television Industries
- Parks

Shaping the Political Landscape

- Frontier Protection
- Transportation
- Texas Independence
- Law Enforcement
- Federal Government
- State Government
- County Government
- U.S. Army
- U.S. Mexican War
- Civil War
- World War I
- World War II
- Civil Rights

Developing the Texas Economy

- Oil and Gas Exploration
- Lumber
- Brewing, Beverage, Food Industry
- Military
- Jails/Prison Industry
- Natural Resources
- Transportation
- Education
- Politics/Governments
- Agriculture
- Ranching Mining

Expanding Science Technology

- Technological Advances
- Agriculture
- Scientific Exploration
- Cold War
- Ranching
- Military
- Transportation
- Navigation
- Natural Resources
- Health
- Education

Transforming the Environment

- The Law and Land Use
- Recreation
- Lumber Industry
- Real Estate Industry
- Ranching/Fencing
- Environmental Awareness/Education
- Agriculture
- Politics and Government
- Transportation
- Mining
- Prehistory Land Use

Changing Role of Texas in the U.S./World

- Politics and Government
- Security and Defense
- U.S./Mexico Relations
- Transportation
- Natural Resources
- Religion
- Westward Expansion
- Province to Republic
- Republic to Statehood
- Confederacy

- TPWD Historic Sites Gap Analysis, 2002

Findings

Some thematic gaps are very broad and a single or few sites or museums may not be enough to interpret their significance in Texas history.

- Few sites exist that are important to the history of the major ethnic groups. For example, the recently acquired Levi Jordan Plantation State Historic Site will partially address the gap in interpreting African American history in Texas, specifically as it relates to slavery and reconstruction.
- Sites about the range of women's experience in Texas or sites that depict the lives of women who influenced history are underrepresented in the statewide system.
- Few sites are interpreted specifically for their significance to Texas history in the early 20th century.

Archeological thematic gaps have specific sites associated with them.

- A site that interprets the Antelope Phase, a prehistoric people who lived in permanent dwellings between 1200-1500 AD in the Texas Panhandle is not within the statewide historic site system.

Priorities

- Further exploration of these emergent thematic gaps is a priority for TPWD. Both public and private holdings can fill the gaps as long as these sites are open to the public.
- TPWD itself can expand interpretation at existing state parks to fill some gaps by maximizing programs and interpretation or through acquisition.

STRATEGIES FOR MEETING THE CONSERVATION AND RECREATION NEEDS ON LAND

The strategies Texas Parks and Wildlife Department will employ to meet the conservation and recreation needs differ greatly between private and public lands. TPWD can encourage private landowners to conserve their lands and create recreational opportunities by providing information and technical advice on habitat management and through a variety of incentive programs. On state parks, WMAs and historic sites, TPWD can improve visitor experience and protect natural and cultural resources by acquiring lands that fit within its role; expanding available activities; providing education, outreach and interpretive programs; and regulating and managing the resources appropriately.

SOUND SCIENCE

- TPWD will base its conservation decisions on sound conservation models.
- TPWD will ensure that science-based, long-term monitoring of fish and wildlife resources that identify status and trends; the studies and assessments of those resources and activities that affect them; and the databases and information that result from them are based on the best science available.

PRIVATE LANDS

* Texas Parks and Wildlife Department must effectively communicate the public benefits that private landowners provide including clean water and abundant wildlife.

Wildlife Management Plans (WMP) for Conservation on Private Lands

- TPWD will double lands under wildlife management plans by 2012 for a total of 28 million acres.
  - TPWD will enhance efforts to increase lands under WMPs in the Tier I ecoregions identified in the Priority Ecoregions for TPWD Conservation Efforts analysis.
  - TPWD will enhance efforts in ecoregions with low percentages of private lands under WMPs.

- Where appropriate, priority wildlife species identified in this report including quail, pronghorn antelope, desert bighorn sheep, mule deer, lesser prairie chicken, waterfowl and declining bird species will be emphasized in Wildlife Management Plans.
- WMPs will emphasize the conservation of important habitat types identified in this report including native prairies, riparian and other important habitats specified in the *Priority Ecoregions for TPWD Conservation Efforts Analysis*.

■ Wildlife Management Plans will emphasize range and habitat management practices that enhance water quality and quantity for Texas springs, rivers, lakes and bay systems.

- TPWD will work with river authorities and other agencies to develop basin-specific best management practices.
- TPWD will work with river authorities and other agencies to develop cost-share programs that help pay for management practices on private land that improve water resources.

Facilitate partnerships for the conservation priorities identified in this plan

■ Improve and enhance partnerships with federal and state agencies, local governments and non-profit conservation and recreation organizations on the strategies and goals of this plan.

■ There are areas of the state that are still not covered by a Joint Venture; TPWD will work towards the continued expansion of this concept into all regions of the state to support bird conservation of all species.

Wildlife Management Cooperatives and Land Trusts for Conservation

■ Wildlife management cooperatives can combat the negative impact of land fragmentation on wildlife habitat; TPWD will explore new strategies to encourage, promote and sustain successful wildlife management cooperatives to meet the conservation priorities identified in the Plan.

■ TPWD will continue to support the development of sustainable land trust organizations; these private organizations are generally local and can provide another conservation option for private landowners.

- TPWD will continue to support the Texas Land Trust Council, which is responsible for education and training for land trusts and promoting national standards for these organizations.

■ TPWD will focus its outreach efforts to support existing and create additional wildlife management cooperatives and local land trusts in the Tier I ecoregions and priority habitats identified in the Priority Ecoregions for TPWD Conservation Efforts analysis.

- TPWD will assist wildlife management cooperatives and land trusts that are interested in conserving rare species, priority wildlife species and habitats; and that are interested in offering access for nature tourism and other public access.

Incentives for Conservation on Private Lands

- TPWD will support the establishment of a purchase of development rights program in Texas that is consistent with the Department's mission in the conservation of natural resources. If successful, this program could eventually address serious threats to wildlife habitat and other natural resources including land fragmentation; funding for this program should not impact TPWD's existing programs.

- The Landowner Incentive Program (LIP) is nationally recognized as an innovative and successful approach to conserving rare and endangered species on private land. The United States Fish and Wildlife Service recently implemented a national program based on LIP with significant funding. TPWD will look for new ways to increase participation, measure success and encourage continued funding for this important program.

- The Department will work with state and federal agencies in developing new incentive programs and improving existing programs to achieve the conservation priorities identified in the Plan.

Hunting and Other Recreational Opportunities

- The vast majority of hunting in Texas occurs on private land and TPWD will continue to lead the nation in promoting hunting as good for habitat conservation. TPWD will explore market-based methods to increase hunting opportunities on private land for as broad a spectrum of people as possible.

- Because hunting is critical to habitat conservation, TPWD will work with landowners to find new ways to increase hunting opportunities including regulatory, economic and other incentives.
  - TPWD will strive to recruit more hunters, especially youth, through outreach efforts, landowner assistance, incentives and encouraging other public land managers to expand hunting opportunities where possible.
  - TPWD will measure its success by increasing hunting license sales from existing levels over the next ten years.
  - In order to maintain current hunting participation, TPWD will continue to provide maximum sustainable hunting opportunities through the longest seasons and most liberal bag limits determined to be feasible.

TPWD will work to create markets to increase recreational activities available on private lands, which normally occur on state parks.

- The Department will work with the Private Lands Advisory Committee to explore programs and strategies aimed at increasing public access to private land.
- TPWD will explore the development of pilot programs with landowners that increase recreational opportunities, which normally take place on parks, such as river access, boating, fishing and wildlife viewing.
  - In order to target groups who have not traditionally had access to the outdoors, the Department must ensure that these programs are affordable.
- TPWD will continue to provide information on the economic benefits to private landowners for opening their lands to other forms of recreational use such as wildlife viewing, hiking and camping.

STATE PARKS AND WILDLIFE MANAGEMENT AREAS

State parks and wildlife management areas will continue to include many of Texas' premier natural and outdoor recreation areas.

New Sites

- TPWD will focus its efforts for creation and provision of new state park sites within a 90-minute drive of the state's five most populous cities (Houston, Dallas, Fort Worth, San Antonio and Austin) and the Lower Rio Grande Valley.
  - Wherever possible, the Department will provide new sites that also conserve a representative landscape of the ecoregion.
  - The goal for new state parks and wildlife management areas will be to encompass at least 5,000-acres to provide optimal wildlife habitat and quality outdoor experiences. This acreage criteria will be flexible enough to accommodate areas of the state that do not have enough available land of that size, or where 5,000 acres is not enough land to support sustainable wildlife habitat.
  - State parks and wildlife management areas on water are the most popular and have high conservation value; whenever possible, new parks and WMAs will be located on rivers, lakes and the coast.

Conservation and Recreation Priorities on Land

- TPWD will continue to provide, through acquisition or other means, sites that are destinations – places of statewide significance that are outstanding examples of Texas' natural and cultural heritage, have high recreational value and where people are willing to drive farther and stay longer. Several of the Department's oldest and most popular sites, including Palo Duro Canyon, Garner, and Davis Mountains state parks fall into this category.

- The Department will seek to acquire sustainable wildlife management areas to facilitate habitat management, research, demonstration, education and recreation in the following areas:
  - Tier I ecoregions defined in this plan.
  - Cross Timbers and Prairies and the High Plains ecoregions that do not have adequate research and demonstration lands.

- When appropriate, TPWD will combine state parks with wildlife management areas into new sites; these sites will have research and technical guidance programs as well as traditional recreational activities.

Existing Sites

- TPWD will focus additions to state parks and wildlife management areas to the sites that have been identified as priority sites for expansion to improve access, the visitor experience and wildlife habitat.

- TPWD will continue to acquire in-holdings or lands at existing sites that improve public access that are critical to site operations.

- TPWD will work to enhance recreational activities available to growing population centers on its existing sites including building more trails and improving access to water.

- TPWD will work to expand the World Birding Center sites in Brownsville, Weslaco and Mission for public access opportunities and wildlife habitat.
  - It will also use these sites as centers to inform visitors and create markets for birdwatching opportunities on private lands.

- TPWD will consolidate acreages of the Las Palomas WMAs in the Lower Rio Grande Valley to create at least one site with adequate research and demonstration capacity.

- State parks and WMAs that are listed in this Plan for transfer will be considered as priorities for divestiture or transfer.

- TPWD will incorporate the goal of watershed habitat management and improving water quality and quantity for all Department lands.

Management and Operations

- State parks and WMAs will focus on providing access to the outdoors and serve as natural classrooms for Texas' predominantly urban population.

- State parks and wildlife management areas will be built around natural resources, not infrastructure; new sites will have infrastructure with low capital and maintenance requirements.

- When demand for lodges, cabins, recreational vehicle areas or other facilities exist, TPWD will dedicate a portion of new sites for these services where they do not negatively affect resources or visitor experience.
  - TPWD will first consider outsourcing or creating partnerships with the private sector to provide these services.
  - Where outsourcing is not possible, TPWD will build and operate developed campgrounds.

- TPWD will accept donations of conservation easements and development rights from willing landowners that are adjacent to state parks and wildlife management areas, that have significant natural resource value and do not require additional TPWD resources to manage.

- Resource conservation is an important goal of state parks. TPWD will emphasize active resource management on all state parks.

- TPWD will develop meaningful standards that measure whether sites are meeting the needs of Texans. The measures should determine:
  - The quality of visitor experience
  - Whether the activities provided fit with public demand
  - The success of education programs
  - How well TPWD is doing at accomplishing resource management objectives

- Public recreation and appropriate facilities will be expanded on wildlife management areas as long as the resources are not negatively impacted.

Finance

- The Department will work towards effectively conveying the message that state parks and WMAs that provide public access, that are well maintained and that provide high quality recreational opportunities significantly benefit local and statewide economies.

- State parks and WMAs do not pay for themselves, but contribute significantly to the local economy. The Department will reliably estimate and report the multiplier effect of state parks on local and state economies.

Conservation and Recreation Priorities on Land

Partnerships

- TPWD will work with federal governmental entities near population centers to increase levels and types of recreational activities available.
- TPWD will partner with local governments, river authorities and other entities to leverage resources to provide more large publicly accessible recreation areas within 90-minutes of the major population centers of the state.

LOCAL PARKS

- TPWD will continue to support local park programs that provide recreation and will encourage communities to include resource conservation in their master plan.
- TPWD will continue to give priority to projects that provide access to water-based recreation, that provide for acquisition and preservation of natural areas and that have a direct correlation to the Department mission.
- TPWD will continue to encourage local government partnerships in order to provide recreational lands in or adjacent to large urban areas.
- TPWD will continue to inform state leadership on the importance and great need for more local parks in Texas.
- TPWD will continue to refine and improve grant programs to local governments to maximize the benefits to all Texans. Recent examples include the creation of the small communities (under 20,000) and the regional parks grant programs.

HISTORIC SITES

* Since the development of the 1999 Texas Cultural Heritage Plan, TPWD has taken a number of steps to improve visitor experiences and operations at the 36 state historic sites. These steps include forming the Historic Sites Advisory Committee, hiring eight regional experts responsible for interpretive programming at state historic sites and developing a Facilities Management System to assess ongoing maintenance and repairing needs for historic sites.

Existing Sites

- TPWD will maintain state historic sites to the highest possible standard.
- TPWD will give special attention and add resources to the highest priority sites identified in this report. The Department will ensure that these sites are being interpreted appropriately and are adequately protected.

- TPWD will ensure that the most accurate story of Texas is told at its existing state parks and historic sites by taking advantage of interpretive programs and exhibits that educate and inform the public.

- TPWD will focus increasing interpretive, education and outreach efforts at existing historic sites and state parks that currently are not being interpreted.

- TPWD will work closely with the Texas Historical Commission and local communities where possible to explore the feasibility of transferring sites or find other uses for the low priority sites identified in this report.

Improve Visitation

- TPWD will take advantage of the growing public demand for Heritage Tourism by working with the Texas Historical Commission, Texas Department of Transportation, Texas Department of Economic Development and other agencies where possible to market historic sites and increase visitation.
  - The Department will work with these agencies to establish feasible marketing strategies to increase visitation at historic sites.

New Sites

- TPWD will continue work with the Historic Sites Advisory Committee, Texas Historical Commission and other experts in Texas history to refine the thematic context list and conduct a thorough gap analysis.
  - TPWD will identify priority gaps and make recommendations for strategies to fill them.
  - TPWD will determine if gaps can be addressed through interpretation or programming at existing state parks and historic sites.

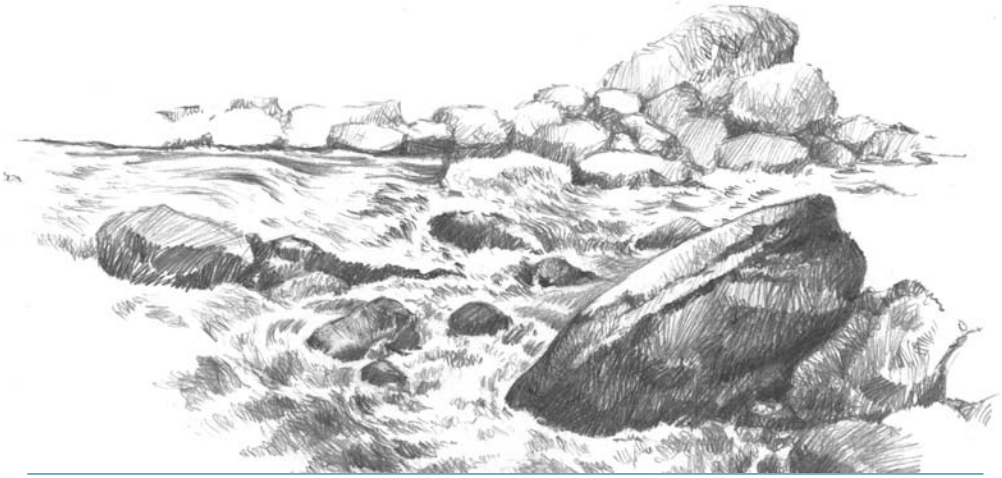
- TPWD must evaluate on a biannual basis whether sites of statewide significance that are not in its inventory could potentially be lost or destroyed if the Department does not take action.

- TPWD will consider if there are adequate funds available for their acquisition, restoration, maintenance and management.

Finance

- Historic sites do not pay for themselves but contribute significantly to the local economy. Texas Parks and Wildlife Department will reliably estimate and report the multiplier effect of historic sites on local and state economies.

Conservation and Recreation Priorities for Water



CONSERVATION PRIORITIES FOR TEXAS WATERS

According to public opinion surveys in the *Texas Parks and Wildlife for the 21st Century* report, water, including both water quantity and quality, was the most important natural resource and environmental concern of Texans in 2001. In a survey of the general population, nearly half mentioned water resource-related concerns without any prompting. In a series of focus groups conducted in various locations around the state, concern over water resources was the only topic consistently mentioned as a major natural resource and environmental issue facing Texas.

Texas has nearly 200,000 miles of streams and rivers and approximately 1.7 million acres of reservoirs, or public water impoundments, that provide habitat for the state's diverse fish and wildlife. Scientists recognize 247 fish species, 19 of which are considered sportfish, that inhabit fresh water for at least a part of their lives. TPWD estimates that 25 percent of native freshwater fish species are threatened, endangered, or already extirpated. In the 15 major river basins, watercourses range from wide, shallow, sandy prairie rivers, to clear, spring-fed streams, to slow-moving bayous with extensive hardwood bottomlands. Springs provide base flow to many of the state's rivers and streams. Many of these spring systems support unique habitats with species found nowhere else in the world. Both the rivers and streams provide water for reservoirs, which range in size from less than one acre to the 185,000 acre Toledo Bend Reservoir.

The coast is one of the most ecologically complex and biologically diverse regions of the state. It is comprised of nine major bays from Sabine Lake in the north to the upper and lower Laguna Madre in the south as well as the Texas Territorial Sea, from the Gulf beach out to nine nautical miles. More than one-third of Texas' population and about 70 percent of its industrial base, commerce and jobs are located within 100 miles of the coastline. More than half of the nation's chemical and petroleum production are located on the coast and the coastal waters support major commercial and recreational fishing industries. Texas leads the nation in marine commerce and the beaches, bays, marshes, prairies and other fish and wildlife habitats of the coast provide numerous recreational opportunities.

AQUATIC CONSERVATION THREATS

✻ The most significant conservation challenges to both freshwater and saltwater systems in Texas are reduced water quality and decreased water quantity.

Factors such as the increasing population, increasing demands for water and increasing shoreline development directly affect water quality and quantity.

Reduced Water Quality

Point source and nonpoint source pollution, which contribute to nutrient loading, directly threaten native fish and wildlife species that rely on clean water. Water that will not support fish and wildlife will not support human needs either. As the population grows and water demands and waste run-off increases, water flow in rivers and streams, or instream flow, decreases. In the next decade, pollutant concentrations in rivers and streams may increase to a point where they have a detrimental effect on aquatic life including low oxygen, harmful algal growth and fish kills.

Navigational Dredging and Disposal

Altered circulation in the deep waters of the coast that result from channel dredging facilitates high salinity water movement into the upper estuarine areas as well as artificial closing of traditional migratory passes for numerous saltwater species. In addition, disposing of dredged material in open water increases turbidity and covers bottom habitat including seagrasses.

Reduced Water Quantity

Decreased or altered water quantity will affect the ecosystems, habitats and wildlife that depend on the natural flow regime of the stream or river. For example, groundwater withdrawals, inflow rerouting, reservoir operations and increased use of water make rivers, streams and springs, and the fish and wildlife resource they support exceptionally vulnerable to the effects of drought.

Reservoir Construction

TPWD recognizes that reservoirs are necessary to store water for water supply, flood control and hydropower generation and to provide much of the freshwater recreational opportunities available to the public. However, reservoir development significantly alters the stream and river systems that supply water for storage as well as the bay and estuary systems downstream. Direct impacts associated with reservoir construction occur through inundation including loss of terrestrial, wetland, riverine, riparian and bottomland hardwood habitat types as well as wildlife displacement. Indirect impacts include reduction and/or alteration of downstream riverine,

estuarine riparian, wetland and bottomland hardwood habitat types which harm species that depend on them.

Other Concerns

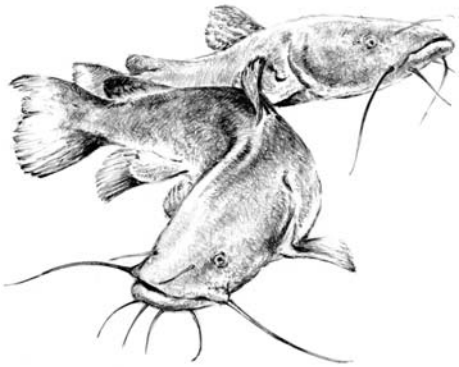
Introduced Species to Aquatic Environments
Exotic plant and animal species that are introduced into Texas waters can rapidly spread and displace or harm native species and threaten the community relationships that are necessary to sustain the aquatic environment. For example, eighteen non-native fish species documented in the state as well as a number of snail and bi-valve species have had a negative impact on native fish communities. Further, TPWD has expended much effort to control aquatic plants, such as water hyacinth, hydrilla and giant salvinia, which have negatively affected native freshwater communities and have limited public access to water.

Noxious Brush and Invasive Plant Species
Undesirable or noxious brush, woody and invasive plant species such as mesquite, saltcedar, Chinese tallow, prickly pear, condalia and ashe juniper absorb vast quantities of water and provide little or no forage for wildlife or livestock. Many of these plant species are present in excessive quantities on rangelands in Texas today and through improved range management techniques, can be significantly reduced or controlled to benefit water quality and quantity as well as wildlife habitat.

Bycatch and Commercial Trawling
Some commercial fishing techniques can have negative impacts on fish species. For example, excessive bottom trawling can alter or damage important habitats, which can lead to a decline in overall fishing size and abundance, increase turbidity and put pressure on all marine species. Bycatch, or the catch of non-targeted species, from commercial trawling harms many other ecologically, commercially and recreationally important species.

CONSERVATION OF TEXAS' FRESHWATER SYSTEMS

✻ Conserving freshwater begins when it rains and where the raindrops make first contact with the soil.



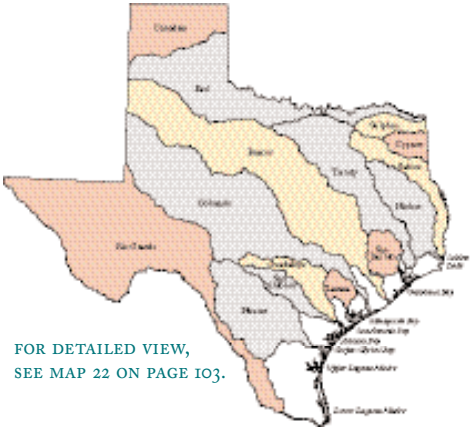
Sufficient, quality freshwater runoff from land into rivers, streams, springs and reservoirs is critical to conserve and maintain the health of aquatic and terrestrial systems. Healthy aquatic systems are necessary for the high quality recreation enjoyed in much of Texas. These systems support tourism, commercial fishing and other significant industries statewide. They also support drinking water, food, power, irrigation, transportation and wastewater treatment. With the responsibility for maintaining recreational fishing and as the state trustee for aquatic resources, TPWD has developed numerous programs to promote the conservation of rivers, streams, springs and reservoirs in order to provide quality recreational opportunities.

INSTREAM FLOW STUDY NEEDS FOR TEXAS RIVER BASIN CONSERVATION

Over the past twelve years, the Department has studied and determined the necessary freshwater inflows to Texas' seven major bay and estuary systems in order to maintain healthy fisheries along the coast. Today, a similar effort is needed for rivers. Instream flow studies are evaluations of river and stream systems that are conducted to determine the appropriate flow regimes necessary to conserve fish, wildlife and recreational resources. TPWD conducts these studies to better understand river systems and to minimize impacts from existing and future water development.

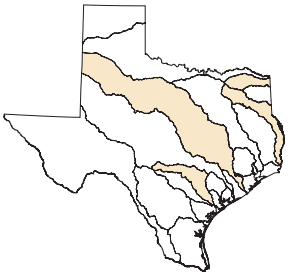
Given that instream flow studies can involve years of research and data analysis, the Department developed a tiered system to make decisions on allocating resources to study the state's 15 major river basins. Each river basin was categorized by the type of instream flow study needed based on water availability, water right permits, proposed water development projects and biological factors. Future revisions of the tiers may be necessary because factors such as information needs, water planning, permitting and the priorities of interagency coordination may change. Senate Bill 2, 77th Legislature, requires the Department, the Texas Water Development Board (TWDB), the Texas Commission on Environmental Quality (TCEQ) and other agencies to establish an interagency instream flow program. This program will be responsible for conducting instream flow studies to determine conditions necessary to support a sound ecological environment in priority rivers and stream. S.B.2 requires that the interagency program complete these priority studies by 2010.

Each of the major river basins are critical for fish, wildlife and recreation both on land and ultimately in our coastal ecosystems. The tiers are classifications of the type of assessment needed in each river basin. For example, Tier I river basins are complex systems where limited information exists, are generally the least impacted by water use and immediate study would be most beneficial considering the fish and wildlife management responsibilities of TPWD. Criteria used to categorize the tiers are described below and within each tier, river basins are listed alphabetically [Map 22].



FOR DETAILED VIEW, SEE MAP 22 ON PAGE 103.

Tier I Study



River basins in Tier I have water resources that may be impacted by water development projects. Proposed projects within these basins may affect broad geographical areas. Conservation of these resources will require studies that include intensive data collection and fieldwork. Over the next ten years, data will be needed from comprehensive studies that address potential cumulative impacts of existing and future water

development. Some specific water development issues in Tier I can also be addressed through evaluation and synthesis of existing data.

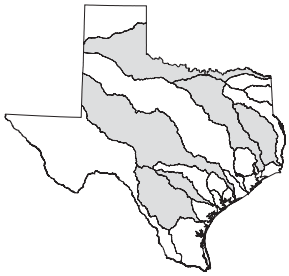
Brazos River Basin: The headwaters for the Brazos River is just across the Texas border in New Mexico. The river flows across the state and ultimately into the Gulf of Mexico south of Galveston. Total drainage for the Brazos River Basin is 42,800 square miles making it the second largest in Texas. A sub-basin study on the middle Brazos River is needed based upon proposed development of several minor reservoirs on tributary streams and a major reservoir on the Little River. TPWD is currently working with TCEQ and TWDB in conducting a site-specific study of the proposed Allen's Creek Reservoir project in the lower basin. Potential reservoir projects in the upper basin may need site-specific information as well.

Guadalupe River Basin: The headwaters of the Guadalupe River are west of Kerrville on the Edwards Plateau. The total drainage of the basin is 6,700 square miles and provides a major source of water to the San Antonio Bay system. Instream flows and future water development strategies are largely dependent on existing water permits and amendments for Canyon Lake. A sub-basin study is ongoing for the lower Guadalupe River. This study along with the completed bay and estuary freshwater inflow study will provide information suitable to address a variety of water development projects.

Sabine River Basin: The Sabine River begins in North Texas near Greenville and flows south making up the Texas-Louisiana border before flowing into the Gulf of Mexico. Total drainage of the basin is 9,756 square miles, 7,426 of which occur entirely in Texas. This basin must be studied because of the potential for substantial water transfers. Other factors include hydropower permitting and several proposed reservoir sites.

Sulphur River Basin: The Sulphur River begins in northeast Texas and eventually flows into the Red River in Arkansas. Total drainage of the basin in Texas is 3,558 square miles. The State Water Plan recommends one potential and three alternative reservoir projects. A basin-level study would be the best approach for addressing these water development strategies. Other issues include water demands from potential hydropower development.

Tier II Study



As with Tier I, basins in Tier II potential water development projects exist. Evaluating these projects will require intensive field work to determine impacts to fish and wildlife resources. However, Tier II basins include projects that can be addressed individually by a site-specific study because proposed water development projects have a more limited geographic scope. In cases where instream flow studies are complete, TPWD will continue to participate in the implementation of recommendations and will monitor their effects on fish and wildlife resources. Evaluation and synthesis of existing data can also address some specific water development issues.

Colorado River Basin: The Colorado River begins in New Mexico and drains 39,900 square miles with more than 95 percent of the drainage basin occurring

in Texas. It flows across Texas for 600 miles before eventually reaching Matagorda Bay. A comprehensive instream flow evaluation for the Lower Colorado River is complete and incorporated into water management plans. This evaluation addresses future information needs without a new comprehensive study. Existing water permits largely determine flow in the upper Colorado basin.

Neches River Basin: The Neches River begins in North Texas near Tyler and flows south into Sabine Lake. Total drainage in the basin, which includes the Angelina River, is 10,011 square miles. Existing reservoirs largely dictate the instream flow conditions in the Neches River. A permitted reservoir site and proposals to raise the water levels at an existing reservoir may require site-specific studies.

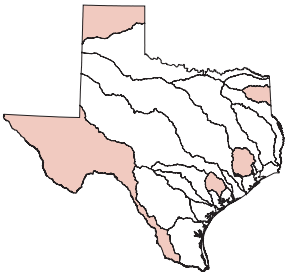
Nueces River Basin: The Nueces River begins in the southwestern Edwards Plateau. Total drainage of the basin is 16,950 square miles and contains the majority of the watershed feeding the Corpus Christi Bay system. Instream flows are largely determined by existing permits and reservoirs in the lower basin. Future water development projects will best be addressed through site-specific evaluation.

Red River Basin: The Red River begins in New Mexico, extends across the Texas Panhandle and follows the Oklahoma-Texas border to Arkansas. The river drains approximately 48,000 square miles, more than half of which occurs in Texas. Water demands from proposed reservoir sites would best be addressed through site-specific evaluation. If planned chloride control projects are effective and feasible, these projects could be expanded in the future and their impacts on water resources will require site-specific studies.

San Antonio River Basin: The headwaters for the San Antonio River are in Bandera County, north and west of San Antonio. The river eventually drains into the San Antonio Bay system and includes 4,180 square miles. There is potential for significant reuse of treated water and an increasing demand for water rights may require minor study or evaluation.

Trinity River Basin: The Trinity River begins north of Dallas and Fort Worth and enters Galveston Bay. The drainage area of the basin is 17,969 square miles and occurs entirely in Texas. There are existing and potential permit applications for substantial water reuse downstream of Dallas and Fort Worth. Reuse projects need to be evaluated to ensure that adequate instream flows are provided to protect fish and wildlife resources. There are also two proposed reservoir sites in this river basin.

Tier III Study



In many cases, synthesis of existing information and limited field efforts will be sufficient to address data needs in Tier III basins. TPWD may have some ongoing level of study or data research and analysis in these basins. TPWD will participate in the synthesis of existing information to address state and federal permitting and other issues that affect fish and wildlife resources in Tier III basins.

Canadian River Basin: The Canadian River flows from New Mexico, across the Texas Panhandle into Oklahoma and eventually into the Arkansas River. Agreements between New Mexico and Texas

determine the instream flow conditions upstream of Lake Meredith Reservoir, which is perpetually below conservation pool level. Downstream flows are dependent on watershed contributions and may be reduced by increased groundwater.

Cypress River Basin: Cypress Creek begins in Northeast Texas in Hopkins, Wood and Franklin Counties, flows into Caddo Lake and eventually enters the Red River. Total drainage of the basin in Texas is 2,812 square miles. No significant water development projects were identified in the State Water Plan, but a potential reservoir site is identified. Hydropower needs could also impact instream flows.

Lavaca River Basin: The Lavaca River begins in Southeast Texas and flows into Lavaca Bay. The basin occurs entirely within Texas and includes 2,309 square miles. Lake Texana water right conditions largely dictate instream flows in the basin. The State Water Plan identifies one potential reservoir site.

Rio Grande River Basin: The headwaters of the Rio Grande are located in southwest Colorado. It is an international river, drains much of New Mexico and has the largest drainage of any basin in Texas with more than 48,000 square miles. Although the Rio Grande faces significant water quality and quantity threats, treaty obligations between the United States and Mexico and agreements between New Mexico and Texas strongly influence the flow regime. The State Water Plan identifies the proposed Brownsville Weir as a recommended reservoir site that further threatens instream flows.

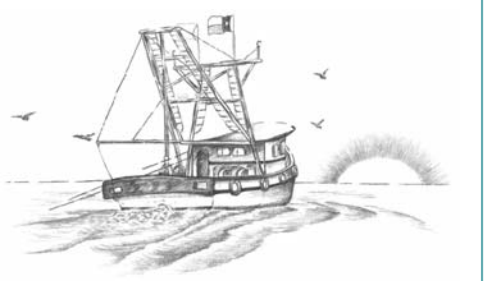
San Jacinto River Basin: The headwaters of the San Jacinto River are just north of Huntsville. It is the second most populous river basin in Texas but only drains 2,800 square miles before entering Galveston Bay. Instream flow conditions are largely determined by existing reservoirs. A proposed major conveyance of water from the Trinity River to Luce Bayou will require site-specific information.

CONSERVATION OF TEXAS BAYS AND ESTUARIES

Conservation of coastal waters and wetlands is intrinsically tied to recreational activities like fishing, hunting, birding and boating. The health of the coastal economy is also tied to the health of the coastal zone. Adequate supplies of clean, fresh water carrying nutrients and sediments to many different coastal wetland habitats like saltmarshes and seagrass beds are essential for economically and ecologically important species of fish, birds and wildlife [Map 23]. As the state agency with responsibility for regulating both commercial and recreational fishing in marine waters, TPWD continually conducts scientific investigations to protect and conserve marine life.

FOR DETAILED VIEW, SEE MAP 23 ON PAGE 104.

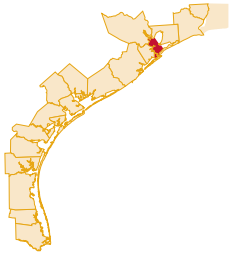
PRIORITY BAY AND ESTUARY SYSTEMS



All bay and estuary systems along the Texas coast have great commercial, recreational and conservation value. Each bay has numerous conservation threats that are specific to that system. All systems face conservation challenges to varying degrees, and a specific issue can quickly change priorities and increase the importance of conservation action. The greatest long-term threat to the health and productivity of these systems is diminished freshwater inflows. For many the more immediate challenges include habitat loss, poor water quality, fisheries management conflicts and related issues. The bay systems were evaluated using information compiled from the Shrimp Habitat chapter of the *Draft Texas Shrimp Fishery: A Report to the Governor and 77th Legislature*. Each bay system was evaluated using the following categories: development, petrochemical production, substrate alterations, exotic species, fishing, water quality, point-source pollution, non-point source pollution and numerous sub-categories (a total of 22 elements). The bay systems were prioritized as High Priority Systems or Priority Systems below [Map 24]. It is difficult not to include most, if not all of bay and estuary systems as a high priority. However, it is important to identify those systems where immediate attention can be most beneficial the fish and wildlife management responsibilities of TPWD.

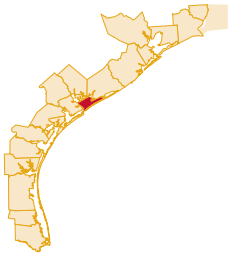
HIGH PRIORITY SYSTEMS

Galveston Bay System



Galveston Bay is the largest estuary on the Texas coast. It is part of the National Estuary Program and faces the greatest conservation challenges of any system. This complex is adjacent to the most populated and industrialized area of the state. Suburban and industrial development are reducing critical wetland habitat at a faster rate than anywhere else along the coast. The majority of Texas' hazardous chemical spills and the largest oil spills occur in this system. Both domestic and industrial wastewater also flow into the bay. Periodic dredging of the channel and bycatch associated with commercial harvest are significant conservation threats to this bay. Exotic species like Chinese tallow, giant salvinia, water hyacinth and grass carp also threaten native habitats throughout the bay. The regional water plan recognizes the importance of freshwater inflows to the bay, but strategies to legally preserve inflows have not been identified.

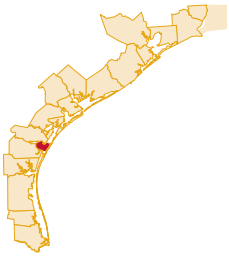
Matagorda Bay System



The Matagorda Bay system includes the Matagorda Peninsula and the Colorado River Delta. It is home to one of the largest shrimp fleets on the coast. The bay is very popular with recreational anglers and commercial fishing fleets, resulting in excess harvest of targeted species and bycatch. Mercury contamination from large smelting operations in the 1970s and 1980s in Lavaca Bay is often exacerbated by frequent dredging activity. Currently, management of inflows is inadequate to protect the bay during water shortages, but further inflow studies are needed to improve management strategies.

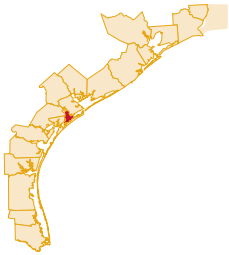
Conservation and Recreation Priorities for Water

Corpus Christi Bay System



The Corpus Christi Bay is also in the National Estuary Program. The primary sources of freshwater inflow are Oso Creek and the Nueces River. However, reservoir construction, increased population and industrial growth in the area have greatly reduced freshwater inflows in this already arid region. Reduced inflows have contributed to salinization of the delta and shoreline erosion. Extensive recreational and commercial fishing cause overharvest and excess bycatch of non-targeted species. Intense industrial, commercial and shoreline development has affected Corpus Christi Bay. Dredging the Intercoastal Waterway and spoil disposition also harm water quality of the system.

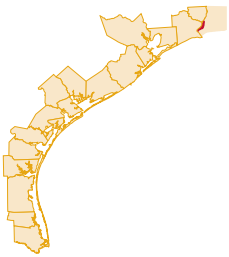
San Antonio Bay System



The San Antonio Bay system consists of the primary bays San Antonio and Espiritu Santo and the secondary bays Hynes, Guadalupe and Shoalwater. Several large natural saltwater lakes occur along Matagorda Island and connect with the primary bays via sloughs and small passes. Threats to San Antonio Bay system come from the commercial harvest, trawling and inadvertent bycatch of non-target species, dredge and fill operations along the Intercoastal Waterway and the lack of adequate freshwater inflows.

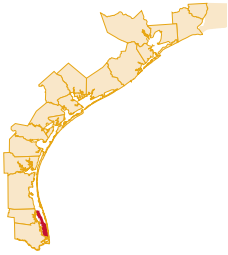
Sabine Lake System

Sabine Lake makes up the southern border between Texas and Louisiana. It is adjacent to one of the largest petrochemical producing complexes in Texas and both industrial and domestic wastewater are discharged into the Sabine Lake system. Water quality and aquatic health in Sabine Lake has improved since the introduction of the Clean Water Act in 1972 and subsequent regulations. Threats to the system include industrial and commercial development along the shoreline, operation of petroleum and chemical plants and general non-point source pollution primarily from agricultural lands. Gulf waters and tidal streams experience low oxygen levels following tropical storms. Other threats include the proposed dredging of the Sabine-Neches Waterway, increasing salinities that damage wetland habitats and the exotic plants that clog tidal streams and channels.



Priority Systems

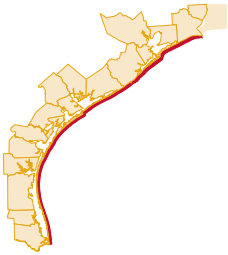
Lower Laguna Madre Bay System



The lower Laguna Madre is a long shallow bay extending from Port Isabel to the Kennedy Land Cut. The Arroyo Colorado and North Floodway are the main freshwater inflow sources for the bay, which is also hypersaline. Rapid population growth in the Lower Rio Grande Valley is affecting the bay system. As with the upper Laguna Madre, dredging, spoil removal and the presence of excess nutrients are primary threats. High nutrient concentrations come from municipal and industrial discharges, agricultural runoff and discharged wastewaters from the largest shrimp farms in the United States. Another serious concern is that there is currently no connection between the Rio Grande and the Gulf because there is not sufficient fresh-water inflow, while exotic plants are constricting the river.

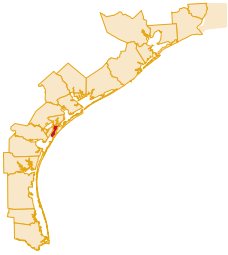
Conservation and Recreation Priorities for Water

Texas Territorial Sea



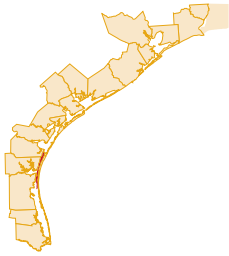
The Texas Territorial Sea is that portion of the Gulf of Mexico extending seaward from Texas' Gulf shoreline out to nine nautical miles. Extensive oil, gas and petrochemical production, marine commerce and transportation are major industries that utilize the Texas Territorial Sea. It is widely used for commercial shrimp trawling, menhaden trawling, longlining, recreational fishing, oil and gas production and recreational scuba diving. Threats to this nearshore gulf area and its associated marine organisms include potential oil and chemical spills, over-harvest of shrimp, finfish and other marine species, bycatch of fish, invertebrates and sea turtles and damages from the hypoxia, or reduced oxygen zone, and harmful algal blooms.

Aransas Bay System



The Aransas Bay complex extends from Aransas Pass to Bayside. Aransas Bay supports an extensive commercial fishery comprised of shrimp, crab, oyster and finfish species. The intense fishing pressure, both recreationally and commercially, threaten the health of the bay. Freshwater inflows are often inadequate to support the rich species diversity in the estuaries and bay area. In addition, the Texas Department of Health has closed several shoreline areas of the bay to all shellfishing because of inadequate sewage treatment.

Upper Laguna Madre System



Located on the lower Texas coast, the upper Laguna Madre system consists of upper Laguna Madre and Baffin Bay systems. The system is a long, narrow and shallow lagoon, bordered on the east by Padre Island and on the west by Corpus Christi. The surrounding areas have very little development and industrialization. The upper Laguna Madre, with no constant openings into the Gulf of Mexico and limited freshwater inflow, is characterized as a hypersaline estuary. The substantial source of freshwater is runoff from various watersheds into Baffin Bay. In the 1990's, the bay regularly experienced brown tide that increased turbidity and reduced seagrass beds and also negatively impacted tourism and recreational fishing. Dredging, moving the spoils and excess nutrient runoff threaten extensive seagrass beds and may be responsible for harmful algal blooms.

IMPORTANT AQUATIC HABITAT TYPES FOR TPWD EFFORTS

As with prairies and riparian habitats on land, there are important, natural water-based resources that cross all ecoregion, river basin and bay system boundaries. These resources are important for wildlife, water quality and quantity and other conservation values and also warrant priority effort by TPWD.

Conservation and Recreation Priorities for Water

Springs and Aquifers

Groundwater systems in Texas are diverse. Rainfall can be taken up by plants, evaporate over time, form runoff into streams, rivers and estuaries, or it can become groundwater by seeping into soil, sand and other land features. Water that moves into groundwater is recharge. Ground formations that store and transport enough water for human use are aquifers.

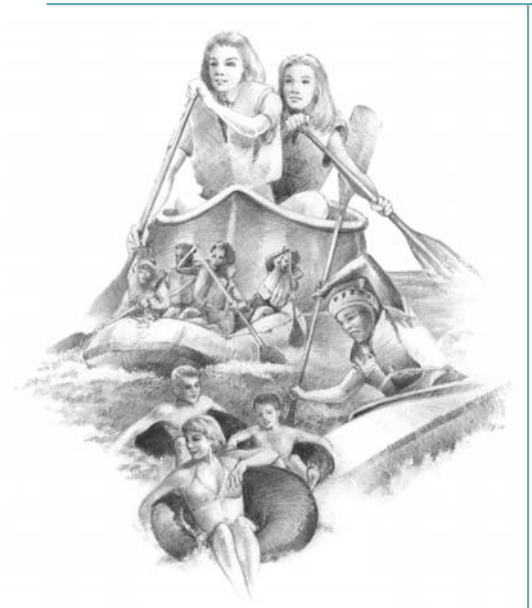
Springs are the natural outlets of aquifers. Springs that have run dry have had profound effects on surface water because they often form the base flows that sustain rivers and streams during drought. It is difficult, if not impossible, to restore aquifers that have been drawn down and continue to have withdrawals that greatly exceed the available recharge, but it is possible to conserve springs that depend on aquifers that recharge quickly.

Wetlands in Texas

Wetlands are among the most important habitats in Texas. These interfaces between water and land are integral in supporting a vast array of plants, fish and wildlife. They also perform numerous valuable functions: they trap water, sediments and nutrients and therefore play a major role in improving water quality and decreasing pollution. They are invaluable for their ability to prevent and minimize flooding, protect shorelines and replenish groundwater sources.

Texas has lost thousands of acres of historic wetlands, while human activities, including landscape alteration for agricultural, industrial or urban uses, significantly threaten remaining wetland habitats. Subsurface mineral and water extraction can also destroy wetlands, especially along the coast. Overharvest of timber threatens wooded wetlands as is evidenced in the state's bottomland hardwoods, pine flatwoods and swamps. Reservoir construction can submerge wetland areas upon filling, or they may be destroyed by diverting or capturing their source of water. Along the coast, reduced flow in rivers and streams can cause loss of freshwater wetlands due to increased saltwater intrusion. In the Panhandle, increased siltation from natural and agricultural erosion threatens playa lakes, which are important habitat for waterfowl and many other wildlife species.

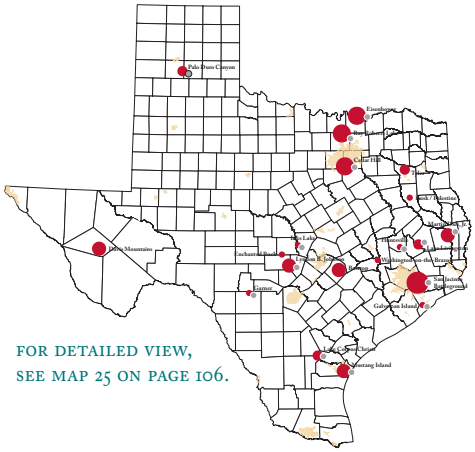
RECREATION PRIORITIES ON TEXAS WATERS



✻ WATER IS THE BASIS FOR A SIGNIFICANT RECREATIONAL RESOURCE IN TEXAS THAT INCLUDES BOATING, FISHING, SWIMMING, SAILING, DIVING, BIRD WATCHING AND PADDLE SPORTS.

The *Texas Parks and Wildlife for the 21st Century* report provides clear evidence of the popularity of water-based recreation. The study found that 39 percent swam, 38 percent fished in salt or fresh water and 30 percent had been motor boating in the previous year. The survey also found that 52 percent of Texans felt that TPWD should place high priority on providing increased access for water-based recreational opportunities, such as swimming, boating and fishing. Further, of the top 20 most-visited state parks, 14 are located on water and provide water recreation opportunities [**Map 25**].

Fishing and boating are the main recreational uses of reservoirs and rivers. According to the 2001 National Survey of Fishing, Hunting and Wildlife Associated Recreation, an estimated 2.4 million anglers fish in Texas each year and spent more than $2.7 billion for fishing-related goods and services in 2001. On the coast, commercial fishing and recreational anglers generate more than $2 billion in economic output each year. Fishing license sales and associated Federal Aid funds from taxes on fishing equipment are the largest sources of revenue for the Texas Parks and Wildlife Department. Boat registration fees are an important source of revenue for the Department as well. Equally important is the support for conservation that these constituents provide; anglers and boaters represent some of the strongest supporters of water quality, water quantity and aquatic habitat conservation.



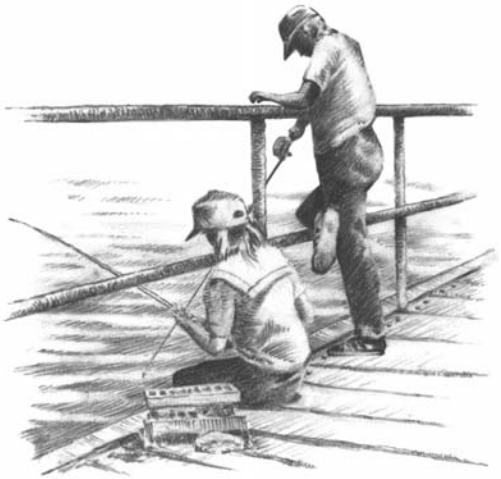
FOR DETAILED VIEW, SEE MAP 25 ON PAGE 106.

Fish hatchery facilities are needed to assure sustained availability of sport fisheries and have a value of $70 million combined. The maintenance and rehabilitation of these hatcheries is imperative as the demand for fish production is greater than present capacity. The gap between demand and TPWD's ability to supply fish to Texas waters increases annually as a result of normal wear and tear.

Over the last two decades, fewer Texans have participated in recreational fishing. The total number of resident fishing licenses sold steadily increased from the early 1970's peaking in the 1982-1983 license year with sale of resident fishing licenses totaling $1.89 million. After decreasing from peak years in the early 1980's, license sales have increased by 4.5 percent since 1997, but are still not at the 1982-1983 levels. Survey information shows that participation in saltwater fishing has increased during this period. These surveys indicate that factors limiting fishing participation include limited access, the increasing average age of anglers, time constraints, costs of fishing equipment and competing interests for leisure time.

Participation in other forms of water-based recreation is increasing. For example, the National Sporting Goods Association reported a 13 percent increase in the use and purchase of paddle craft, including kayaks and canoes. The Department has anticipated some of these changes and has explored strategies to diversify and expand opportunities for recreating on water. For example, TPWD recently developed a series of paddling trails along the coast that are popular attractions and several local communities have expressed an interest in building access points and facilities for these trails.

THREATS TO WATER-BASED RECREATION



Since conservation of Texas' water resources is intrinsically tied to recreation on those resources, the most significant threat to water recreation is the decline in quantity and quality. Water quality and quantity shapes fish communities, impacts TPWD's ability to manage the recreational fisheries and affects the public's ability to access waters. Recreation on each bay has its own set of threats, many of which are common among the bay systems, while some are more localized.

Access

A survey of anglers in the *Texas Parks and Wildlife for the 21st Century* report, revealed that 47 percent of anglers felt that freshwater shoreline access is only fair to poor while 45 percent felt the number and size of boat ramps where they fish is fair to poor. In addition, 73 percent of freshwater anglers felt that

Conservation and Recreation Priorities for Water

TPWD should spend more time, money and personnel on acquiring more public areas to increase fishing opportunities.

Given that Texas has a relatively small percentage of land open for public recreation, people are increasingly turning to public waters including rivers, streams, reservoirs and the coastline for recreation. Access to rivers is inadequate to support this increasing demand. Existing public river access points are generally at road crossings and are seldom adequate for safe access. Most of these access points lack adequate parking areas, trash receptacles, signage and restroom facilities. Since much of the state is in private ownership, legal access to rivers is limited and ambiguity about access and trespass exists. The current legal means of defining public and private property is complex and contributes to conflicts that involve the inadvertent trespass of private lands.

Public reservoirs serve as principal freshwater recreation sites. Access to reservoirs is increasingly threatened by lowered water levels related to municipal, agricultural, and industrial uses. These demands can result in dramatic fluctuations in water levels, resulting in decreased access and harm to fish communities.

Decreasing Numbers of Anglers

As with most of the United States, Texas experienced a decline in the sale of fishing licenses during the 1980's and 1990's. Numerous factors have contributed to this overall decline and will affect recruitment of new anglers. As the number of these important constituents decreases, the water resources that they support through user fees and advocacy will be threatened by competing water demands, potential pollution and other harm.

User Conflicts

As the population and resultant demands for public recreational opportunities on water increase, conflicts among users have begun to increase as well. For example, the use of motorized vehicles in streambeds has damaged resources, and has created a conflict between landowners and other river users. Likewise, boaters and personal watercraft users are beginning to compete for boat ramps and space on reservoirs. According to angler surveys in the *Texas Parks and Wildlife for the 21st Century* report, 25 percent of freshwater anglers surveyed reported conflicts with jetskiers.

On the coast, recreational anglers and commercial fishing operations are often at odds over "fair use" of the resource. Recreationists point to habitat damage and excessive harvest from commercial fishing, while commercial anglers argue that their opportunity to earn income through fishing should not be restricted in favor of recreation.

STRATEGIES FOR MEETING THE CONSERVATION AND RECREATION NEEDS ON WATER

TPWD has responsibility for maintaining healthy bays, adequate fish populations, productive commercial fisheries and excellent recreational fisheries. TPWD will work with the public, stakeholder groups, private landowners and regulatory agencies to ensure that adequate quantity and quality of water is available to support land and water ecosystems and public outdoor recreation.

MAINTAIN OR IMPROVE WATER QUALITY

TPWD will work to assure water quality needs are met in all streams, rivers, reservoirs and coastal systems.

- TPWD will continue to collaborate with the Texas Commission on Environmental Quality and other regulatory agencies to promote the conservation of water quality in streams and rivers.
- TPWD will support efforts to integrate biological and physical habitat data into water quality standards.
- TPWD will continue to conduct research and evaluate water quality concerns in Texas' freshwater and coastal water resources.
- TPWD will continue research studies to evaluate water quality concerns in tidal streams, bays and estuaries.

COASTAL NAVIGATIONAL DREDGING AND SPOIL DISPOSAL

- TPWD will remain involved in the approval of dredging plans and be actively involved in finding alternative spoil sites.
- TPWD will continue to support methods of channel and port expansion that minimize impacts to marine resources.

MAINTAIN ADEQUATE WATER QUANTITY

Implement and update tiered instream flow study priorities.

- TPWD will complete instream flow studies at the basin and subbasin level in coordination with TCEQ and TWDB. Site-specific assessments will also be required to address specific water development projects.
- TPWD will design studies to assist in regional water planning and water right decision making.

Conservation and Recreation Priorities for Water

TPWD will work to implement freshwater inflow and instream flow studies recommendations.

- TPWD will support amending the Texas Water Code to better recognize instream uses (instream flows, freshwater inflows to bays and estuaries, water quality, fish and wildlife resources, aesthetics and recreation) as beneficial uses when appropriating state water to ensure water is available for the health of fish and wildlife.

- TPWD will continue to work with regulators, regional water planning groups and stakeholders to develop state and regional water plans that protect the needs of fish and wildlife by incorporating flow regimes that adequately protect aquatic systems.

- TPWD will continue to work with regulators, permit holders and stakeholders on water right permits to protect the needs of fish and wildlife by incorporating permit special conditions that adequately protect aquatic systems.

TPWD will encourage the conversion or transfer of existing unused water rights to the Texas Water Trust to protect instream uses.

- TPWD will recommend that when a right is converted to a different use, sold or transferred out of basin those actions should include permit conditions to mitigate detrimental impacts and ensure flows necessary to maintain the health of fish and wildlife.

TPWD will work with private landowners on watershed management approach to increase water quantity and quality in rivers and streams to increase freshwater inflows to the bays and estuaries.

- TPWD will incorporate the goal of watershed management and improving water quality and quantity into all Wildlife Management Plans (WMP).

- TPWD will work with the Texas Department of Agriculture, Texas Agricultural Extension Service, River Authorities and other state and federal agencies to fund projects that increase water yields while protecting or improving wildlife habitat.

PROTECT TEXAS SPRINGS, WETLANDS AND SEAGRASS

- TPWD will fully implement the Department's Wetlands Conservation Plan and the Seagrass Plan.

- TPWD will work to assure that future legislation affecting groundwater also protects springs and other beneficial uses for wildlife.

- TPWD will continue to participate in the Groundwater Availability Models effort being directed by TWDB and advocate that these models be used to manage groundwater pumping to minimize impacts to springs and other associated surface water features.

- TPWD will encourage groundwater districts to implement management practices that protect springs and spring habitats in their plans.

IMPROVE OUTREACH AND EDUCATION

To increase support for conserving Texas freshwater and coastal water resources, TPWD must increase outreach and education efforts.

- TPWD must increase efforts to produce public education materials that discuss the importance of river, spring, reservoir, wetland, bay and estuary conservation.
- TPWD will encourage anglers and boaters to increase their role as conservationists.
- TPWD will assist local communities in planning and education programs that promote water conservation for fish and wildlife.
- TPWD will work with schools to integrate water resource and recreation information into their curriculum.

INCREASE FISHING PARTICIPATION

- TPWD will market angling to non-traditional constituencies to encourage participation and to evaluate the success of existing programs aimed at recruiting new anglers.
  - TPWD will pursue funding to develop fishing information and access guides for public waters.
- TPWD will cooperate with other agencies, organizations and the fishing industry to increase angler participation.
- TPWD will increase outreach and education efforts as well as enhance fish stocking in urban areas to recruit new anglers.
- TPWD will assess trends in angler preferences, expectations, catch rates, socio-demographics and satisfaction in order to maintain current anglers.
- TPWD will develop strategies that limit resource impacts and reduce conflict between angling and boating constituents.
- TPWD will periodically evaluate efforts to increase participation in fishing and refine techniques to maximize recruitment success.

REDUCE USER CONFLICTS

- TPWD will work with advisory committees and recreational groups to develop strategies that limit resource impacts and reduce conflict between users.
- TPWD will continue education and communication with all affected user groups concerning recreation impacts on water resources.

INCREASE TPWD'S KNOWLEDGE AND UNDERSTANDING OF AQUATIC ECOSYSTEMS

TPWD will base conservation decisions that impact fish and wildlife resources using the best science available.

- TPWD will continue to prioritize waterways that are important for conservation.
- TPWD will develop and refine tools for analyzing aquatic systems and develop new conservation strategies.

Conservation and Recreation Priorities for Water

- TPWD will expand the ecologically significant streams segment data to include more robust criteria and categories.

- TPWD will identify river and stream segments most at risk from over-appropriation.

TPWD will continue to increase the understanding of biological resources present in Texas rivers, streams, spring and reservoir systems.

- TPWD will make historical reports and associated data available for research to document long term changes to flora and fauna of rivers and streams.

- TPWD will improve monitoring and research on aquatic species or groups suspected to be declining or whose status is unknown.

TPWD will research and monitor bay and estuary systems.

- TPWD will work with TWDB to establish freshwater inflow needs, nutrient and sediment loading regimes to Texas' minor estuaries, specifically East Matagorda Bay, South Bay, Christmas Bay Coastal Preserve, Cedar Lakes and the San Bernard River estuary and the Brazos River estuary.

- TPWD will work with the TWDB to apply the process for determining freshwater inflows, nutrient and sediment loading regimes to tidal streams.

- TPWD will maintain water quality monitoring programs to identify threats, guide management and avoid or minimize impacts to bay and estuary systems.

- TPWD will develop indices of biotic integrity to measure the health of marine ecosystems.

- TPWD will increase support of research on Texas algal blooms, develop routine monitoring and rapid response to algal bloom events.

IMPROVE RECREATIONAL FISHERIES

TPWD will seek to improve habitat management strategies.

- TPWD will evaluate the current freshwater fisheries habitat management techniques and research new and developing strategies to address water quality and quantity, exotic species, harmful diseases and structural deficiencies.

TPWD will continue to aggressively manage sportfish stocks to assure angler satisfaction as a means of maintaining the presence of anglers.

- TPWD will evaluate ongoing maintance needs for fish hatcheries and develop a program to fund their repair and improvement needs.

- TPWD will establish the economic importance of freshwater and marine recreational fishing activities in public waters.

CREATE NEW OPPORTUNITIES AND IMPROVE ACCESS

TPWD will develop new strategies and create new opportunities for urban Texans to recreate on rivers and lakes in their communities.

- TPWD will continue to develop water access programs and provide information on activities like paddling trails, maps and other navigation tools.
- TPWD will explore strategies in which landowners can generate revenue for allowing public access to rivers and streams on their lands.
- TPWD will explore the creation of partnerships with coastal communities to establish coastal aquatic parks and protected areas through TPWD's local grants and other programs.
- TPWD will evaluate existing public access to water at state parks, wildlife management areas and other facilities and improve it wherever possible.
- TPWD will work with local communities and other agencies to acquire and manage access points along rivers and lakeshores.
- TPWD will work with other agencies to improve existing access points to rivers and lakes for fishing and other water recreation where possible and plan for declining water levels if necessary.
- TPWD will work with the General Land Office to clearly define public and private waters.

REDUCE EXCESS COMMERCIAL FISHING IMPACTS

Reduce excess fishing effort in the commercial fishing industries.

- TPWD will continue license buyback programs for commercial shrimp, crab and finfish fisheries.
- TPWD will evaluate the need for a license management program, including license buyback, in the Gulf shrimp fishery.
- TPWD will research and support methods that reduce the quantity and mortality of bycatch.

EXOTIC SPECIES

- TPWD will continue to prevent the introduction of potentially harmful, non-indigenous fishes, shellfish and aquatic plants into freshwater and marine environments through education and regulations.
- TPWD will implement the State Aquatic Plant Management Plan.

Major Goals and Objectives

The following goals and objectives (revised and adopted January 2005) are provided as a method of measuring success of this Plan. To do so, the Texas Parks and Wildlife Department will annually evaluate and report its progress over the preceding year and its priorities for the following year to the Texas Parks and Wildlife Commission. In addition, TPWD will review and update the goals/objectives by 2010.

Goal 1: Improve Access to the Outdoors

Objectives

1.1 Identify opportunities to expand outdoor recreation, water access, hunting, and fishing on both public and private lands and waters.

1.2 Acquire and develop a minimum of four, 5,000 acre or larger state parks near major urban centers of the state.

1.3 Identify opportunities for adding land to existing state parks and wildlife management areas consistent with this Plan.

1.4 Acquire new wildlife management areas in the Cross Timbers and Prairies and the High Plains ecoregions.

1.5 Promote awareness and support of safe and responsible use of the outdoors.

1.6 Manage grant funds to enhance access to the outdoors.

Goal 2: Preserve, Conserve, Manage, Operate and Promote Agency Sites for Recreational Opportunities, Biodiversity, and the Cultural Heritage of Texas.

Objectives

2.1 Develop and implement plans for regular maintenance, conservation, restoration, and improvement of all agency facilities.

2.2 Develop agency priorities for spending available repair and development funds

2.3 Develop interpretive, educational and recreational programs at agency sites that demonstrate and promote understanding of the importance of natural and cultural resource conservation.

2.4 Protect, maintain, and restore appropriate terrestrial and aquatic habitat on agency sites.

2.5 Develop criteria for a statewide historic sites system in conjunction with the Texas Historic Commission.

2.6 Develop management priorities among existing TPWD historic sites.

2.7 Promote energy conservation and the use of alternative energy systems and programs.

2.8 Operate TPWD sites to increase public support, recreation participation, visitation, revenue, and promote the agency's core conservation message

2.9 Manage agency sites to demonstrate healthy natural ecosystems and support recreational uses consistent with the agency's conservation mission.

2.10 Transfer eligible state parks and wildlife management areas listed in this Plan when appropriate.

GOAL 3: ASSIST LANDOWNERS IN MANAGING THEIR LANDS FOR SUSTAINABLE WILDLIFE HABITAT CONSISTENT WITH THEIR GOALS.

Objectives

3.1 Promote awareness of and support for resource management through technical guidance to landowners.

3.2 Prioritize incentive-based management strategies as an alternative to regulatory strategies when appropriate.

3.3 Incorporate watershed management strategies in all Wildlife Management Plans (WMP).

3.4 Increase acres under Wildlife Management Plans to 20 million acres by 2008

3.5 Increase percentages of Wildlife Management Plans in high priority ecoregions and habitats identified in this Plan

3.6 Support establishment of a purchase of development rights program in Texas that is consistent with the agency's mission.

3.7 Streamline permitting processes that ensures resource conservation.

GOAL 4: INCREASE PARTICIPATION IN HUNTING, FISHING, BOATING AND OUTDOOR RECREATION

Objectives

4.1 Increase opportunities for youth to participate in outdoor recreation.

4.2 Promote and expand outdoor recreational activities.

4.3 Develop strategies to recruit, inform and retain new, lapsed and current outdoor users.

4.4 Increase access to and safety on public waters.

4.5 Promote outdoor recreation opportunities in urban areas.

GOAL 5: ENHANCE THE QUALITY OF HUNTING, FISHING, BOATING AND OUTDOOR RECREATION.

Objectives

5.1 Manage and conserve (e.g., monitor, analyze, regulate, enhance, restore and protect) natural resources for healthy and sustainable ecosystems.

5.2 Refine hatchery programs to improve performance of fishes stocked into public waters.

5.3 Develop private/public partnerships to maintain, enhance, and restore ecosystems and promote outdoor recreational opportunities.

5.4 Simplify regulations consistent with the agency's mission.

5.5 Restore aquatic and terrestrial habitat where feasible to sustain and enhance healthy ecosystems

5.6 Manage commercial resource activities to ensure long-term sustainability.

5.7 Create artificial reefs to enhance coastal recreational opportunities.

5.8 Promote safe and responsible boating.

GOAL 6: IMPROVE SCIENCE, DATA COLLECTION AND INFORMATION DISSEMINATION TO MAKE INFORMED MANAGEMENT DECISIONS.

Objectives

6.1 Complete a comprehensive science review.

6.2 Develop and support integrated databases that include baseline resource inventories

6.3 Make all relevant information readily accessible to internal and external stakeholders.

6.4 Develop an implementation plan based on the science review and establish a systematic review process

6.5 Evaluate and apply emerging technologies when possible.

GOAL 7: MAINTAIN OR IMPROVE WATER QUALITY AND QUANTITY TO SUPPORT THE NEEDS OF FISH, WILDLIFE AND RECREATION

Objectives

7.1 Promote watershed and range management practices that improve water quality and quantity.

7.2 Promote cross-agency and stakeholder cooperation that enhances water quality, quantity and habitat.

7.3 Incorporate instream flow and freshwater inflow needs into water permitting, planning, development and management processes.

7.4 Incorporate fish, wildlife, and recreation needs into the Regional Water Planning process.

7.5 Promote understanding of and support for the water needs of fish, wildlife and outdoor recreation.

7.6 Work with stakeholders to ensure that Water Quality Standards increasingly incorporate biological data to protect the health and productivity of Texas waters.

7.7 Encourage the conversion or transfer of existing unused water rights to the Texas Water Trust to protect instream uses.

ADDITIONAL GOAL 8: CONTINUOUSLY IMPROVE TPWD BUSINESS MANAGEMENT SYSTEMS, BUSINESS PRACTICES AND WORK CULTURE.

Objectives

8.1 Promote a work culture that fosters agency-wide understanding of resource and business management and a team approach to problem solving.

8.2 Provide quality customer service.

8.3 Develop efficient and consistent processes that produce good financial systems and business outcomes.

8.4 Balance conservation and good business practices to achieve the agency mission.

8.5 Recruit, train, and retain quality employees at all levels of the agency.

8.6 Provide accurate and timely communication to oversight organizations.

8.7 Develop effective internal and external communication processes.

8.8 Develop an agency-wide plan for acquiring additional funding to support the agency's mission.

Conclusion

The Texas Parks and Wildlife Department has operated without a comprehensive plan that addresses the conservation, recreation and historic needs of Texas. The *Land and Water Resources Conservation and Recreation Plan* provides this important guidance for the Department and fulfills the mandate of TPWD's Sunset Legislation. This Plan will allow the Department to make strategic decisions regarding the location of new parks, wildlife management areas or historic sites, the investment of resources for determining the needs of Texas' waterways and its efforts with private landowners. It will guide actions on land acquisition and divestiture, historic site development, partnerships and implementation of programming to meet Texas' growing conservation and recreation needs over the next ten years.

The foremost priorities identified in the Plan are:

- TPWD needs to provide more large recreational sites closer to the growing urban centers, ideally 5,000-acre recreation areas within 90-minutes of Texas' largest cities.
- TPWD needs to expand efforts with private landowners to improve water quality and quantity through watershed management and conserve important wildlife habitat. TPWD must create new opportunities to increase public access for recreation, especially hunting, in collaboration with the landowner community.
- TPWD needs to more effectively communicate the value and importance of ensuring that adequate freshwater flows in Texas' rivers and bays for fish, wildlife and recreation.

This Plan is not a static document. Every four years, new information will be gathered and developed, new needs and trends will be identified and the strategies and priorities of the Plan will reflect these changes.

The first task for the Texas Parks and Wildlife Department is to evaluate its existing programs, facilities and services to ensure that they complement the Department's legislative mandate, its mission and this Plan. TPWD will scrutinize existing planning

documents to determine if they are in line with this report and will use this document and as a critical budgetary tool.

TPWD is not the sole provider of conservation programs or recreational sites in Texas. This report is a comprehensive assessment of how the Department's sites and programs work within the framework of federal, state, local and private entities. Given limited resources, the Department will coordinate with private organizations, local governments and federal and state agencies to facilitate improved public access to the outdoors and to improve conservation of land and water statewide.

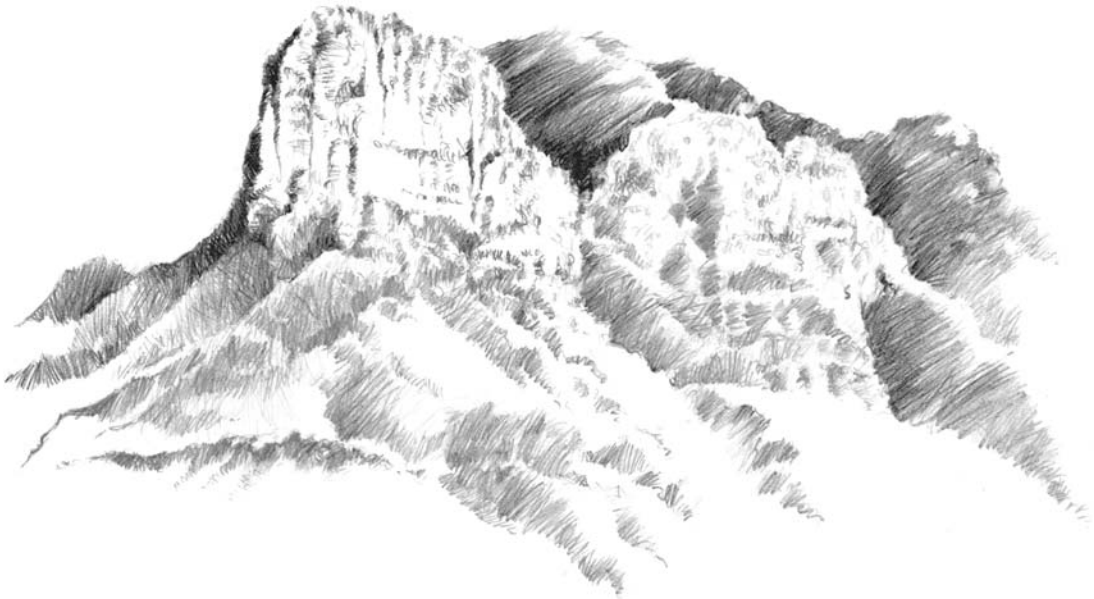
Wherever possible, the Department will combine its conservation and recreation efforts. This will conserve significant landscapes, provide public access to the outdoors and provide opportunities to educate visitors about the importance of wildlife, water and other natural resources. For example, conservation of an important habitat type or representative examples of the ecoregion will be a priority when acquiring lands for recreation near major population centers.

Many of the priorities, strategies and goals established in this report will require additional funding. Currently, the Department does not have the financial resources to purchase or develop a new state park, wildlife management area, historic site or fish hatchery. In addition, reallocating the resources necessary to double land under wildlife management plans and complete instream flow studies will be challenging. Many of the goals in the Plan will require a mix of traditional public funding and increasing private sector involvement because of the finite public resources available. TPWD must rely on private market solutions in order to attract resources, entrepreneurs and capital.

The window of opportunity for conservation of natural resources and providing adequate access for outdoor recreation in Texas is closing. The state's population is expanding rapidly, land fragmentation is increasing and water resources are already stretched in many areas. Failure to ensure adequate water for wildlife now will impose a great cost on the citizens of Texas in the future. The loss or decline of these resources will have a greater impact on the economy than is readily apparent: it will negatively impact local economic development from the loss of hunting, fishing and other recreational tourism; it will increase state and federal regulations; it will increase costs to businesses and industries; and it will impact public services including municipal water supply and treatment. Furthermore, the cost of acquiring land to serve the public's recreational needs will also increase over time.

The state is changing rapidly and this *Land and Water Resources Conservation and Recreation Plan* is an effort to meet the challenges of the new century. The necessary conservation of land and water and provision of recreational opportunities will require a renewed effort and commitment from the Texas Parks and Wildlife Department, state leaders, conservation and recreation organizations, the private sector and citizens.

Maps, Graphs and Tables



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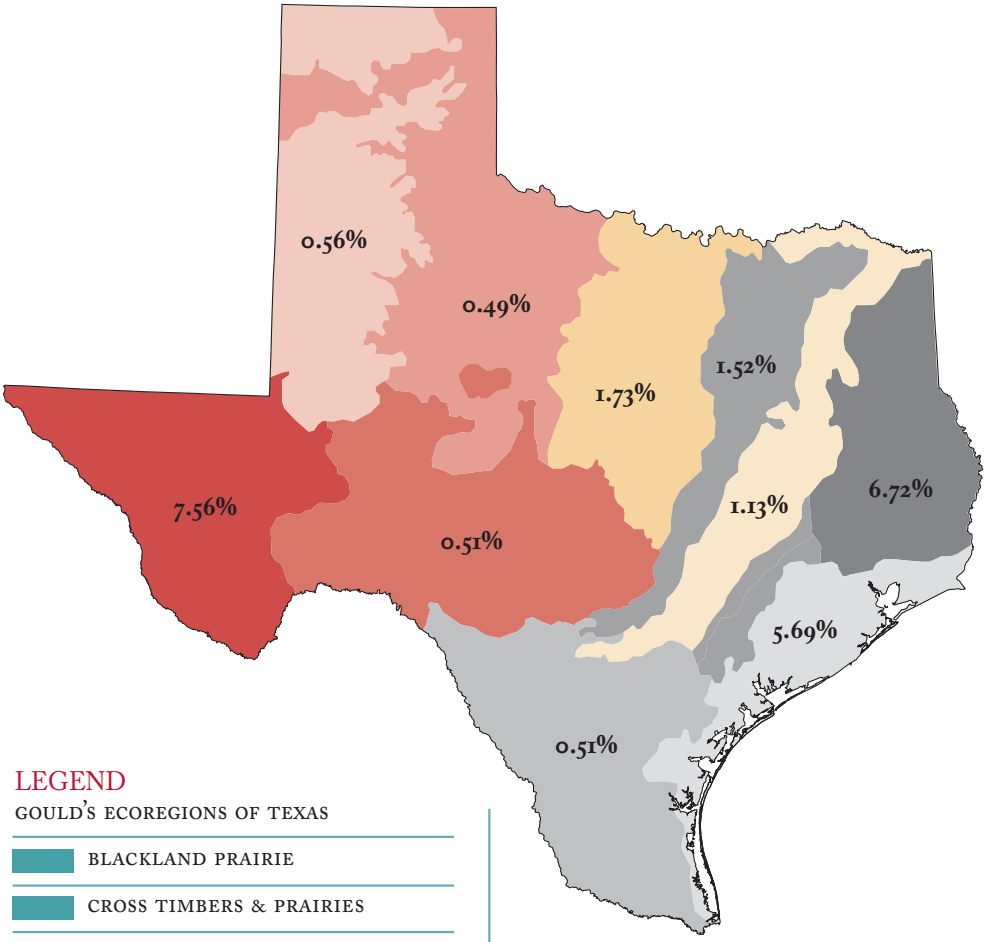
Map 1

PUBLIC AND PRIVATE CONSERVATION LAND



LEGEND

GOULD'S ECOREGIONS OF TEXAS

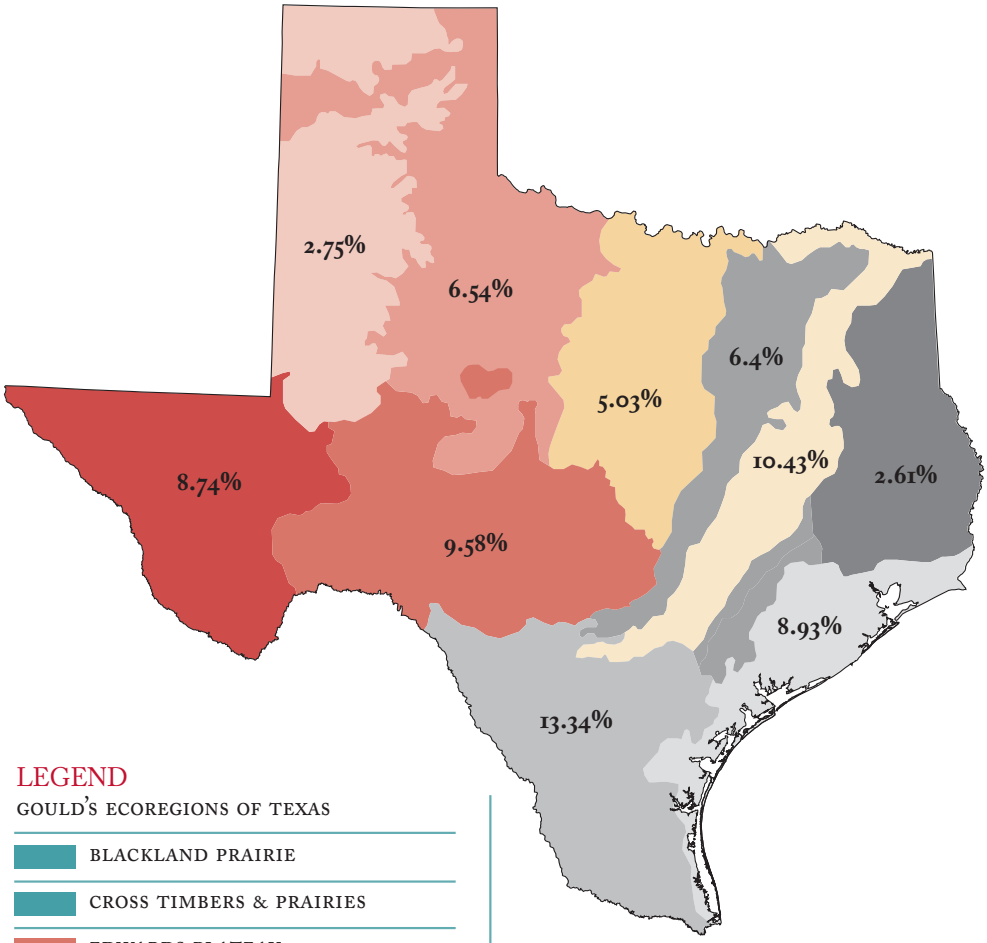
- BLACKLAND PRAIRIE
- CROSS TIMBERS & PRAIRIES
- EDWARDS PLATEAU
- GULF COAST PRAIRIES & MARSHES
- HIGH PLAINS
- PINEYWOODS
- POST OAK SAVANNAH
- ROLLING PLAINS
- SOUTH TEXAS PLAINS
- TRANS-PECOS

CONSERVATION LANDS INCLUDES ALL STATE, FEDERAL AND CONSERVATION NGO OWNED LANDS. CITY OWNED PARK LANDS WERE INCLUDED ONLY IF THEY WERE IDENTIFIED AS SPECIFICALLY FOR PERSERVATION, OR IF THEY WERE GREATER THAN 250 ACRES AND NOT GOLF COURSES OR OTHER HUMAN RECREATIONAL SPORTS COMPLEXES.

BASE MAP: GOULD, F.W. 1975. TEXAS PLANTS – A CHECKLIST AND ECOLOGICAL SUMMARY. TEXAS AGRICULTURAL EXPERIMENT STATION, PUBLICATION 585.

Map 2

PERCENT WILDLIFE MANAGEMENT PLANS



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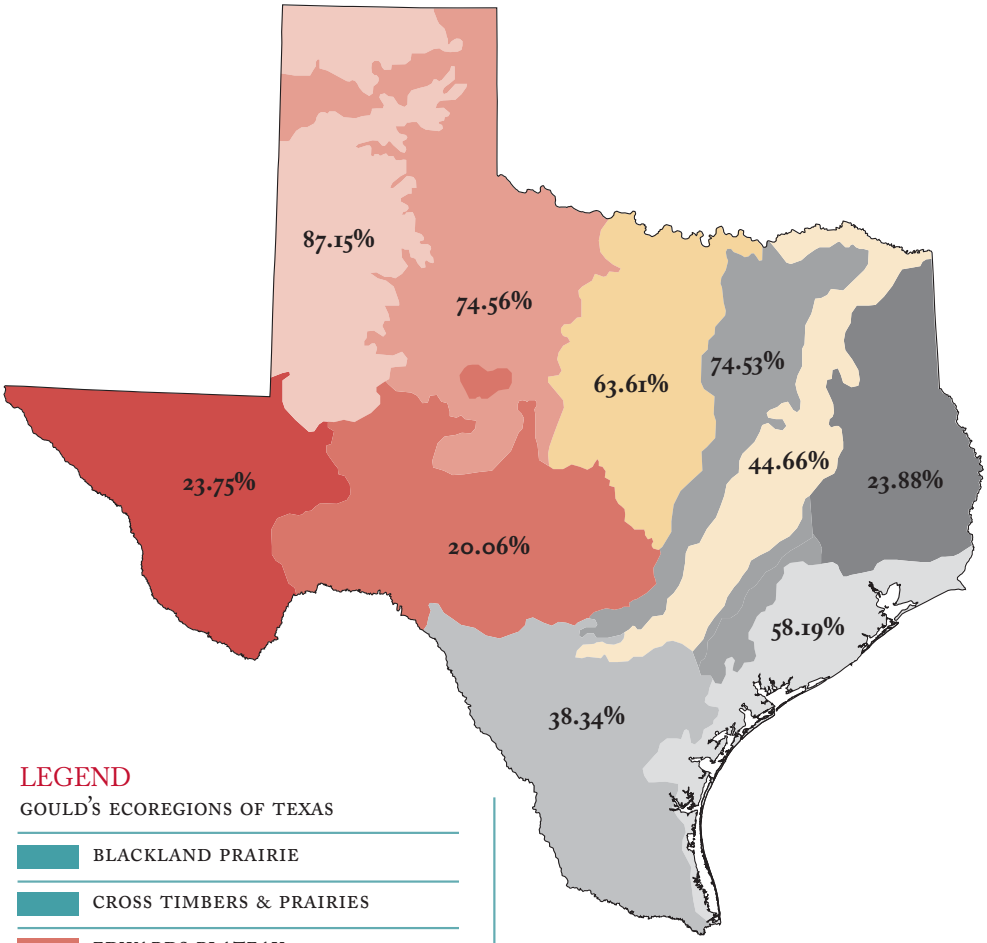
PERCENT OF ECOREGION OPERATED UNDER A WILDLIFE MANAGEMENT PLAN.

BASE MAP: GOULD, F.W. 1975. TEXAS PLANTS – A CHECKLIST AND ECOLOGICAL SUMMARY. TEXAS AGRICULTURAL EXPERIMENT STATION, PUBLICATION 585.

Map 3

PERCENT OF CONVERTED LANDS



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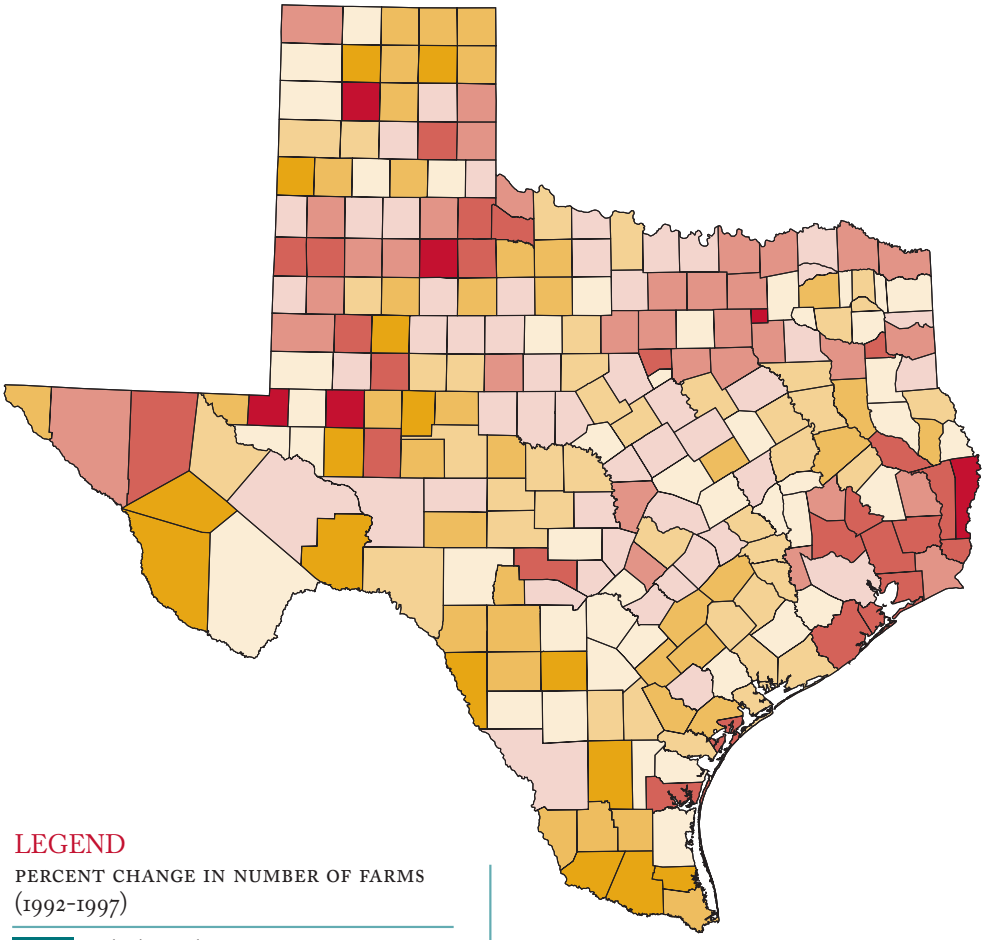
PERCENT OF ECOREGION CONVERTED TO URBAN OR AGRICULTURAL USE.

CONVERTED LANDS DATA FROM:
NATIONAL LANDCOVER DATASET, USGS, 1992.

BASE MAP: GOULD, F.W. 1975. TEXAS PLANTS – A CHECKLIST AND ECOLOGICAL SUMMARY. TEXAS AGRICULTURAL EXPERIMENT STATION, PUBLICATION 585.

Map 4

LAND FRAGMENTATION BY COUNTY



LEGEND

PERCENT CHANGE IN NUMBER OF FARMS (1992-1997)

- -16.16 – -6.98
- -6.97 – -0.66
- 0.67 – 4.62
- 4.63 – 8.01
- 8.02 – 12.03
- 12.04 – 17.53
- 17.54 – 29.20
- 29.21 – 56.00

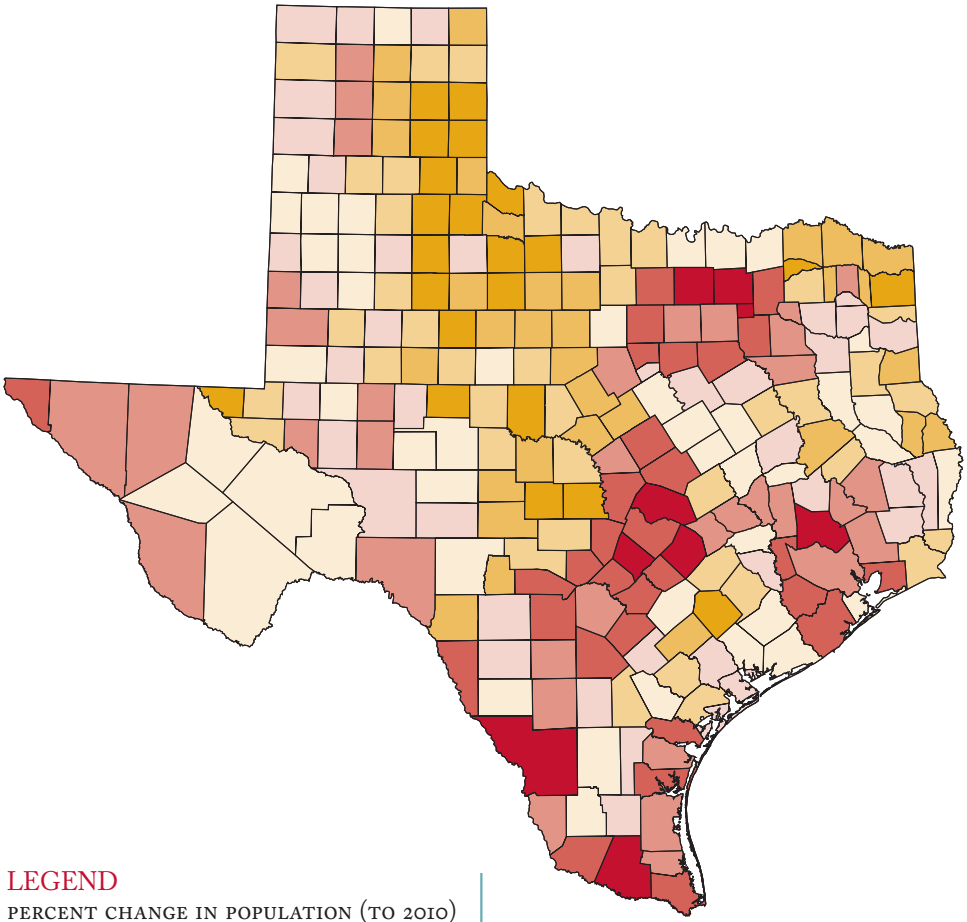
NUMBER OF FARMS DATA FROM:

NEAL WILKINS, PH.D. TEXAS AGRICULTURAL EXTENSION SERVICE, COLLEGE STATION, TEXAS.

TPWD IS SOLELY RESPONSIBLE FOR USE OF DATA AS INDEXED FOR LAND FRAGMENTATION.

Map 5

PROJECTED POPULATION GROWTH TO 2010



LEGEND

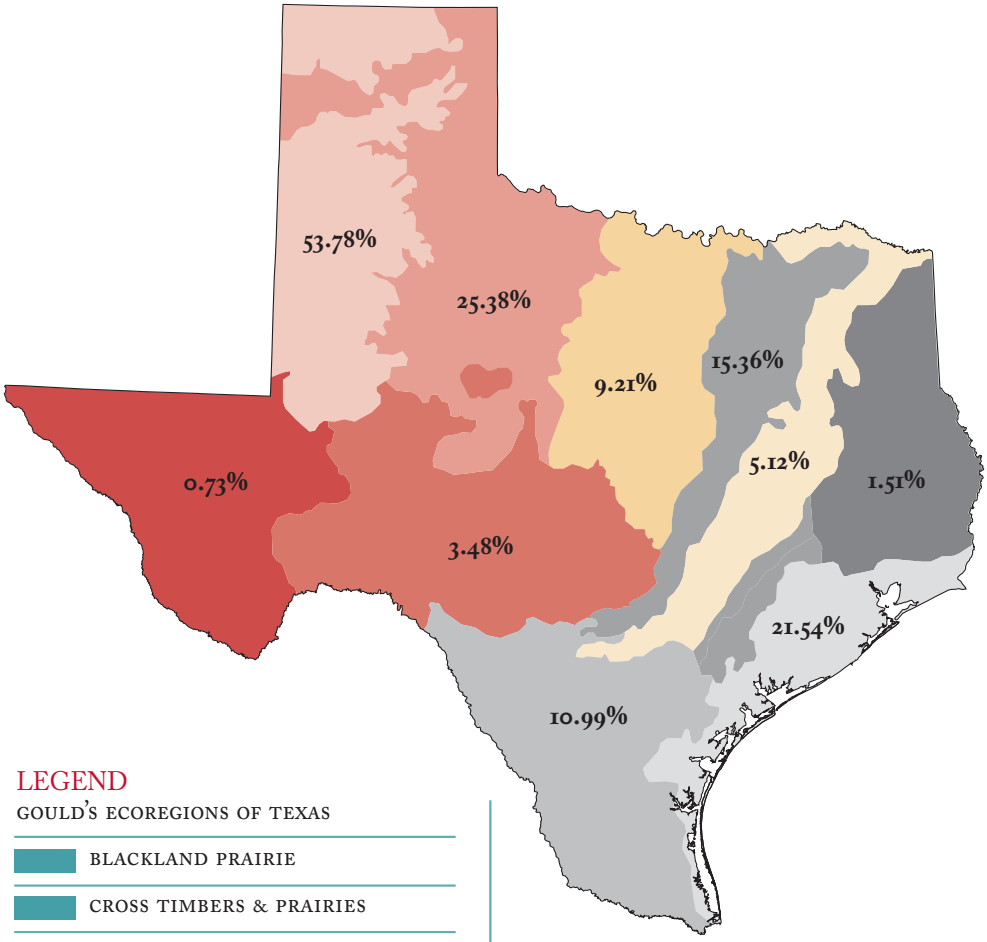
PERCENT CHANGE IN POPULATION (TO 2010)

- -5.89 – -0.85
- -0.84 – -2.36
- 2.37 – 5.25
- 5.26 – 7.81
- 7.82 – 10.77
- 10.78 – 16.79
- 16.80 – 26.90
- 26.91 – 38.80

PROJECTED POPULATION DATA FROM: TEXAS STATE DEMOGRAPHER'S OFFICE PROJECTIONS USING THE MEDIAN SCENARIO OF 1/2 OF THE MIGRATION OF 1990-2000 WITH CALCULATED GROWTH. DATA PROVIDED BY KEVIN KLUGE, TEXAS WATER DEVELOPMENT BOARD.

Map 6

PERCENT OF ECOREGION IN CROPLAND USE



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- TRANS-PECOS

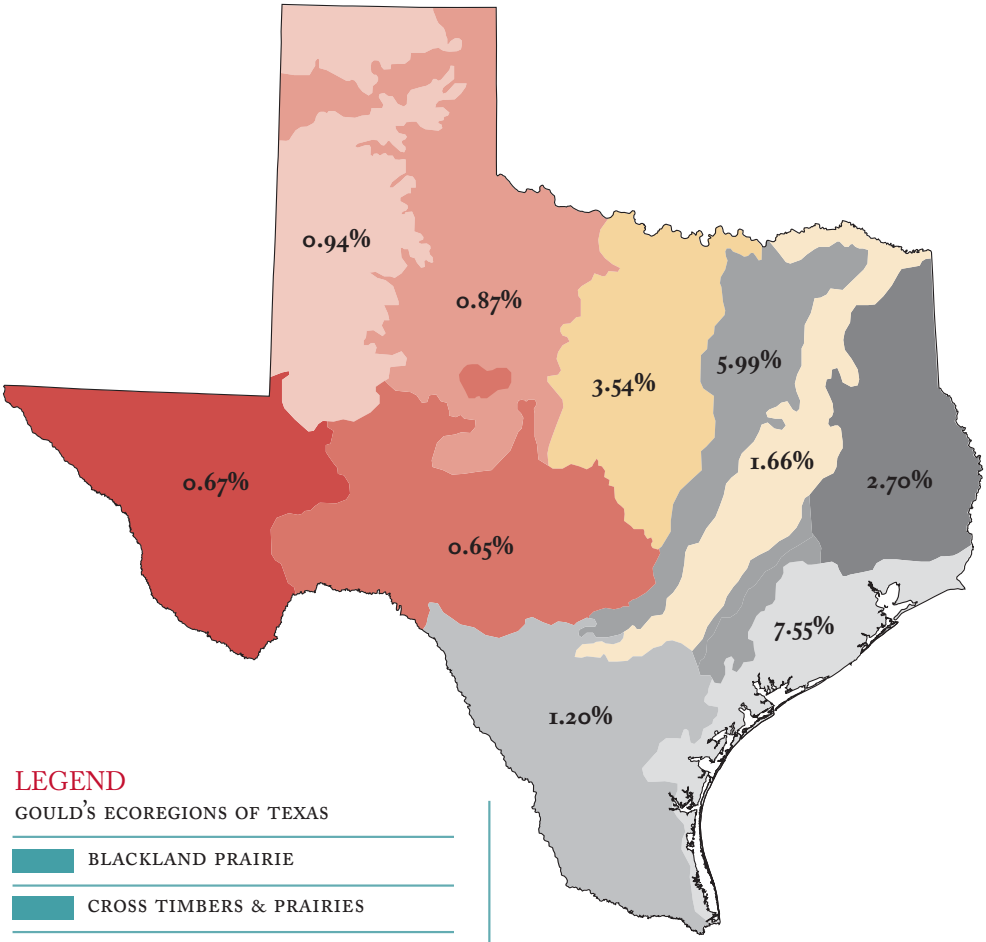
CROPLAND DATA FROM:

NATIONAL LANDCOVER DATASET, USGS, 1992.

BASE MAP: GOULD, F.W. 1975. TEXAS PLANTS – A CHECKLIST AND ECOLOGICAL SUMMARY. TEXAS AGRICULTURAL EXPERIMENT STATION, PUBLICATION 585.

Map 7

PERCENT OF ECOREGION AS URBAN AREAS



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URBAN AREAS DATA FROM:

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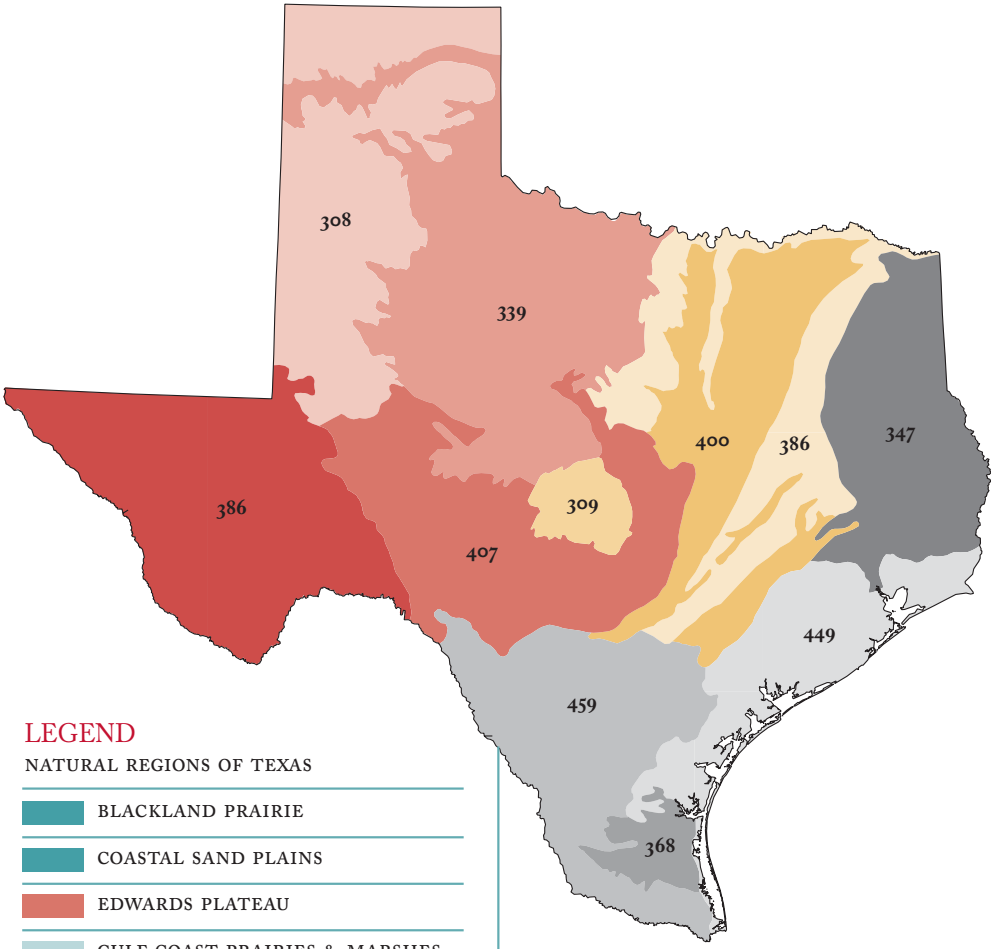
BASE MAP: GOULD, F.W. 1975. TEXAS PLANTS – A CHECKLIST AND ECOLOGICAL SUMMARY. TEXAS AGRICULTURAL EXPERIMENT STATION, PUBLICATION 585.

Map 8

VERTEBRATE DIVERSITY BY NATURAL REGION



LEGEND

NATURAL REGIONS OF TEXAS

- BLACKLAND PRAIRIE
- COASTAL SAND PLAINS
- EDWARDS PLATEAU
- GULF COAST PRAIRIES & MARSHES
- HIGH PLAINS
- LLANO UPLIFT
- OAK WOODS & PRAIRIES
- PINEYWOODS
- ROLLING PLAINS
- SOUTH TEXAS BRUSH COUNTRY
- TRANS-PECOS

REPRESENTS NUMBER OF VERTEBRATE SPECIES OCCURRING IN EACH NATURAL AREA.

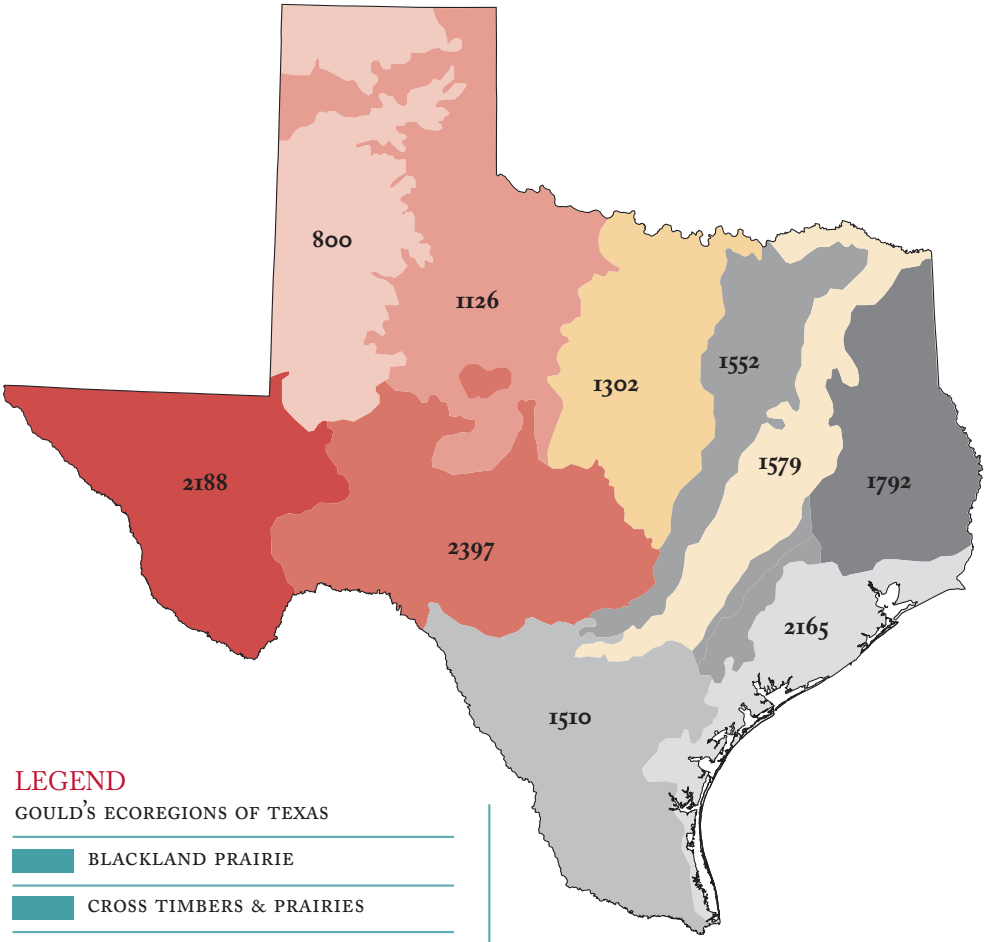
VERTEBRATE DATA FROM:

TEXAS TECH UNIVERSITY, LUBBOCK, TEXAS.

BASE MAP: 1978. PRESERVING TEXAS' NATURAL HERITAGE. LYNDON B. JOHNSON SCHOOL OF PUBLIC AFFAIRS. LBJ SPA PRRR: 3. AUSTIN, TEXAS.

Map 9

PLANT TAXA BY ECOREGION



LEGEND

GOULD'S ECOREGIONS OF TEXAS

- BLACKLAND PRAIRIE
- CROSS TIMBERS & PRAIRIES
- EDWARDS PLATEAU
- GULF COAST PRAIRIES & MARSHES
- HIGH PLAINS
- PINEYWOODS
- POST OAK SAVANNAH
- ROLLING PLAINS
- SOUTH TEXAS PLAINS
- TRANS-PECOS

REPRESENTS NUMBER OF PLANT SPECIES OCCURRING IN EACH ECOREGION.

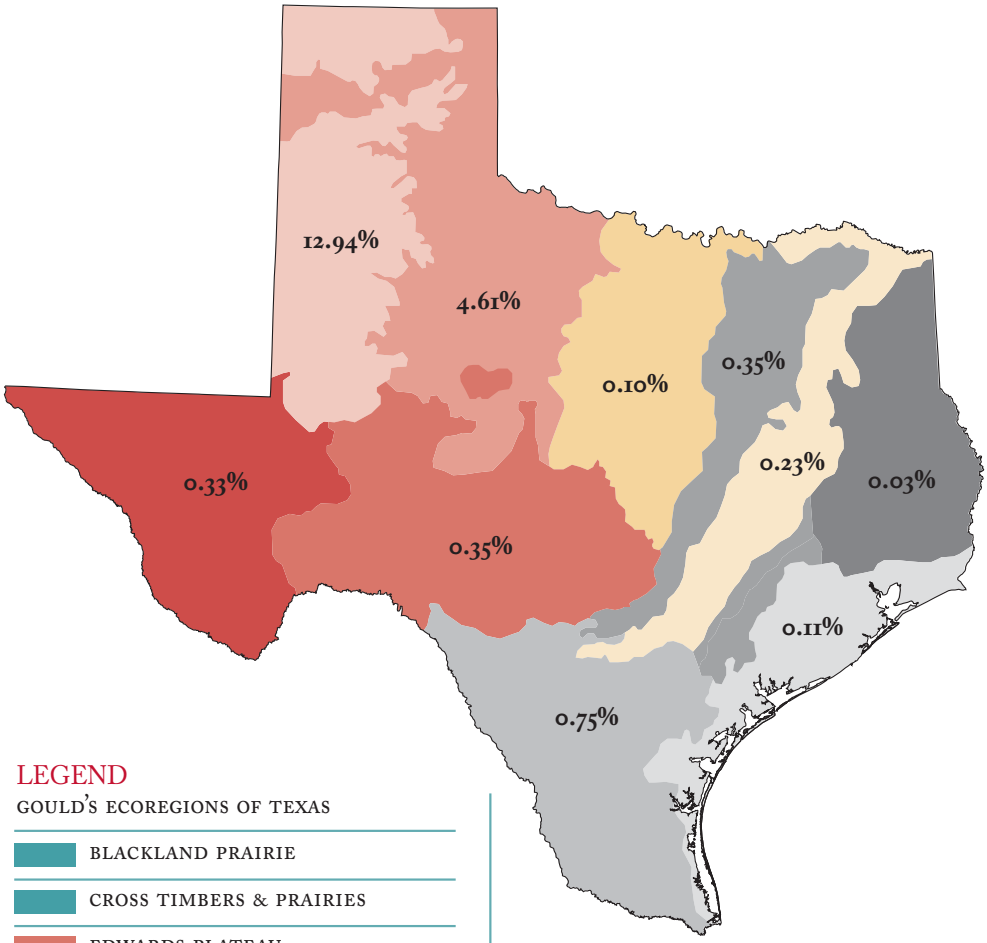
SOURCE DATA FROM:

HATCH, STEPHAN L., KANCHEEPURAM N. GANDHI, AND LARRY E. BROWN. 2001. A CHECKLIST OF THE VASCULAR PLANTS OF TEXAS, VERSION 2001. TEXAS A&M UNIVERSITY.

BASE MAP: GOULD, F.W. 1975. TEXAS PLANTS – A CHECKLIST AND ECOLOGICAL SUMMARY. TEXAS AGRICULTURAL EXPERIMENT STATION, PUBLICATION 585.

Map 10

CONSERVATION RESERVE PROGRAM LANDS



LEGEND

GOULD'S ECOREGIONS OF TEXAS

- BLACKLAND PRAIRIE
- CROSS TIMBERS & PRAIRIES
- EDWARDS PLATEAU
- GULF COAST PRAIRIES & MARSHES
- HIGH PLAINS
- PINEYWOODS
- POST OAK SAVANNAH
- ROLLING PLAINS
- SOUTH TEXAS PLAINS
- TRANS-PECOS

CRP DATA FROM:

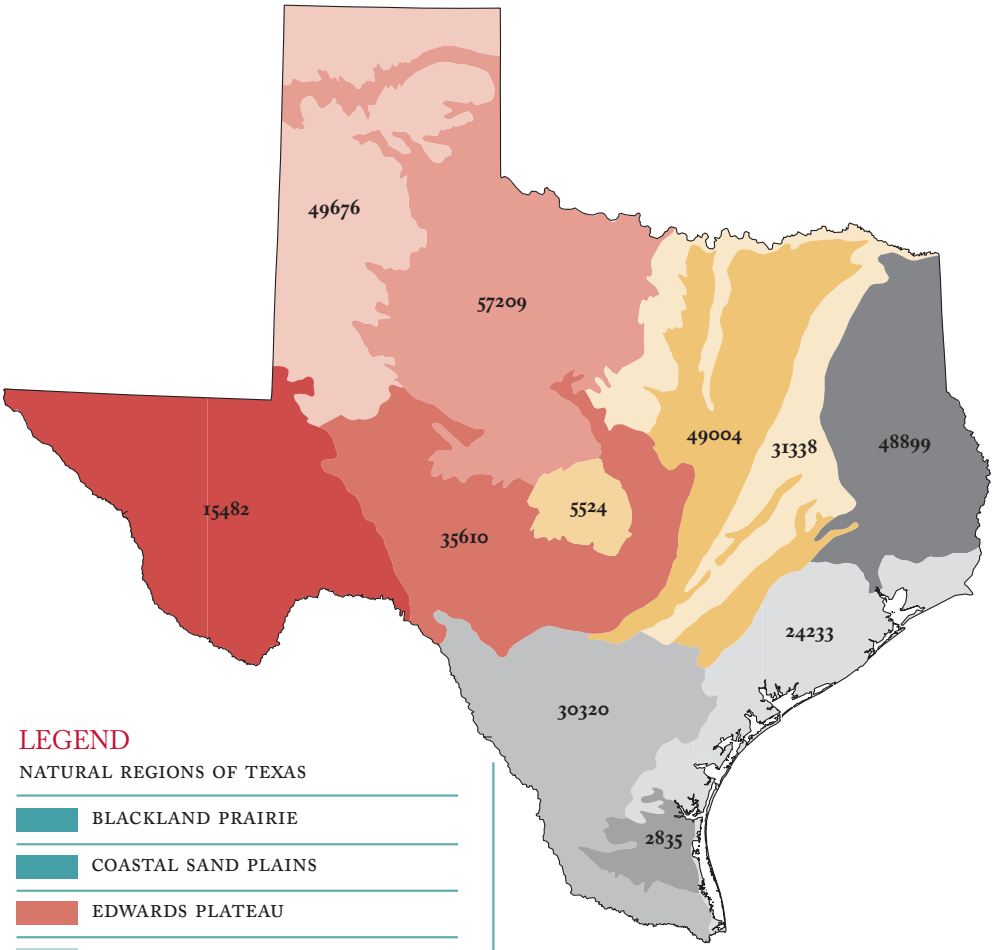
USDA FARM SERVICE AGENCY WEB SITE.

http://www.fsa.usda.gov/crpstorpt/06approved/r1summyr/tx.htm

BASE MAP: GOULD, F.W. 1975. TEXAS PLANTS – A CHECKLIST AND ECOLOGICAL SUMMARY. TEXAS AGRICULTURAL EXPERIMENT STATION, PUBLICATION 585.

Map 11

NUMBER OF ROAD MILES BY NATURAL REGION



LEGEND

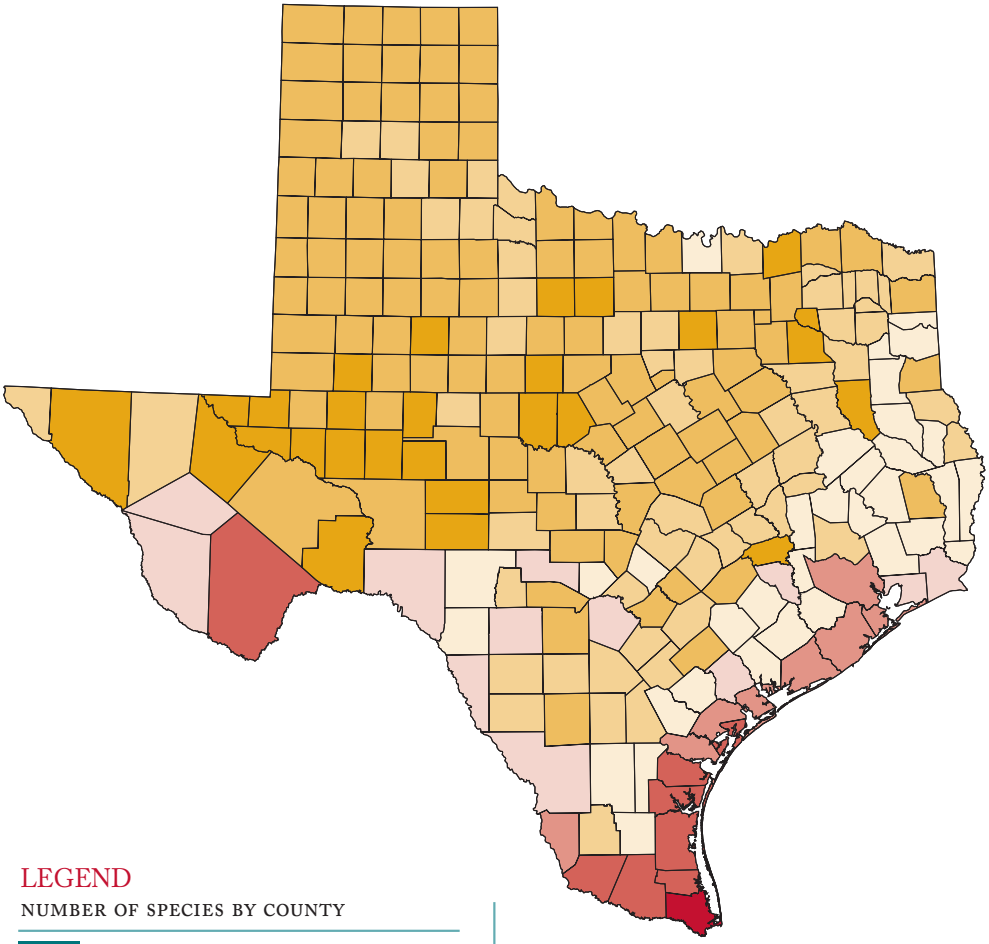
NATURAL REGIONS OF TEXAS

- BLACKLAND PRAIRIE
- COASTAL SAND PLAINS
- EDWARDS PLATEAU
- GULF COAST PRAIRIES & MARSHES
- HIGH PLAINS
- LLANO UPLIFT
- OAK WOODS & PRAIRIES
- PINEYWOODS
- ROLLING PLAINS
- SOUTH TEXAS BRUSH COUNTRY
- TRANS-PECOS

BASE MAP: 1978. PRESERVING TEXAS' NATURAL HERITAGE. LYNDON B. JOHNSON SCHOOL OF PUBLIC AFFAIRS. LBJ SPA RRRR: 3. AUSTIN, TEXAS.

Map 12

THREATENED AND ENDANGERED SPECIES



LEGEND

NUMBER OF SPECIES BY COUNTY

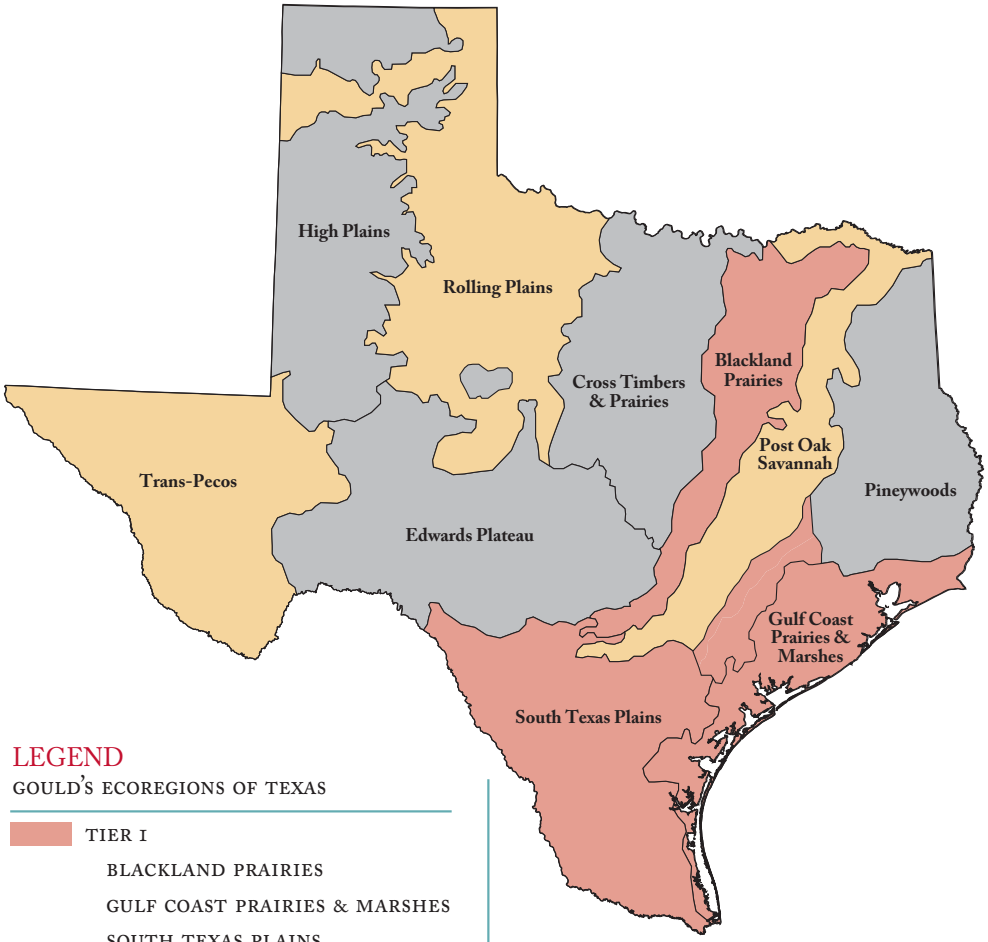
- 2 – 6
- 7 – 8
- 9 – 11
- 12 – 14
- 15 – 19
- 20 – 27
- 28 – 35
- 36 – 43

DATA FROM:

TPWD ENDANGERED RESOURCES PROGRAM. VERTEBRATE STATE THREATENED AND ENDANGERED SPECIES AND PLANT FEDERALLY LISTED THREATENED AND ENDANGERED SPECIES SUMMED FOR EACH COUNTY.

Map 13

FINAL PRIORITY FOR TPWD EFFORTS



LEGEND

GOULD'S ECOREGIONS OF TEXAS

TIER 1
- BLACKLAND PRAIRIES
- GULF COAST PRAIRIES & MARSHES
- SOUTH TEXAS PLAINS

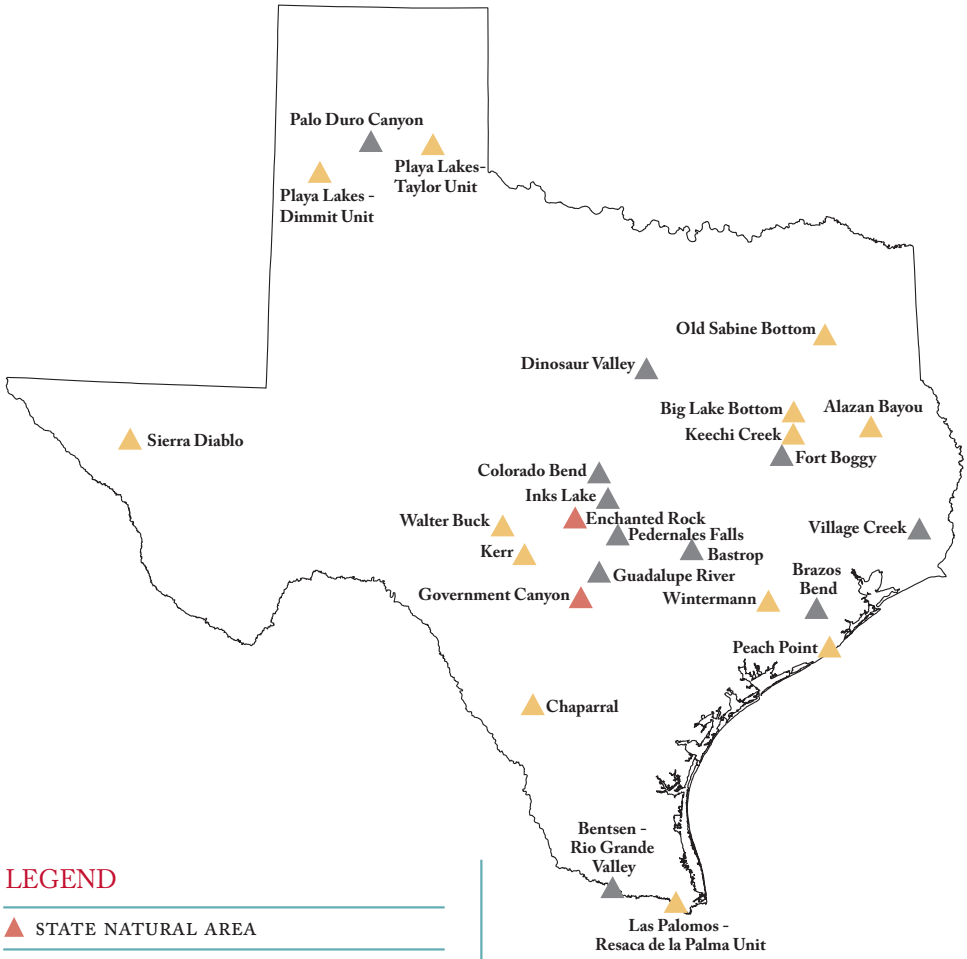
TIER 2
- CROSS TIMBERS & PRAIRIES
- EDWARDS PLATEAU
- HIGH PLAINS
- PINEYWOODS

TIER 3
- POST OAK SAVANNAH
- ROLLING PLAINS
- TRANS-PECOS

BASE MAP: GOULD, F.W. 1975. TEXAS PLANTS – A CHECKLIST AND ECOLOGICAL SUMMARY. TEXAS AGRICULTURAL EXPERIMENT STATION, PUBLICATION 585.

Map 14

PRIORITY PARKS & WMAs FOR EXPANSION

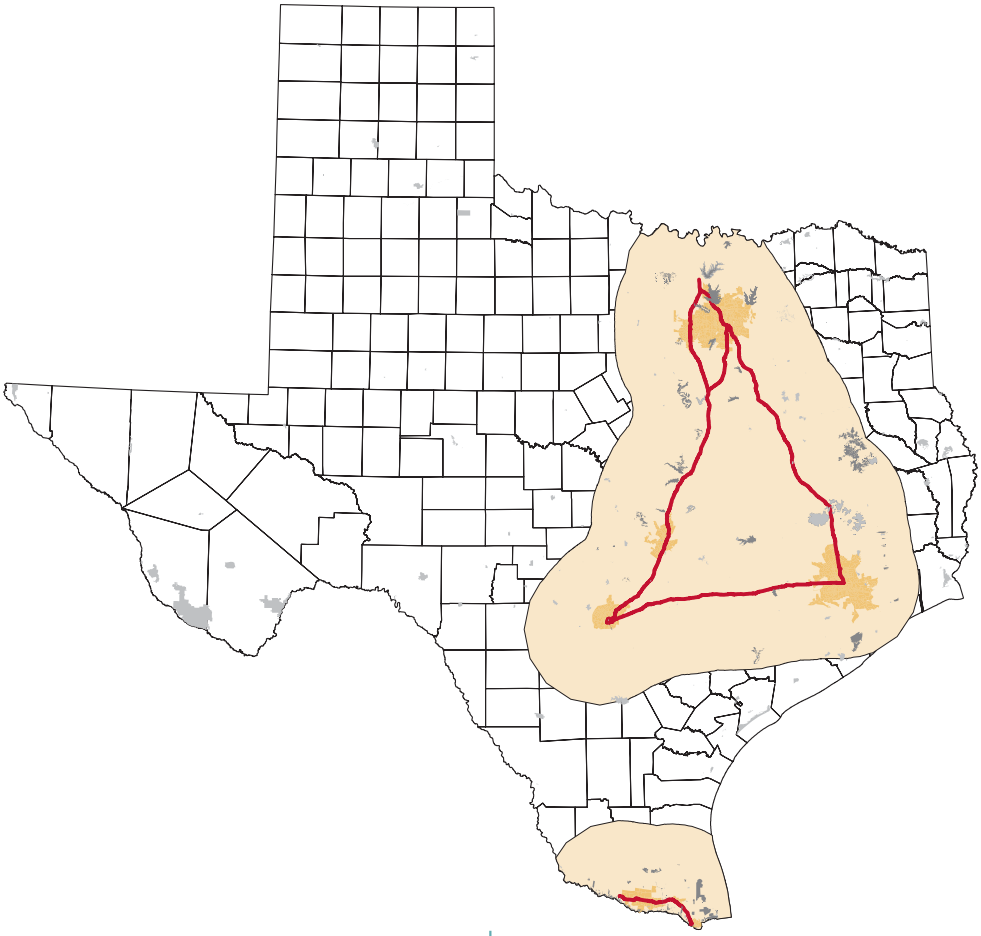


LEGEND

- STATE NATURAL AREA
- STATE PARK
- WILDLIFE MANAGEMENT AREA

Map 15

RECREATION LANDS WITHIN 60 MILES OF MAJOR URBAN CORRIDORS



LEGEND

- TPWD LANDS
- FEDERAL LANDS
- MAJOR CORRIDORS
- URBAN AREAS
- 60 MILE BUFFER ON HIGHWAYS

THE SHADED AREA INCLUDES:

26.88% OF TPWD ACRES
75% OF TEXAS POPULATION

24.25% OF COMBINED FEDERAL AND TPWD ACRES
75% OF TEXAS POPULATION

DATA FROM:
TPWD'S 2002 LAND AND WATER RESOURCES INVENTORY.

Map 16

SERVICE DRIVE FROM STEPHEN F. AUSTIN STATE PARK

LEGEND

- URBAN AREAS
- 90 MINUTE BUFFER
- MAJOR ROADS

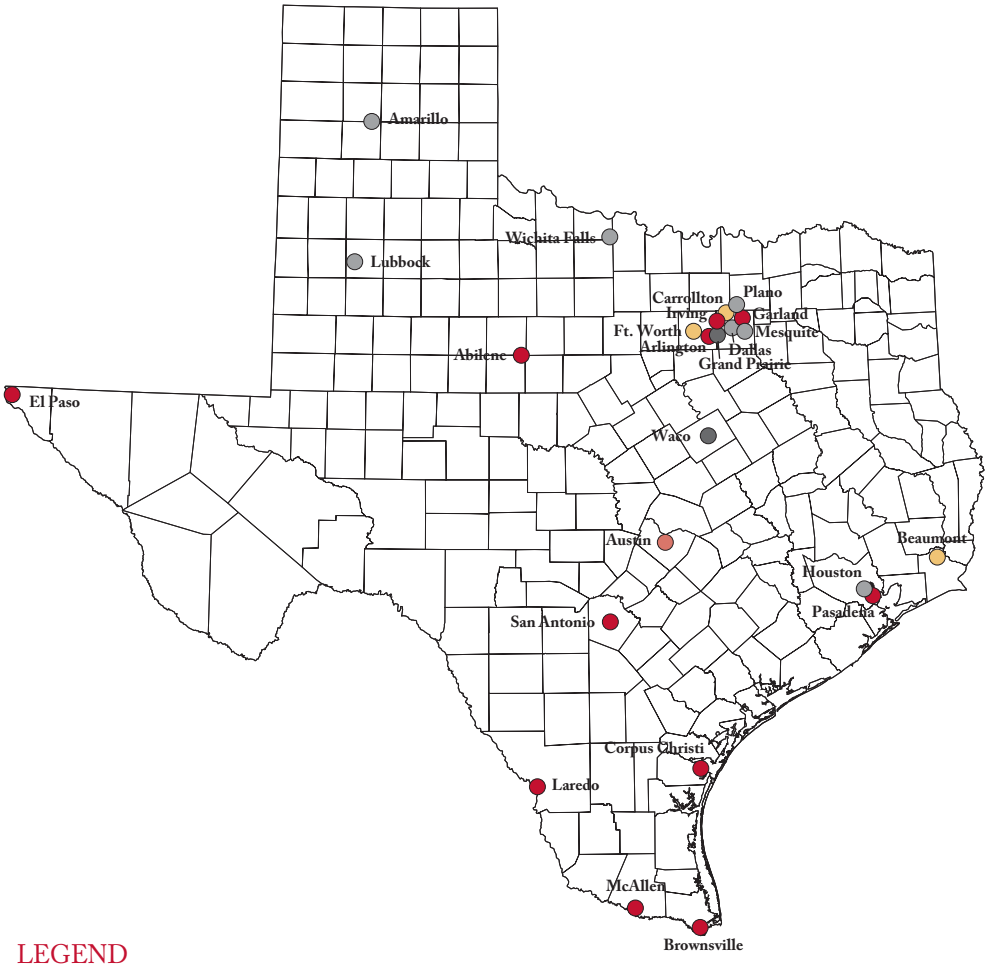
THE SHADED AREA INCLUDES A 90 MINUTE DRIVE TIME SERVICE AREA FROM STEPHEN F. AUSTIN STATE PARK.

DATA FROM:

TPWD'S 2002 LAND AND WATER RESOURCES INVENTORY.

Map 17

LOCAL PARK ACRES — CITIES >100,000



LEGEND

CITY PARK AREAS PER 1,000 PERSONS

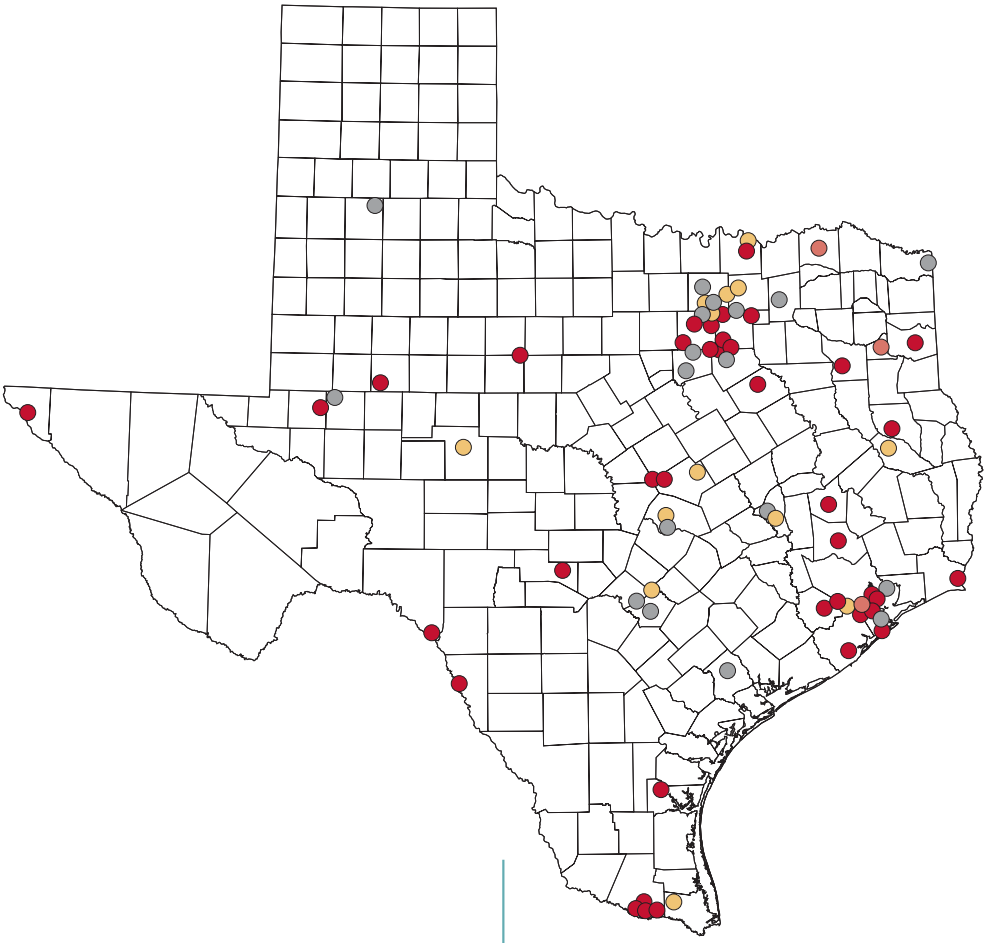
- 0.1 – 10
- 10.01 – 20
- 20.01 – 30
- 30.01 – 40
- 40.01 – 50

MAP PROJECTION FROM:

LAMBERT CONFORMAL CORSIC. METERS, NAD83 PARK ACREAGE LAND DATA ACQUIRED FROM 2000-2002 MAP DATE: 3 JUNE 2002

Map 18

LOCAL PARK AREAS — CITIES 20,000–100,000



LEGEND

CITY PARK AREAS PER 1,000 PERSONS

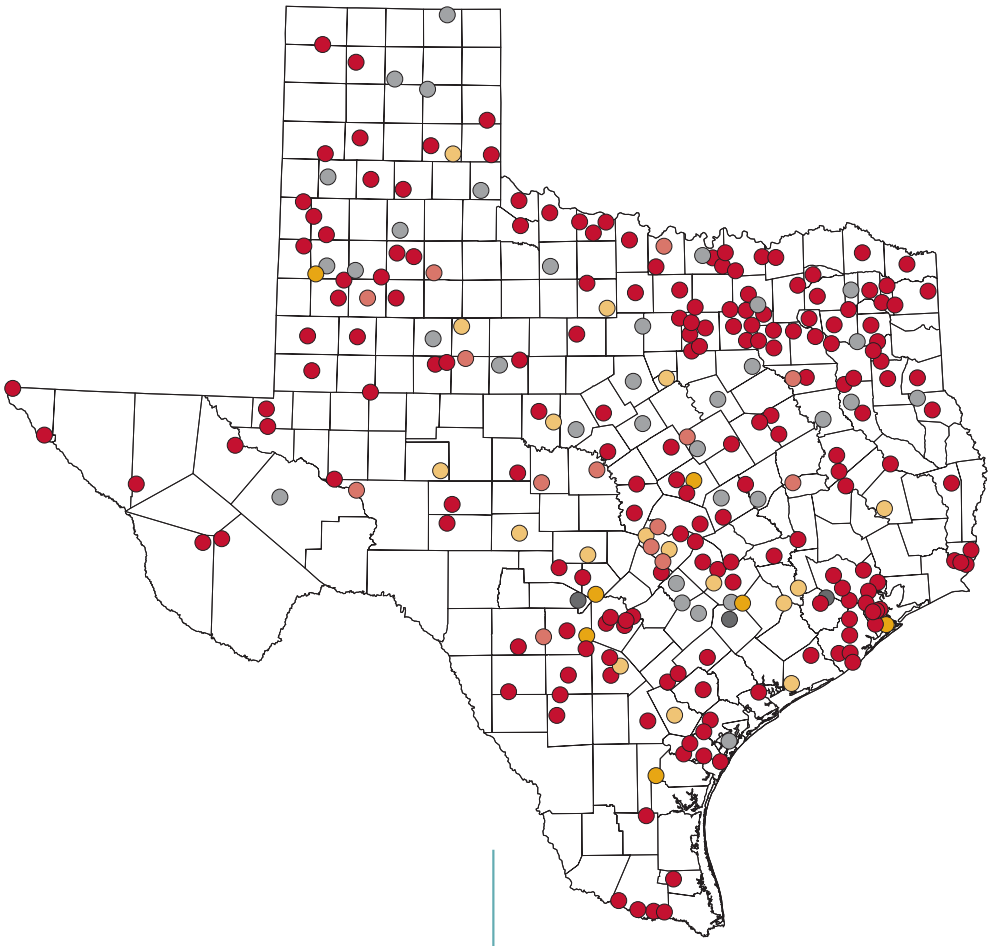
- 0.1 – 10
- 10.01 – 20
- 20.01 – 30
- 30.01 – 40

MAP PROJECTION FROM:

LAMBERT CONFORMAL CORSIC. METERS, NAD83 PARK ACREAGE LAND DATA ACQUIRED FROM 2000-2002 MAP DATE: 3 JUNE 2002

Map 19

LOCAL PARK ACRES — CITIES <20,000



LEGEND

CITY PARK AREAS PER 1,000 PERSONS

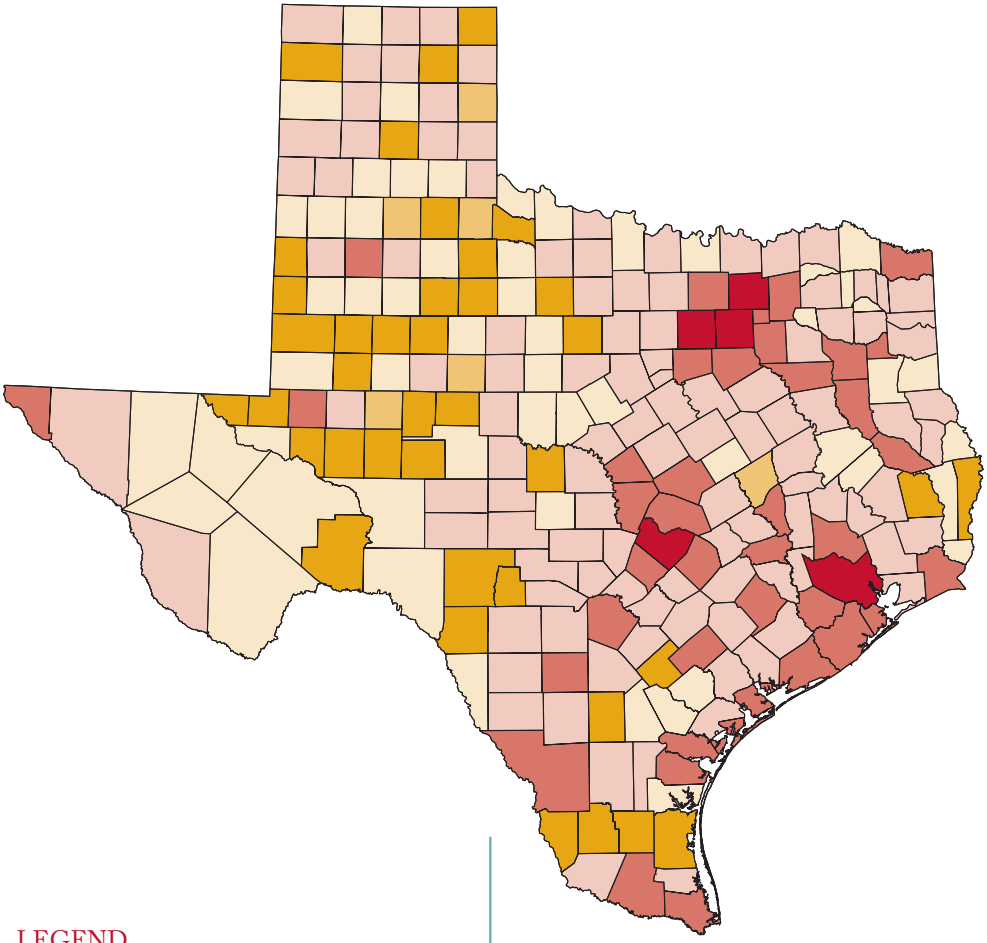
- 0.1 – 10
- 10.01 – 30
- 30.01 – 50
- 50.01 – 100
- 100.01 – 200
- 200.01 – 700

MAP PROJECTION FROM:

LAMBERT CONFORMAL CORSIC. METERS, NAD83 PARK ACREAGE LAND DATA ACQUIRED FROM 2000-2002 MAP DATE: 3 JUNE 2002

Map 20

TPWD LOCAL PARKS GRANTS DOLLARS PER COUNTY



LEGEND

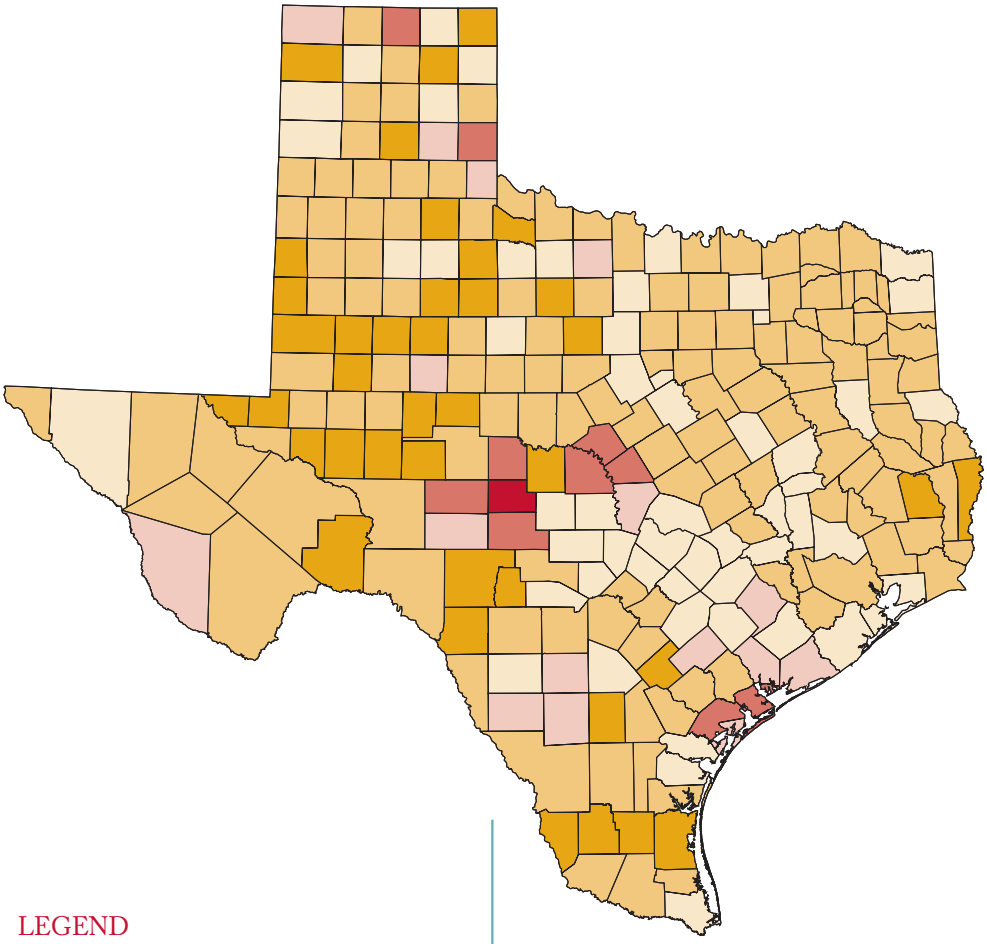
- $0.00
- $100.00 – $1,000.00
- $1,000.01 – $100,000.00
- $100,000.01 – $1,000,000.00
- $1,000,000.01 – $10,000,000.00
- $10,000,000.01 – $30,000,000.00

DATA FROM:

TPWD'S LOCAL PARK GRANT DATABASE.

Map 21

TPWD LOCAL PARKS GRANTS DOLLARS PER CAPITA



LEGEND

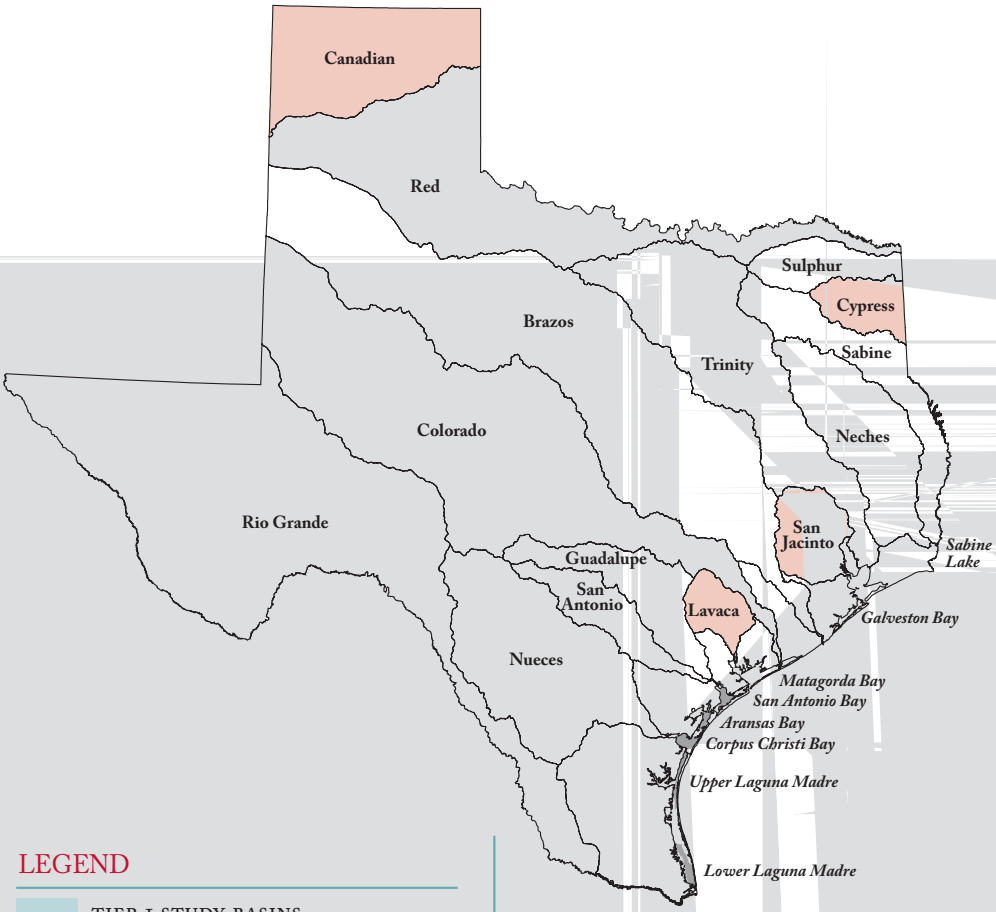
- $0.00
- $0.01 – $20.00
- $20.01 – $50.00
- $50.01 – $100.00
- $100.01 – $150.00
- $300.00 – $350.00

DATA FROM:

TPWD'S LOCAL PARK GRANT DATABASE.

Map 22

RIVER BASINS, MAJOR BAYS & ESTUARIES

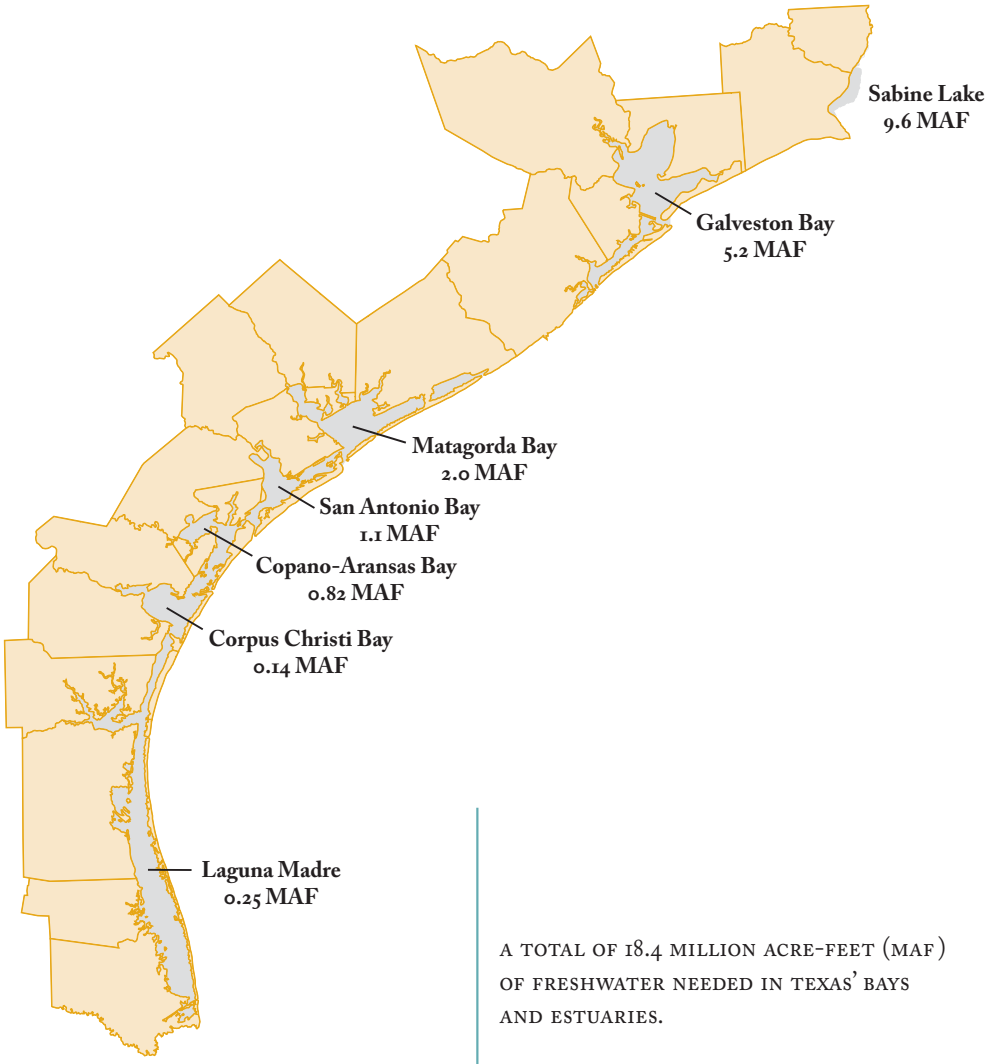


LEGEND

- TIER 1 STUDY BASINS
- TIER 2 STUDY BASINS
- TIER 3 STUDY BASINS
- MAJOR BAYS

Map 23

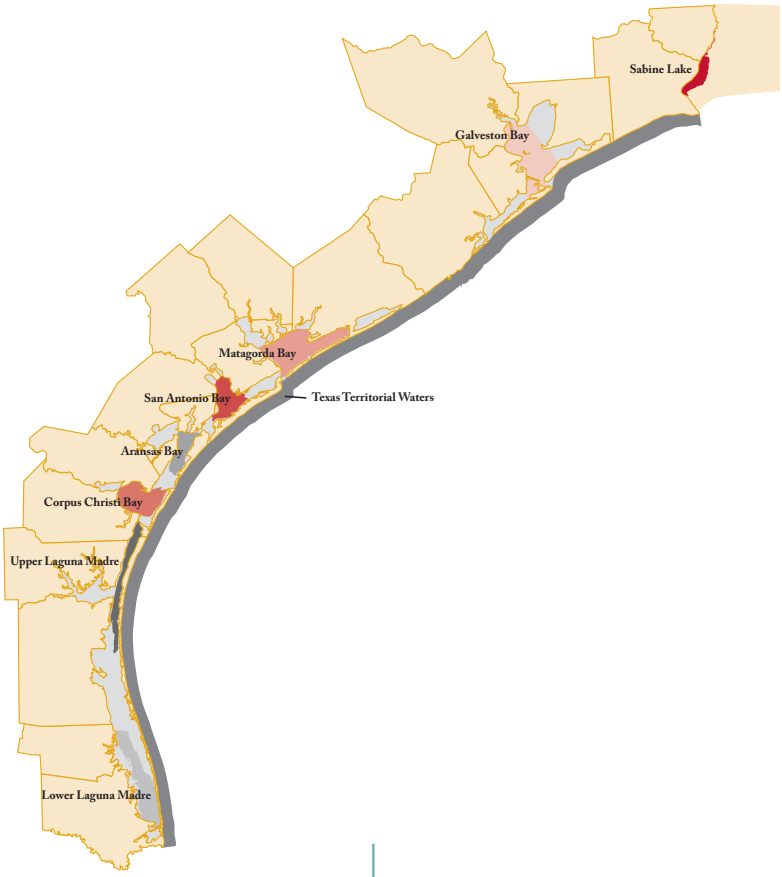
FRESHWATER INFLOW NEEDS



A TOTAL OF 18.4 MILLION ACRE-FEET (MAF) OF FRESHWATER NEEDED IN TEXAS' BAYS AND ESTUARIES.

Map 24

COASTAL WATERS PRIORITIES



LEGEND

HIGH PRIORITY SYSTEMS

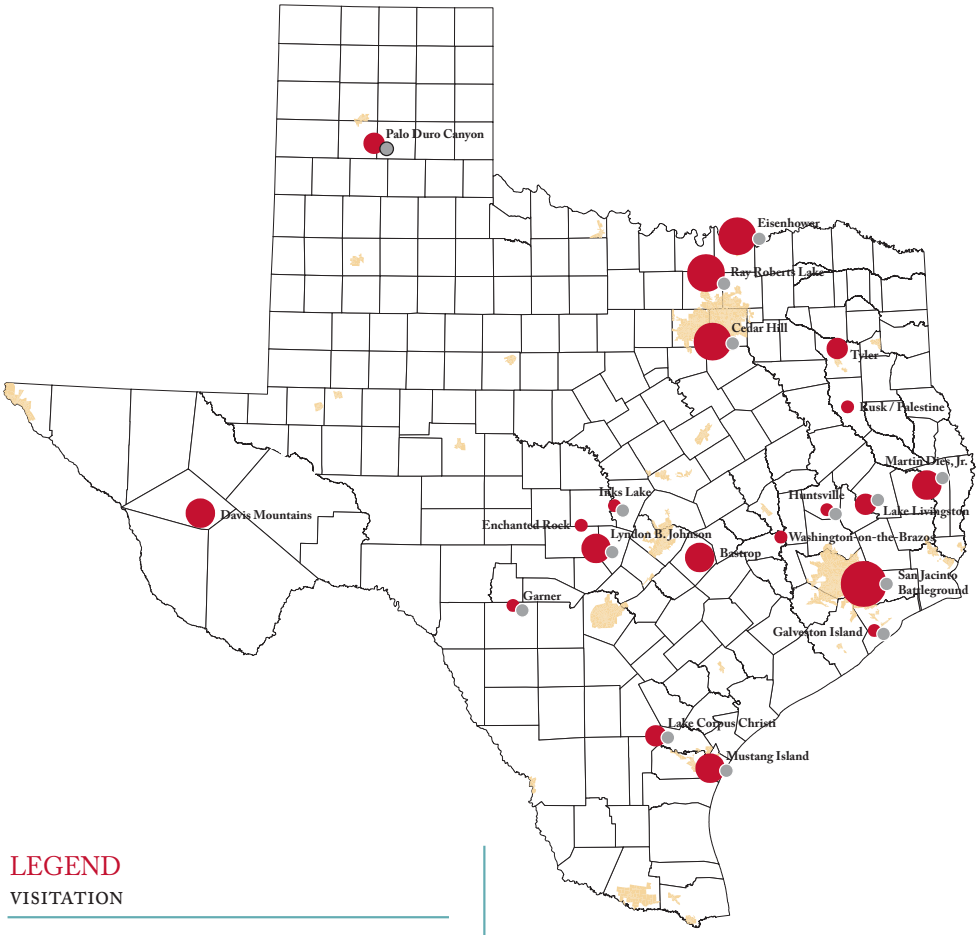
- 1
- 2
- 3
- 4
- 5

PRIORITY SYSTEMS

- 1
- 2
- 3
- 4

Map 25

MOST VISITED TPWD PROPERTIES (2001)



LEGEND

VISITATION

- 217747 – 298737
- 298738 – 396629
- 396630 – 544566
- 544567 – 722941
- 722942 – 1197798
- MAJOR WATER FEATURE
- MAJOR CITIES

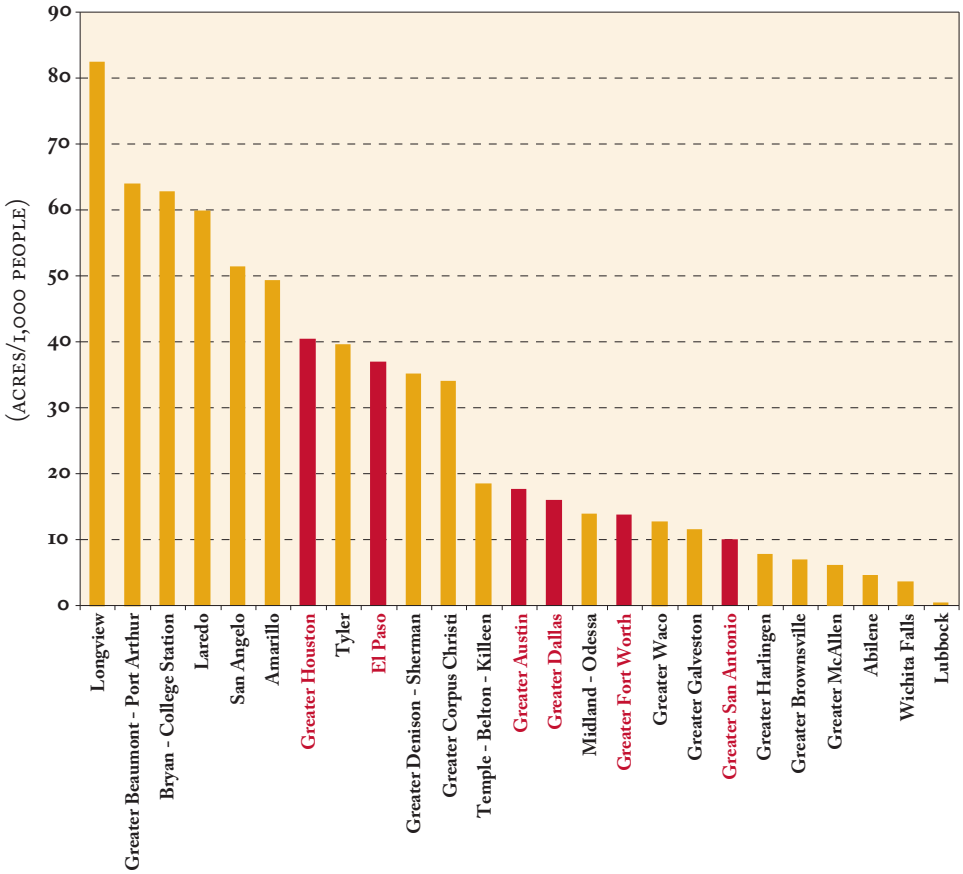
DATA FROM:

TPWD'S 2002 LAND AND WATER RESOURCES INVENTORY.

Graph 1

TPWD RECREATION AND CONSERVATION LANDS

WITHIN 90 MINUTES OF CITY AREAS

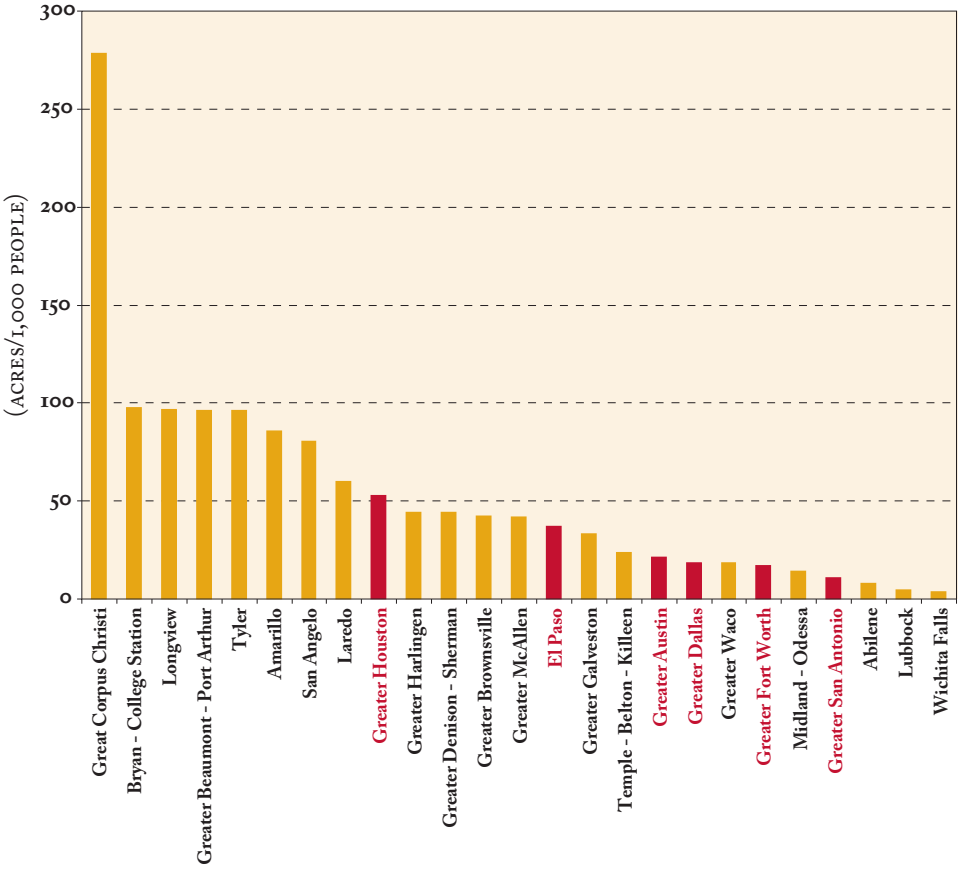


DATA FROM:
TPWD'S 2002 LAND AND WATER RESOURCES INVENTORY.

Graph 2

TPWD AND FEDERAL RECREATION AND CONSERVATION LANDS

WITHIN 90 MINUTES OF CITY AREAS

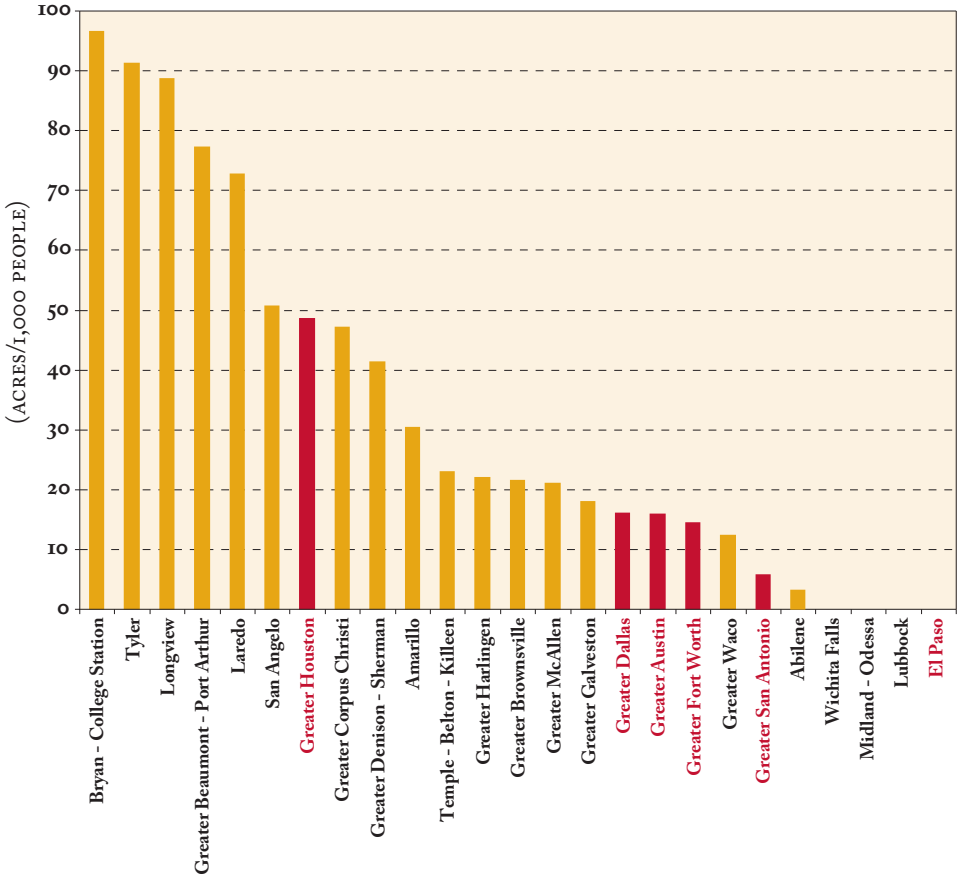


DATA FROM:
TPWD'S 2002 LAND AND WATER RESOURCES INVENTORY.

Graph 3

TPWD AND FEDERAL HUNTING ACREAGE

WITHIN 90 MINUTES OF CITY AREAS

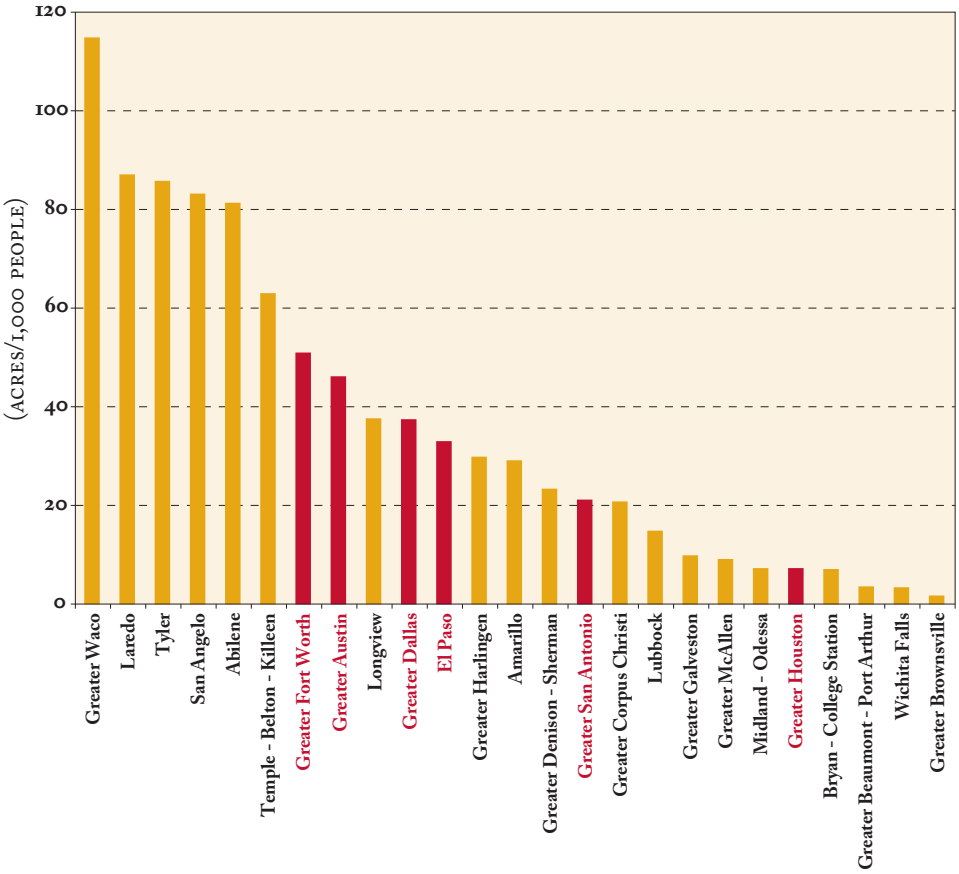


DATA FROM:
TPWD'S 2002 LAND AND WATER RESOURCES INVENTORY.

Graph 4

TPWD AND FEDERAL CAMPSITES

WITHIN 90 MINUTES OF CITY AREAS

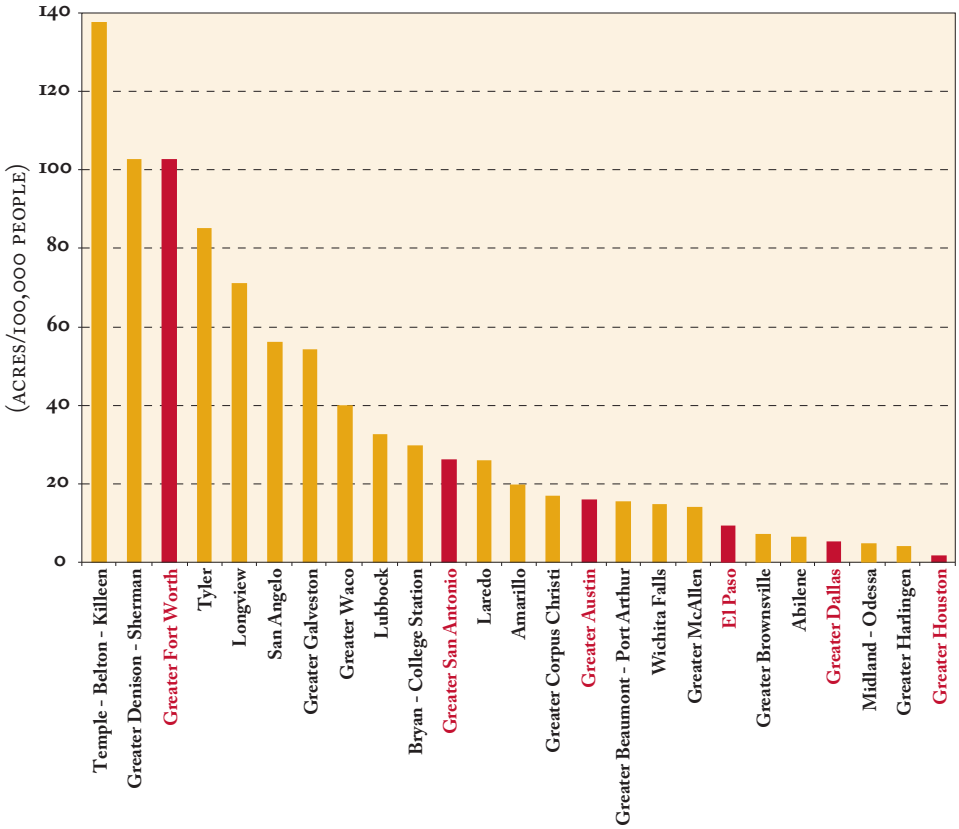


DATA FROM:
TPWD'S 2002 LAND AND WATER RESOURCES INVENTORY.

Graph 5

TPWD AND FEDERAL HIKING TRAIL MILES

WITHIN 90 MINUTES OF CITY AREAS

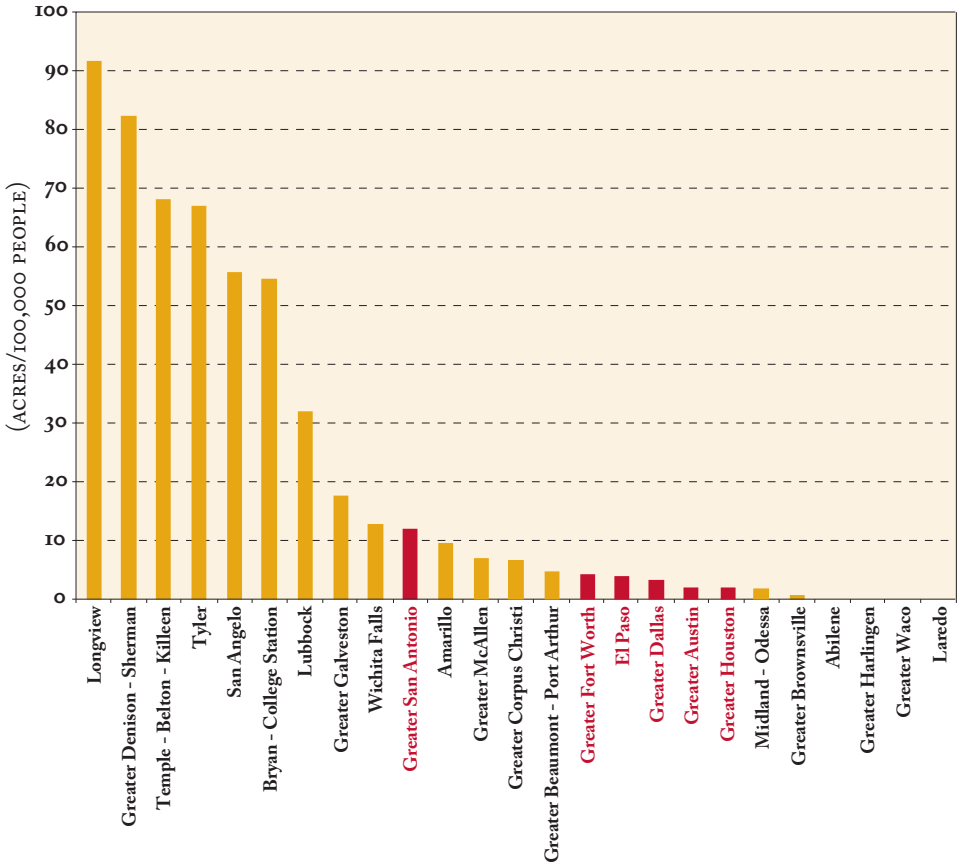


DATA FROM:
TPWD'S 2002 LAND AND WATER RESOURCES INVENTORY.

Graph 6

TPWD AND FEDERAL EQUESTRIAN TRAIL MILES

WITHIN 90 MINUTES OF CITY AREAS

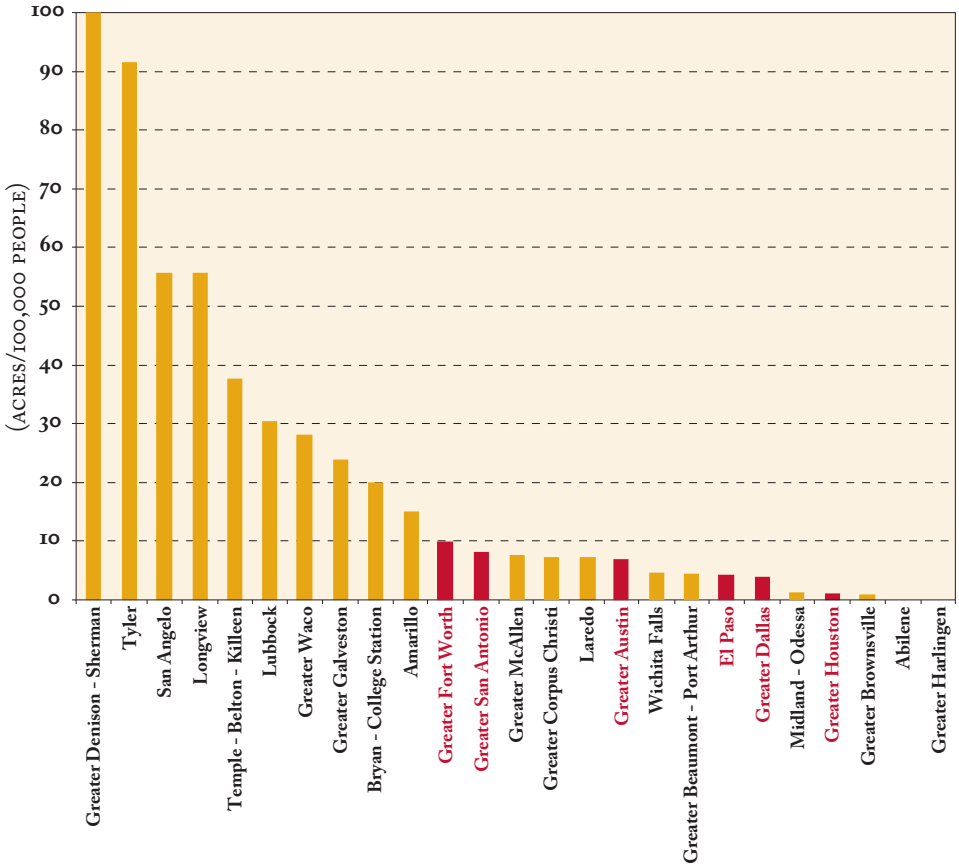


DATA FROM:
TPWD'S 2002 LAND AND WATER RESOURCES INVENTORY.

Graph 7

TPWD AND FEDERAL BIKING TRAIL MILES

WITHIN 90 MINUTES OF CITY AREAS



DATA FROM:
TPWD'S 2002 LAND AND WATER RESOURCES INVENTORY.

Table 1

PRIORITY ECOREGION DATA

	Conserved Status		Primary Level of Threat			Biological Value		Other Factors Considered				
Ecoregions	% Conserved Lands	% of Wildlife Managed Lands	% Projected Population Change **	Frag. Index ***	% Converted Lands ****	Vertebrate Diversity	# Vascular Plants	CRP as a % of Ecoregion	Commercial Timber as a % of Ecoregion	Road Miles by Natural Area	# G1/G2 Species	S1/S2 as a % of Total Vert. Diversity
Gulf Coast	5.69	8.93	15.2	3.74	29.09	449	2165	<1	<1	24,233	21	14
Piney Woods	6.72	2.81	12.28	3.26	4.21	347	1792	<1	17	48,899	15	15.3
Edwards Plateau	0.51	9.58	16.4	1.48	4.13	407	2397	<1	<1	35,610	25	15.7
Cross Timbers	1.73	5	17.49	1.23*	12.75	340	1302	<1	<1	31338*	15*	11.1*
Blackland Prairie	1.52	5.77	17.29	4.26	21.35	400	1552	<1	<1	49,004	7	7.5
High Plains	0.56	2.6	8.33	2.48	54.72	308	800	16.4	<1	49,676	3	12
South Texas	0.51	13.6	24.35	1.65	12.19	459	1510	<1	<1	30,320	39	13.9
Post Oak Savannah	1.13	11.18	10.39	1.23*	6.78	386	1579	<1	<1	31338*	15*	11.1*
Rolling Plains	0.49	6.51	5.03	2.38	26.25	339	1126	46	<1	57,209	4	11.5
Trans-Pecos	7.56	8.74	16.77	0.81	1.4	386	2188	<1	<1	15,482	120	18.9

* Indicates value for Post Oak Savannah and Cross Timbers
** TPWD estimates from Texas State Demographer data
*** TPWD estimates from Texas Agricultural Extension Service data
**** TPWD estimates from National Landcover Dataset, USGS, 1992

Table 2

STATE PARK AND NATURAL AREA VISITATION (2001)

Rank	State Park	Visitation
1	Eisenhower SP	722,941
2	Cedar Hill SP	674,327
3	Mustang Island SP	515,183
4	Davis Mountains SP	512,327
5	Bastrop SP	448,899
6	Martin Dies Jr. SP	440,463
7	Lake Corpus Christi SP	396,629
8	Palo Duro Canyon SP	387,056
9	Ray Roberts Lake SP - Isle Du Bois	359,735
10	Tyler SP	355,784
11	Lake Livingston SP	322,726
12	Inks Lake SP	298,737
13	Enchanted Rock SNA	290,522
14	Huntsville SP	268,039
15	Ray Roberts Lake SP - Johnson	244,379
16	Garner SP	244,213
17	Rusk / Palestine SP	238,680
18	Galveston Island SP	217,747
19	Guadalupe River SP	216,539
20	Martin Creek Lake SP	197,976
21	Choke Canyon SP - Calliham	194,935
22	Goose Island SP	192,567
23	Balmorhea SP	192,459
24	Lake Whitney SP	188,491
25	Lockhart SP	187,954
26	Brazos Bend SP	185,383
27	Cooper Lake SP - South Sulphur	184,430
28	Lake Colorado City SP	180,114
29	Kerrville - Schreiner SP	176,058
30	Pedernales Falls SP	171,206
31	Cleburne SP	168,799
32	McKinney Falls SP	168,610
33	Blanco SP	168,346
34	Fort Parker SP	166,953
35	Lake Brownwood SP	166,588
36	Palmetto SP	164,720
37	Dinosaur Valley SP	162,168
38	Choke Canyon SP - South Shore	150,296
39	Lake Texana SP	149,647
40	Lake Casa Blanca International SP	145,185
41	Falcon SP	143,390
42	Lake Somerville SP - Birch	139,558
43	Matagorda Island SP	132,924
44	Lake Arrowhead SP	124,693
45	Abilene SP	119,422
46	Caddo Lake SP	119,360
47	Lost Maples SNA	118,610
48	San Angelo SP	117,856
49	Cooper Lake SP - Doctors Creek	116,526
50	Caprock Canyons SP	115,272
51	Lake Bob Sandlin SP	111,583
52	Lake Mineral Wells SP and Trailway	106,615
53	Sheldon Lake SP	103,617
54	Bentsen-Rio Grande Valley SP	102,974
55	Daingerfield SP	102,613
56	Buescher SP	102,572
57	Lake Somerville SP - Nails	101,223
58	Fairfield Lake SP	99,097
59	Possum Kingdom SP	94,868
60	Mother Neff SP	94,095
61	Texas State RR SP / Rusk Depot	84,039
62	Hill Country SNA	82,041
63	Atlanta SP	76,814
64	Bonham SP	75,370
65	South Llano River SP	68,364
66	Village Creek SP	67,916
67	Purtis Creek SP	65,295
68	Meridian SP	63,304
69	Sea Rim SP	62,676
70	Lake Houston SP	59,807
71	Monahans Sandhills SP	56,464
72	Indian Lodge SP	47,588
73	Copper Breaks SP	41,122
74	Colorado Bend SP	37,783
75	Big Spring SP	34,097
76	Franklin Mountains SP / Wyler Tramway	22,344
77	Big Bend Ranch SP	10,890
78	Mission Tejas SP	10,687
79	Kickapoo Cavern SP	1,721
80	Devils River SNA	1,643
81	Caprock Canyons SP and Trailway	NA
82	Eagle Mountain Lake SP	NA
83	Fort Boggy SP	NA
84	John J. Stokes San Marcos River	NA
85	Lake Rita Blanca SP	NA
86	Lake Tawakoni SP	NA
87	Longhorn Cavern SP	NA
88	Ray Roberts Lake SP - Greenbelt Trailway	NA
89	Bright Leaf SNA	NA
90	Chinati Mountains SNA	NA
91	Devil's Sinkhole SNA	NA
92	Government Canyon SNA	NA
93	Honey Creek SNA	NA

TPWD LAND AND WATER RESOURCES INVENTORY, 2002.

Table 3

WILDLIFE MANAGEMENT AREA VISITATION (2001)

Rank	State Park	Estimated Visitation
1	Walter Buck	20,142
2	Old Tunnel	11,300
3	J.D. Murphree	6,500
4	Richland Creek	5,860
5	Aquilla	5,050
6	Caddo Grasslands	5,000
7	Gus Engeling	4,771
8	Chaparral	3,973
9	Cooper	3,727
10	Matador	2,683
11	Sam Houston NF	2,505
12	Old Sabine Bottom	2,500
13	Peach Point	2,500
14	Pat Mayse	2,339
15	White Oak Creek	2,180
16	Gene Howe	2,020
17	Las Palomas	2,000
18	Guadalupe Delta	1,500
19	Elephant Mountain	1,300
20	Tawakoni	1,200
21	Kerr	1,100
22	Granger	1,067
23	Black Gap	1,025
24	Mad Island	1,000
25	Ray Roberts	921
26	Lower Neches	875
27	The Nature Center	800
28	Tony Houseman	800
29	James E. Daughtrey	750
30	Moore Plantation	639
31	Candy Abshier	600
32	Keechi Creek	504
33	Somerville	500
34	Bannister	493
35	Angelina-Neches/Dam B	405
36	Alabama Creek	383
37	Caddo Lake	335
38	Alazan Bayou	264
39	M. O. Neasloney	250
40	Big Lake Bottom	231
41	Mason Mountain	221
42	North Toledo Bend	203
43	Nannie M. Stringfellow	100
44	Cedar Creek Islands	50
45	Redhead Pond	50
46	Sierra Diablo	50
47	D. R. Wintermann	50
48	Playa Lakes	40
49	Atkinson Island	NA
50	Matagorda Island	NA
51	McGilvray-Muse	NA
52	Welder Flats	NA

TPWD LAND AND WATER RESOURCES INVENTORY, 2002.

Table 4

PUBLIC HUNTING ACREAGE

90 MINUTE DRIVE TIME SERVICE AREA

City Unit	City Population	TPWD & Federal Hunting Acres per 1000	TPWD Hunting Acres per 1000	Federal Hunting Acres per 1000
Greater Houston	3,899,400	48.5	38.4	10.1
Greater Dallas	3,094,075	15.9	13.7	2.2
Greater Fort Worth	1,531,517	14.4	11.5	2.9
Greater San Antonio	1,347,728	5.6	5.4	0.2
Greater Austin	951,234	15.8	12.3	3.5
El Paso	625,539	0.0	0.0	0.0
Greater McAllen	487,388	20.9	3.7	17.2
Greater Corpus Christi	278,017	47.0	2.9	44.1
Greater Beaumont - Port Arthur	267,431	77.2	61.5	15.7
Lubbock	216,488	0.0	0.0	0.0
Temple - Belton - Killeen	194,353	22.9	17.9	5.0
Midland - Odessa	188,031	0.0	0.0	0.0
Amarillo	181,989	30.3	0.0	30.3
Laredo	168,032	72.7	72.7	0.0
Greater Brownsville	163,975	21.4	3.7	17.7
Greater Waco	158,343	12.3	6.7	5.6
Bryan - College Station	138,166	96.4	61.5	34.9
Greater Galveston	121,647	17.9	9.9	8.0
Abilene	117,415	3.0	0.0	3.0
Wichita Falls	116,802	0.0	0.0	0.0
Tyler	103,377	91.1	34.6	56.5
Greater Harlingen	100,310	21.9	3.7	18.2
San Angelo	90,041	50.5	50.5	0.0
Longview	89,254	88.5	77.2	11.3
Greater Denison - Sherman	67,669	41.3	32.6	8.7

TPWD LAND AND WATER RESOURCES INVENTORY, 2002.

Table 5

CAMPSITES

90 MINUTE DRIVE TIME SERVICE AREA

City Unit	City Population	TPWD & Federal Campsites per 100,000	TPWD Campsites per 100,000	Federal Campsites per 100,000
Greater Houston	3,899,400	7.0	4.5	2.5
Greater Dallas	3,094,075	37.3	8.7	28.6
Greater Fort Worth	1,531,517	50.7	5.8	44.9
Greater San Antonio	1,347,728	20.9	6.5	14.4
Greater Austin	951,234	46.0	2.6	43.4
El Paso	625,539	32.7	32.7	0.0
Greater McAllen	487,388	8.9	8.9	0.0
Greater Corpus Christi	278,017	20.6	11.5	9.0
Greater Beaumont - Port Arthur	267,431	3.4	3.4	0.0
Lubbock	216,488	14.6	14.3	0.3
Temple - Belton - Killeen	194,353	62.8	16.9	45.9
Midland - Odessa	188,031	7.1	7.1	0.0
Amarillo	181,989	28.8	28.8	0.0
Laredo	168,032	86.8	86.8	0.0
Greater Brownsville	163,975	1.5	1.5	0.0
Greater Waco	158,343	114.6	10.9	103.6
Bryan - College Station	138,166	6.9	4.5	2.4
Greater Galveston	121,647	9.7	9.7	0.0
Abilene	117,415	81.1	47.2	33.9
Wichita Falls	116,802	3.1	3.1	0.0
Tyler	103,377	85.5	44.0	41.5
Greater Harlingen	100,310	29.6	29.6	0.0
San Angelo	90,041	83.0	67.8	15.2
Longview	89,254	37.4	2.6	34.7
Greater Dennison - Sherman	67,669	23.2	6.2	17.0

TPWD LAND AND WATER RESOURCES INVENTORY, 2002.

Table 6

HIKING TRAIL MILES

90 MINUTE DRIVE TIME SERVICE AREA

City Unit	City Population	TPWD & Federal Hiking Trail Miles per 100,000	TPWD Hiking Trail Miles per 100,000	Federal Hiking Trail Miles per 100,000
Greater Houston	3,899,400	1.51	1.51	0.00
Greater Dallas	3,094,075	5.02	3.92	1.10
Greater Fort Worth	1,531,517	102.38	5.40	96.98
Greater San Antonio	1,354,003	25.89	6.34	19.55
Greater Austin	951,234	15.65	15.33	0.32
El Paso	625,539	9.14	4.72	4.42
Greater McAllen	487,388	13.74	1.40	12.34
Greater Corpus Christi	278,017	16.55	1.91	14.64
Greater Beaumont - Port Arthur	267,431	15.32	12.08	3.24
Lubbock	216,488	32.32	29.70	2.62
Temple - Belton - Killeen	194,353	137.50	38.49	99.01
Midland - Odessa	188,031	4.63	2.02	2.61
Amarillo	181,989	19.49	13.74	5.75
Laredo	168,032	25.72	1.79	23.93
Greater Brownsville	163,975	6.81	2.32	4.49
Greater Waco	158,343	39.78	34.86	4.92
Bryan - College Station	138,166	29.41	28.30	1.11
Greater Galveston	121,647	53.86	32.39	21.47
Abilene	117,415	6.22	6.22	0.00
Wichita Falls	116,802	14.47	14.47	0.00
Tyler	103,377	84.81	84.35	0.46
Greater Harlingen	100,310	3.79	3.79	0.00
San Angelo	90,041	55.86	55.86	0.00
Longview	89,254	70.72	47.50	23.22
Greater Denison - Sherman	67,669	102.41	102.41	0.00

TPWD LAND AND WATER RESOURCES INVENTORY, 2002.

Table 7

EQUESTRIAN TRAIL MILES

90 MINUTE DRIVE TIME SERVICE AREA

City Unit	City Population	TPWD & Fed. Equestrian Trail Miles per 100,000	TPWD Equestrian Trail Miles per 100,000	Federal Equestrian Trail Miles per 100,000
Greater Houston	3,899,400	1.80	1.80	0.00
Greater Dallas	3,094,075	3.10	3.10	0.00
Greater Fort Worth	1,531,517	4.11	4.11	0.00
Greater San Antonio	1,354,003	11.73	5.56	6.17
Greater Austin	951,234	1.82	1.82	0.00
El Paso	625,539	3.73	3.52	0.21
Greater McAllen	487,388	6.73	0.00	6.73
Greater Corpus Christi	278,017	6.47	6.47	0.00
Greater Beaumont - Port Arthur	267,431	4.49	4.49	0.00
Lubbock	216,488	31.83	29.70	2.13
Temple – Belton - Killeen	194,353	67.98	0.00	67.98
Midland - Odessa	188,031	1.63	0.00	1.63
Amarillo	181,989	9.34	9.34	0.00
Laredo	168,032	0.00	0.00	0.00
Greater Brownsville	163,975	0.46	0.00	0.46
Greater Waco	158,343	0.00	0.00	0.00
Bryan - College Station	138,166	54.28	54.28	0.00
Greater Galveston	121,647	17.44	9.86	7.58
Abilene	117,415	0.00	0.00	0.00
Wichita Falls	116,802	12.59	12.59	0.00
Tyler	103,377	66.75	66.75	0.00
Greater Harlingen	100,310	0.00	0.00	0.00
San Angelo	90,041	55.53	55.53	0.00
Longview	89,254	91.45	39.21	52.24
Greater Denison - Sherman	67,669	82.13	82.02	0.11

TPWD LAND AND WATER RESOURCES INVENTORY, 2002.

Table 8

BIKING TRAIL MILES

90 MINUTE DRIVE TIME SERVICE AREA

City Unit	City Population	TPWD & Federal Biking Trail Miles per 100,000	TPWD Biking Trail Miles per 100,000	Federal Biking Trail Miles per 100,000
Greater Houston	3,899,400	0.84	0.84	0.00
Greater Dallas	3,094,075	3.67	3.67	0.00
Greater Fort Worth	1,531,517	9.64	4.57	5.07
Greater San Antonio	1,354,003	7.98	5.41	2.57
Greater Austin	951,234	6.75	6.75	0.00
El Paso	625,539	4.05	3.52	0.53
Greater McAllen	487,388	7.35	0.62	6.73
Greater Corpus Christi	278,017	7.15	2.88	4.27
Greater Beaumont - Port Arthur	267,431	4.23	4.23	0.00
Lubbock	216,488	30.25	29.70	0.55
Centro - Plex	194,353	37.43	24.13	13.30
Midland - Odessa	188,031	1.11	0.00	1.11
Amarillo	181,989	14.84	14.84	0.00
Laredo	168,032	6.98	0.00	6.98
Greater Brownsville	163,975	0.64	0.00	0.64
Greater Waco	158,343	27.96	26.52	1.44
Bryan - College Station	138,166	19.77	18.96	0.81
Greater Galveston	121,647	23.71	20.55	3.16
Abilene	117,415	0.00	0.00	0.00
Wichita Falls	116,802	4.45	4.45	0.00
Tyler	103,377	91.41	91.41	0.00
Greater Harlingen	100,310	0.00	0.00	0.00
San Angelo	90,041	55.53	55.53	0.00
Longview	89,254	55.46	55.46	0.00
Greater Dennison - Sherman	67,669	99.86	99.75	0.11

TPWD LAND AND WATER RESOURCES INVENTORY, 2002.

Table 9

TPWD SITES (5,000-ACRE)

90 MINUTE DRIVE TIME SERVICE AREA

City Unit	City Population	Number of Properties
Greater Houston	3,899,400	3
Greater Dallas	3,094,075	5
Greater Fort Worth	1,531,517	2
Greater San Antonio	1,354,003	3
Greater Austin	951,234	3
El Paso	625,539	1
Greater McAllen	487,388	0
Greater Corpus Christi	278,017	2
Greater Beaumont - Port Arthur	267,431	1
Lubbock	216,488	0
Temple – Belton - Killeen	194,353	3
Midland - Odessa	188,031	0
Amarillo	181,989	1
Laredo	168,032	1
Greater Brownsville	163,975	0
Greater Waco	158,343	2
Bryan - College Station	138,166	1
Greater Galveston	121,647	1
Abilene	117,415	0
Wichita Falls	116,802	0
Tyler	103,377	3
Greater Harlingen	100,310	0
San Angelo	90,041	1
Longview	89,254	3
Greater Denison - Sherman	67,669	3

TPWD LAND AND WATER RESOURCES INVENTORY, 2002.

Table 10

LOCAL PARK ACRES PER CITY

City Unit	Acres per 1,000 Population	City Population	Number of Parks	Total City Park Acres
Houston	10.30	1,953,631	478	20,107.83
Dallas	19.70	1,188,580	450	23,378.63
San Antonio	7.90	1,144,646	208	9,064.05
Austin	37.20	656,562	266	24,408.10
El Paso	5.10	563,662	144	2,891.98
Fort Worth	21.10	534,694	230	11,302.91
Arlington	10.00	332,969	108	3,328.46
Corpus Christi	8.00	277,454	127	2,210.07
Plano	15.80	222,030	93	3,505.86
Garland	10.00	215,768	99	2,153.10
Lubbock	17.80	199,564	93	3,546.13
Irving	9.00	191,615	49	1,733.15
Laredo	0.90	176,576	79	164.15
Amarillo	15.00	173,627	68	2,601.72
Pasadena	1.20	141,674	19	172.37
Brownsville	7.00	139,722	25	984.94
Grand Prairie	43.10	127,427	59	5,494.94
Mesquite	15.30	124,523	95	1,907.99
Abilene	5.80	115,930	15	675.81
Beaumont	20.30	113,866	34	2,307.38
Waco	49.10	113,726	56	5,586.99
Carrollton	23.10	109,576	65	2,532.38
McAllen	1.20	106,414	16	129.42
Wichita Falls	18.30	104,197	49	1,902.13
Midland	12.80	94,996	49	1,219.34
Richardson	13.10	91,802	30	1,198.08
Odessa	7.30	90,943	47	668.22
San Angelo	20.30	88,439	126	1,796.44
Killeen	5.60	86,911	16	489.56
Tyler	6.70	83,650	41	557.92
Denton	11.70	80,537	33	941.45
Lewisville	11.70	77,737	46	910.76
Longview	31.50	73,344	82	2,308.37
College Station	20.10	67,890	46	1,365.18
Baytown	15.90	66,430	46	1,054.47

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Table 10 continued

LOCAL PARK ACRES PER CITY

City Unit	Acres per 1,000 Population	City Population	Number of Parks	Total City Park Acres
Bryan	10.50	65,660	34	687.06
Sugar Land	3.10	63,328	18	198.94
Round Rock	17.70	61,136	62	1,081.05
Victoria	11.50	60,603	15	699.48
Port Arthur	7.00	57,755	31	406.31
Harlingen	20.90	57,564	25	1,203.19
Galveston	4.10	57,247	9	233.95
North Richland Hills	19.70	55,635	48	1,098.76
Temple	24.50	54,514	80	1,336.77
McKinney	22.60	54,369	25	1,226.28
Missouri City	23.60	52,913	61	1,247.28
Flower Mound	11.40	50,702	63	578.42
Edinburg	4.90	48,465	14	235.97
Bedford	3.30	47,152	10	156.48
Pharr	0.20	46,660	3	7.38
Euless	9.40	46,005	16	430.29
League City	4.40	45,444	22	199.01
Mission	2.00	45,408	11	90.34
Rowlett	3.90	44,503	4	173.88
Allen	35.20	43,554	55	1,533.62
Grapevine	20.40	42,059	38	856.08
Texas City	12.90	41,521	58	534.88
Haltom City	4.70	39,018	9	183.14
DeSoto	11.50	37,646	56	431.67
Pearland	36.80	37,640	23	1,385.01
Conroe	1.90	36,811	4	69.02
New Braunfels	11.40	36,494	16	416.15
Hurst	13.60	36,273	32	493.67
Duncanville	6.20	36,081	13	225.18
Coppell	14.10	35,958	17	508.30
Sherman	8.20	35,082	14	288.04
Huntsville	8.60	35,078	30	301.34
Texarkana	16.70	34,782	16	580.65
San Marcos	23.90	34,733	36	829.99
Del Rio	9.30	33,867	51	316.59

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Table 10 continued

LOCAL PARK ACRES PER CITY

City Unit	Acres per 1,000 Population	City Population	Number of Parks	Total City Park Acres
Frisco	28.30	33,714	34	953.28
Lufkin	25.00	32,709	24	816.85
Cedar Hill	8.90	32,093	16	284.05
La Porte	1.10	31,880	1	33.85
Nacogdoches	2.60	29,914	3	78.08
Copperas Cove	3.60	29,592	3	107.34
Friendswood	2.30	29,037	5	68.14
Deer Park	1.70	28,520	2	47.46
Georgetown	20.80	28,339	40	588.24
Mansfield	8.50	28,031	15	237.20
Farmers Branch	6.80	27,508	30	188.37
Socorro	0.10	27,152	1	2.98
Weslaco	2.90	26,935	4	77.27
Lake Jackson	6.00	26,386	3	158.61
San Juan	0.80	26,229	4	20.74
Cleburne	17.40	26,005	6	452.99
Paris	32.70	25,898	9	846.27
Lancaster	0.20	25,894	1	6.40
Kingsville	9.40	25,575	7	240.25
Big Spring	0.60	25,233	1	16.28
Corsicana	9.40	24,485	5	230.54
Rosenberg	2.60	24,043	4	63.31
Greenville	10.10	23,960	11	243.16
Marshall	5.30	23,935	7	125.66
San Benito	4.50	23,444	6	104.74
University Park	1.90	23,324	6	44.54
Denison	24.40	22,773	6	555.63
Eagle Pass	1.80	22,413	3	39.42
Plainview	15.20	22,336	16	339.53
Seguin	11.60	22,011	10	255.40
Watauga	4.80	21,908	8	106.08
Southlake	17.70	21,519	17	381.28
Waxahachie	10.30	21,426	14	221.63
Alvin	7.60	21,413	13	162.16
Burleson	14.40	20,976	7	302.09

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Table 10 continued

LOCAL PARK ACRES PER CITY

City Unit	Acres per 1,000 Population	City Population	Number of Parks	Total City Park Acres
Kerrville	7.90	20,425	7	160.41
Benbrook	0.90	20,208	2	18.99
Balch Springs	0.60	19,375	1	10.82
Alice	60.60	19,010	11	1,152.04
Brownwood	15.10	18,813	21	284.39
Schertz	3.00	18,694	4	55.17
Bay City	0.80	18,667	1	15.35
Orange	2.40	18,643	6	44.71
Angleton	1.40	18,130	1	25.00
Rockwall	0.90	17,976	2	15.33
Pampa	17.70	17,887	12	316.51
Palestine	12.60	17,598	8	222.40
Nederland	1.40	17,422	3	24.91
Harker Heights	1.30	17,308	3	21.99
Mineral Wells	12.40	16,946	3	209.69
Pflugerville	2.10	16,335	1	34.39
Ennis	14.40	16,045	9	231.18
South Houston	1.10	15,833	3	18.12
Groves	1.30	15,733	2	19.78
Bellaire	0.20	15,642	1	2.56
Gatesville	1.30	15,591	2	20.12
Gainesville	7.60	15,538	2	118.69
Wylie	11.00	15,132	1	167.06
Uvalde	2.40	14,929	3	35.87
Stephenville	11.20	14,921	1	167.75
Universal City	2.60	14,849	1	38.89
White Settlement	2.40	14,831	1	36.19
Portland	2.50	14,827	8	37.55
Donna	1.70	14,768	5	25.04
Belton	52.90	14,623	8	773.23
Hereford	3.20	14,597	4	47.29
Humble	0.80	14,579	1	12.23
Sulphur Springs	5.30	14,551	2	76.76
Borger	12.20	14,302	12	173.81
West University Place	0.20	14,211	1	2.16

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Table 10 continued

LOCAL PARK ACRES PER CITY

City Unit	Acres per 1,000 Population	City Population	Number of Parks	Total City Park Acres
Addison	0.60	14,166	1	9.05
Mount Pleasant	7.00	13,935	6	97.57
Jacksonville	19.90	13,868	6	276.62
Dumas	4.20	13,747	6	58.31
La Marque	56.20	13,682	3	768.73
Mercedes	2.00	13,649	1	27.49
Terrell	6.90	13,606	4	93.45
Port Neches	0.40	13,601	1	5.60
Taylor	8.10	13,575	3	110.55
Pecan Grove	49.30	13,551	6	668.11
Brenham	6.00	13,507	4	81.02
Beeville	23.40	13,129	9	307.62
Canyon	6.70	12,875	2	85.71
Levelland	18.50	12,866	8	238.61
Robstown	3.20	12,727	7	41.13
Freeport	7.80	12,708	3	99.21
Saginaw	8.30	12,374	7	103.01
Port Lavaca	7.80	12,035	2	93.62
Vernon	4.70	11,660	2	55.25
Lockhart	10.50	11,615	2	121.38
Converse	3.60	11,508	1	41.30
Sweetwater	163.70	11,415	5	1,869.03
Kilgore	6.70	11,301	5	75.61
Athens	9.00	11,297	8	101.50
Henderson	8.30	11,273	3	93.34
Richmond	0.40	11,081	1	4.56
Burkburnett	2.60	10,927	3	28.34
Seagoville	1.30	10,823	2	14.12
Snyder	10.60	10,783	2	113.93
Galena Park	4.00	10,592	3	42.27
Clute	2.20	10,424	2	23.03
Jacinto City	1.70	10,302	2	17.93
Bonham	2.40	9,990	4	23.50
Lamesa	8.10	9,952	8	81.06
Sachse	0.40	9,751	1	4.39

CONTINUED ➤

Table 10 continued

LOCAL PARK ACRES PER CITY

City Unit	Acres per 1,000 Population	City Population	Number of Parks	Total City Park Acres
Raymondville	1.40	9,733	3	14.10
Andrews	3.60	9,652	2	35.02
Azle	6.20	9,600	2	59.93
Santa Fe	0.70	9,548	1	6.21
Pecos	4.10	9,501	4	39.13
Brownfield	7.10	9,488	6	67.52
Seabrook	2.00	9,443	1	19.14
Ingleside	3.00	9,388	2	28.10
Leon Valley	2.60	9,239	1	23.74
Live Oak	9.30	9,156	1	85.42
Webster	1.20	9,083	1	11.02
Fredericksburg	25.30	8,911	2	225.29
Highland Park	7.90	8,842	12	70.20
Graham	27.00	8,716	4	235.27
Kirby	6.90	8,673	4	59.95
Pleasanton	25.70	8,266	6	212.32
Jasper	9.10	8,247	4	74.76
Hillsboro	18.40	8,232	3	151.28
Aransas Pass	0.50	8,138	2	3.69
Richland Hills	1.60	8,132	3	12.78
Fabens	5.10	8,043	1	41.28
Lakeway	30.10	8,002	5	241.21
Hondo	4.80	7,897	4	38.25
Fort Stockton	12.40	7,846	6	97.15
Perryton	10.10	7,774	3	78.42
Commerce	5.60	7,669	3	43.08
Leander	32.10	7,596	1	244.02
Crowley	1.60	7,467	1	12.07
Rockport	16.40	7,385	2	120.97
Hidalgo	2.20	7,322	2	16.41
Dalhart	0.50	7,237	1	3.80
Gonzales	18.40	7,202	3	132.33
Crystal City	6.20	7,190	5	44.84
Pearsall	1.00	7,157	3	6.91
Crockett	6.30	7,141	1	44.87

CONTINUED ➤

Table 10 continued

LOCAL PARK ACRES PER CITY

City Unit	Acres per 1,000 Population	City Population	Number of Parks	Total City Park Acres
River Oaks	0.50	6,985	1	3.59
Jersey Village	1.30	6,880	1	8.71
Monahans	2.20	6,821	3	14.95
Navasota	3.10	6,789	1	21.05
Lampasas	7.30	6,786	4	49.85
Childress	15.70	6,778	1	106.24
Carthage	1.00	6,664	1	6.91
Cuero	2.80	6,571	2	18.31
Mexia	1.50	6,563	1	10.16
Littlefield	9.90	6,507	4	64.24
Kaufman	0.60	6,490	1	3.72
Iowa Park	3.70	6,431	3	23.72
Boerne	55.60	6,178	6	343.20
Slaton	3.80	6,109	2	23.28
Gladewater	5.10	6,078	2	30.86
Seminole	6.40	5,910	4	37.68
Breckenridge	4.60	5,868	3	27.20
Everman	1.30	5,836	1	7.86
Alpine	5.00	5,786	4	29.17
Atlanta	8.50	5,745	2	48.61
Yoakum	27.20	5,731	2	155.89
Granbury	4.20	5,718	3	24.25
Kermit	4.80	5,714	4	27.37
Elgin	2.40	5,700	1	13.90
Center	2.00	5,678	1	11.16
Sinton	3.30	5,676	2	18.71
Cameron	13.50	5,634	8	76.13
Rio Bravo	1.00	5,553	1	5.30
Brady	37.30	5,523	4	206.07
Diboll	3.20	5,470	2	17.61
Rockdale	7.80	5,439	2	42.27
Livingston	25.30	5,433	2	137.63
Whitehouse	1.80	5,346	2	9.89
Bastrop	5.60	5,340	4	30.13
Falfurrias	9.80	5,297	5	52.03

CONTINUED ➤

Table 10 continued

LOCAL PARK ACRES PER CITY

City Unit	Acres per 1,000 Population	City Population	Number of Parks	Total City Park Acres
Horizon City	1.60	5,233	1	8.49
Bowie	5.90	5,219	3	31.05
Decatur	1.00	5,201	1	5.45
Palacios	20.50	5,153	3	105.44
Coleman	5.70	5,127	2	29.45
Tulia	7.50	5,117	3	38.20
Giddings	5.80	5,105	1	29.68
Windcrest	2.10	5,105	1	10.64
Rusk	1.80	5,085	3	9.40
Luling	18.90	5,080	6	96.21
New Boston	2.60	4,808	2	12.51
Gilmer	1.10	4,799	1	5.12
Burnet	4.80	4,735	2	22.92
McGregor	17.80	4,727	1	84.22
Hearne	12.80	4,690	3	59.84
Teague	5.80	4,557	1	26.46
Mineola	4.80	4,550	2	21.80
Jacksboro	1.80	4,533	1	8.04
Muleshoe	3.00	4,530	2	13.37
Lago Vista	17.20	4,507	4	77.50
Comanche	9.80	4,482	1	43.91
La Grange	3.40	4,478	5	15.21
Dimmitt	19.80	4,375	2	86.84
Hunters Creek Village	1.10	4,374	1	4.68
Colorado City	5.20	4,281	1	22.29
Castle Hills	0.60	4,202	1	2.71
Devine	2.00	4,140	3	8.14
Smithville	3.00	3,901	1	11.61
Clarksville	2.90	3,883	2	11.33
Anthony	1.60	3,850	1	6.04
Eastland	5.30	3,769	1	19.96
Whitesboro	4.20	3,760	2	15.83
Jourdanton	0.50	3,732	1	2.03
Post	9.10	3,708	1	33.79
Taylor Lake Village	4.00	3,694	2	14.86

CONTINUED ➤

Table 10 continued

LOCAL PARK ACRES PER CITY

City Unit	Acres per 1,000 Population	City Population	Number of Parks	Total City Park Acres
Floydada	10.60	3,676	4	38.84
Dilley	5.10	3,674	3	18.85
Eagle Lake	23.40	3,664	1	85.65
Cotulla	2.40	3,614	1	8.62
Winnsboro	2.90	3,584	2	10.54
Wills Point	1.60	3,496	1	5.74
Kenedy	0.80	3,487	1	2.96
Salado	0.30	3,475	1	1.21
Karnes City	7.80	3,457	3	27.10
Olney	7.80	3,396	3	26.40
Wilmer	2.30	3,393	2	7.76
Poteet	1.00	3,305	3	3.37
La Joya	0.30	3,303	1	0.90
Henrietta	7.60	3,264	1	24.64
Nocona	32.40	3,198	3	103.74
Electra	5.70	3,168	2	18.14
El Lago	2.30	3,075	1	7.01
Grand Saline	2.90	3,028	1	8.86
Quanah	2.10	3,022	1	6.31
Balcones Heights	0.70	3,016	1	2.10
Hamilton	18.60	2,977	2	55.46
Refugio	3.90	2,941	1	11.57
Sonora	3.70	2,924	2	10.69
Tahoka	31.40	2,910	2	91.32
Seymour	10.90	2,908	1	31.65
Lucas	5.70	2,890	1	16.40
Barrett	0.40	2,872	1	1.13
Hutchins	4.40	2,805	1	12.47
Brazoria	0.90	2,787	1	2.44
Trinity	2.20	2,721	1	5.94
Schulenburg	18.10	2,699	4	48.89
Castroville	56.90	2,664	1	151.51
San Saba	31.70	2,637	3	83.57
Junction	23.70	2,618	1	62.08
Eden	5.80	2,561	1	14.87

CONTINUED ➤

Table 10 continued

LOCAL PARK ACRES PER CITY

City Unit	Acres per 1,000 Population	City Population	Number of Parks	Total City Park Acres
Stanton	7.60	2,556	2	19.37
Wolfforth	11.50	2,554	1	29.48
George West	8.70	2,524	3	22.05
Daingerfield	6.40	2,517	1	16.15
Odem	1.40	2,499	1	3.52
Van Horn	9.00	2,435	2	22.01
Buda	4.10	2,404	1	9.92
Comfort	5.50	2,358	2	12.96
Hallettsville	41.80	2,345	1	97.92
Mount Vernon	14.10	2,286	4	32.23
Wellington	6.60	2,275	2	15.11
Malakoff	1.90	2,257	1	4.23
Ralls	5.80	2,252	1	13.14
Morton	5.90	2,249	2	13.17
Canadian	0.90	2,233	1	2.05
Dalworthington Gardens	20.90	2,186	1	45.60
Cooper	4.80	2,150	1	10.25
Glen Rose	22.00	2,122	1	46.78
Marfa	3.20	2,121	1	6.88
Quitman	8.90	2,030	1	18.15
Shamrock	2.80	2,029	2	5.70
Weimar	64.30	1,981	3	127.40
Goliad	0.50	1,975	1	1.02
Clarendon	0.70	1,974	1	1.30
Eldorado	3.00	1,951	1	5.87
Rio Hondo	8.10	1,942	5	15.73
Liberty City	2.40	1,935	1	4.63
Justin	5.00	1,891	2	9.49
Crosbyton	4.50	1,874	1	8.36
Hughes Springs	4.20	1,856	1	7.83
McCamey	5.00	1,805	2	8.98
Goldthwaite	8.30	1,802	1	14.88
Ingram	2.50	1,740	1	4.35
Woodsboro	4.90	1,685	2	8.20
Beach City	6.60	1,645	1	10.87

CONTINUED ➤

Table 10 continued

LOCAL PARK ACRES PER CITY

City Unit	Acres per 1,000 Population	City Population	Number of Parks	Total City Park Acres
Baird	10.40	1,623	1	16.83
Rotan	23.50	1,611	1	37.88
Sabinal	36.20	1,586	5	57.46
Sundown	66.50	1,505	3	100.15
Shoreacres	3.60	1,488	1	5.31
Calvert	5.50	1,426	1	7.81
Naples	0.70	1,410	1	1.04
Rollingwood	15.60	1,403	1	21.88
Hawkins	15.90	1,331	1	21.18
Iraan	32.90	1,238	1	40.74
Collinsville	4.90	1,235	1	6.11
Gunter	8.50	1,230	1	10.41
Bells	8.70	1,190	1	10.34
Bullard	3.20	1,150	1	3.63
Crowell	2.50	1,141	1	2.80
Timpson	14.30	1,094	1	15.60
Spur	117.80	1,088	1	128.16
Santa Anna	22.40	1,081	2	24.23
Runge	8.30	1,080	2	8.93
Sudan	1.70	1,039	1	1.74
Emory	1.50	1,021	1	1.57
Riesel	6.40	973	1	6.24
Bandera	75.90	957	3	72.65
San Felipe	23.90	868	1	20.78
Mertzon	28.20	839	1	23.70
Lindsay	13.70	788	1	10.83
Silverton	2.20	771	1	1.68
Normangee	696.60	719	2	500.87
Crawford	185.90	705	1	131.06
Loraine	5.50	656	1	3.58
Lovelady	1.70	608	1	1.02
Ropesville	5.90	517	1	3.03
Star Harbor	134.30	416	2	55.88
Hedley	22.10	379	1	8.39
Sunset Valley	375.30	365	1	137.00
Kirvin	33.00	122	1	4.03

TPWD LAND AND WATER RESOURCES INVENTORY, 2002.

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Mad Island Public Use Links:

- Mad Island Home
- Rules
- Maps & Directions
- Activities at a Glance
  - Hunting
  - Wildlife Viewing
- Events

Wildlife Management Area Links:

- Find a Wildlife Management Area
  - Ordered by County
  - Ordered by Name
  - Browse by Location
  - Search by Activity
    - Biking
    - Camping
    - Driving
    - Equestrian
    - Fishing
    - Hiking
    - Hunting
    - Wildlife Viewing
- Wildlife Management Area Calendar
- Required Permits

Mad Island

Phone: (979) 244-6805
Address:
County Courthouse, Room 101
Bay City, TX 77414

Contact: Lang Alford

Dates Open: Open for teal and duck hunters during hunting season. A reservation is needed for wildife tours. Contact the Area Manager for specific dates.

Description

The Mad Island WMA was purchased to preserve coastal wetland habitat for wintering waterfowl. Conservation tours are scheduled during the year for visitors to observe hundreds of bird species along the Texas coast. The 7,200 acres consists of fresh to brackish marsh land with sparse brush and flat coastal prairie. Wildlife includes puddle and diver ducks, sandhill cranes, alligators, mottled duck, raccoon, river otter, mink, armadillo, white-tailed deer, bobcat, gray fox and cottontail, jack and swamp rabbits. Hunting for alligators, feral hogs and waterfowl are permitted through special scheduled hunts.

Please note:

- There aren't any restroom facilities.
- Bring your own drinking water.
- Commercial facilities are available in Bay City and Collegeport.
- No camping or open fires are allowed.
- Insect repellant is recommended for mosquitoes.
- Waterproof footwear is advised.

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2005 Land and Water Resources Conservation and Recreation Plan

- Executive Summary
- Introduction
- Texas Parks and Wildlife Department Roles
- Conservation and Recreation Priorities on Land in Texas
  - Priorities for Conservation on Land in Texas
  - Priority Ecoregions for Conservation Efforts
  - High Priority Habitats on Land
  - Priorities for Recreation on Land
  - Qualitative Department Site Evaluations
  - Outdoor Recreation Analysis
  - Local Park Analysis
  - Priorities for Increasing Public Recreation on Private Lands
  - Priority Wildlife Management Needs for Recreation
  - Priorities for Historic Sites in Texas
  - Strategies for Meeting the Conservation and Recreation Needs on Land
- Conservation and Recreation Priorities for Water
- Major Goals and Objectives for the Next Ten Years
- Conclusion

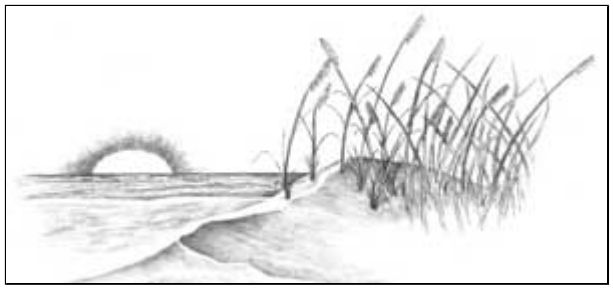
Additional Information:

- Information on the Current Planning Process

Priority Ecoregions for Conservation Efforts

For assistance with accessibility on any TPWD documents, please contact accessibility@tpwd.state.tx.us

Tier I – High Priority Ecoregions for TPWD Efforts



Blackland Prairie
Percent of Ecoregion under Wildlife Management Plans = 5.77%
Percent of Ecoregion in Public and Nonprofit Conserved Land = 1.52%

Conserved Status: This ecoregion ranked medium in conserved status because there is only a small percentage of public and non-profit conservation land and private property operated under wildlife management plans.

Threats: This is the most severely altered of Texas' ecoregions, since most blackland prairie has been converted to crops or development. Only an estimated 5,000 acres remain in their historic condition in terms of plant species. All habitats in this ecoregion are threatened by rapid population growth in most of the ecoregion and accompanying conversion to urban and pasture, fragmentation and decreasing land parcel size.

Rare Plants and Communities: This ecoregion ranks lowest in number of rare plant species and seventh in number of endemics, but all four native blackland prairie grass communities are rare.

Rare Animals: Many tall grass prairie birds have declined drastically due to land conversion and fragmentation. This region is important stopover habitat for migrant songbirds and wintering raptors.

Priorities: Protection and restoration of remnant prairies is a high priority.

Gulf Coast Prairies and Marshes
Percent of Ecoregion under Wildlife Management Plans = 8.93%
Percent of Ecoregion in Public and Nonprofit Conserved Land = 5.69%

- **2005 Land and Water Resources Conservation and Recreation Plan** (PDF 8.1 MB)
- **2005 Maps, Graphs and Tables Section Only of Land and Water Conservation Plan** (PDF 4.2 MB)

Conserved Status: Overall, this ecoregion ranked relatively high in conserved status second only to the Trans-Pecos ecoregion, although conservation efforts are not evenly distributed across the region. The coastal marshes and barrier islands are relatively well conserved, whereas the inland prairies, coastal woodlands and some beach habitats are not.

Threats: All factors considered, this is among the most threatened of the ten ecoregions and the more threatened of the two high diversity ecoregions. The high population growth and associated development along the coast have fragmented land, converted prairies, changed river flows, decreased water quality and increased sediment loads and pollutants on marshes and estuaries. Projections indicate continued high growth and increasing fragmentation in most parts of this ecoregion.

Rare Plants and Communities: The region ranked high in rare plant species and endemism including five rare plant communities. All of the region's 24 rare plants occur inland where the conserved status is lowest.

Rare Animals: Attwater's prairie chicken, whooping crane, aplomado falcon, white-tailed hawk, Gulf Coast hog-nosed and eastern spotted skunks are all in need of attention, as are many of bird species that depend on this important migratory stopover area.

Priorities: Protection efforts should focus on inland prairies and coastal woodlands. Many beach areas and mud flats need additional protection.

South Texas Plains
Percent of Ecoregion under Wildlife Management Plans = 13.6%
Percent of Ecoregion in Public and Nonprofit Conserved Land = 0.51%

Conserved Status: This ecoregion ranked relatively high in conserved status overall. The South Texas Plains consists mostly of level to rolling terrain characterized by dense brush. Little of the brush country is conserved on public lands, but a relatively high percent is in large stable ownerships and operated under wildlife management plans. Much of the high quality brush habitat that still exists in the Lower Rio Grande Valley (LRGV) is in public ownership, but it is insufficient to sustain many of the region's threatened plants, animals and communities.

Threats: Overall, this region ranked relatively high. Threats are concentrated in the LRGV due to the expanding human population, fragmentation, conversion to croplands, urban development, insufficient river flow and introduction of exotic plants.

Rare Plants and Communities: Rare plant communities include the Texas ebony-anacua, Texas palmetto and Texas ebony-snake-eyes assemblages. Rare species include Walker's manioc, star cactus, Texas ayenia and Zapata bladderpod.

Rare Animals: The LRGV has particularly rich bird and butterfly faunas, as well as the endangered ocelot and jaguarundi.

Priorities: The remaining fragments of brush in the LRGV should be protected and corridors between these habitats should be protected and restored.

Tier II – Secondary Priority Ecoregions for TPWD Efforts

Cross Timbers and Prairies
Percent of Ecoregion under Wildlife Management Plans = 5.03%
Percent of Ecoregion in Public and Nonprofit Conserved Land = 1.73%

Conserved Status: This ecoregion and the High Plains ecoregion rank the lowest in conserved status. There is little public land, few private preserves and a low percentage of private land under wildlife management plans.

Threats: This ecoregion ranked medium in terms of land conversion, but the potential for rapid conversion and fragmentation in the future is suggested by high projected population growth. Threats in the region include fragmentation and land conversion of prairies, forests and savannahs; mesquite invasion of degraded grasslands, and proliferation of exotic grasses. Rivers and streams have been altered by an extensive reservoir system. Hundreds of miles of riparian, or river, forests have been inundated and downstream flows reduced. Most ground nesting birds, grassland mammals, amphibians and egg-laying reptiles are also threatened by fire ant invasion.

Rare Plants and Communities: This ecoregions harbors only one rare plant and has relatively low endemism. Patches of blackland prairie grasslands within the Cross Timbers are made up of threatened communities similar to those described for other ecoregions.

Rare Animals: The region provides nesting habitat for the federally endangered black-capped vireo and the golden cheeked warbler.

Priorities: Protecting the ecoregion's prairies, woodlands and remaining river corridors should be a priority.

Edwards Plateau
Percent of Ecoregion under Wildlife Management Plans = 9.58%
Percent of Ecoregion in Public and Nonprofit Conserved Land = 0.51%

Conserved Status: Despite a small amount of public and non-profit conservation land, the region ranked medium due to the relatively high percentage of private land managed under wildlife management plans.

Threats: Land conversion values for the ecoregion, overall, were relatively low. However, projected population growth and subdivisions of large tracts of land are high, particularly in the eastern portion where intense development and fragmentation threatens the biodiversity and the region's unique hydrology.

Rare Plants and Communities: The Edwards Plateau is internationally recognized for its unique flora associated with karst (limestone, cave, spring, stream systems). It has the highest number of plant endemism of any ecoregion in the state and ranks third in number of rare plants. Of the 29 plant communities found here, three occur nowhere else in Texas and two are found nowhere else in the world.

Rare Animals: Karst habitats support many species of salamanders and cave insects, many of which are restricted to only a few sites. This is the most important ecoregion for herpetological and invertebrate species due to high endemism, sensitive habitats and intense threats. Black-capped vireos and golden-cheeked warblers are the two bird species of greatest concern.

Priorities: The sheltered canyons, springs, caves and river systems are home to most of the biological diversity and should be priorities for public and private conservation efforts. Conserving relatively intact grasslands and maintaining sufficient old growth juniper habitat for the golden-cheeked warbler, especially in the western hill country, are also a priority.

High Plains
Percent of ecoregion under Wildlife Management Plans = 2.6%
Percent of Ecoregion in Public and Nonprofit Conserved Land = 0.56%

Conserved Status: This ecoregion is the least conserved because there is a low percentage of public and non-profit conserved land and wildlife management plans.

Threats: This ecoregion experienced a high rate of conversion to crops, but a considerable portion of it is now enrolled in the USDA's Conservation Reserve Program that has higher conservation value than cropland. Threats include fragmentation and land management practices that are harmful to species such as lesser prairie chickens. Other threats include the damming of springs, streams and rivers, the draining and conversion of playa lakes and surface mining.

Rare Plants and Communities: Plant endemism is low, but there are two rare species, five endemics and several distinct plant communities.

Rare Animals: Birds of concern in this region include ferruginous and Swainson's hawks, burrowing owls, mountain plovers and lesser prairie chickens. The black-tailed prairie dog, swift fox and pronghorn antelope need conservation attention.

Priorities: Increasing the percentage of conserved land to support several important game species and threatened animals is a priority.

Pineywoods
Percent of Ecoregion under Wildlife Management Plans = 2.81%
Percent of Ecoregion in Public and Nonprofit Conserved Land = 6.72%

Conserved Status: This ecoregion ranked medium in conserved status because of the relatively high percentage of publicly owned land and medium percentage of land under wildlife management plans. The northern half of the ecoregion is not well conserved and has unique habitats and rare species of plants and reptiles.

Threats: The Pineywoods ranked relatively low in terms of land conversion, but high in terms of projected population growth. Much of the longleaf pine and hardwood forests habitats have been converted to loblolly plantations, which have limited conservation value. The primary threats are fragmentation and land conversion, for instance the consolidation of timber interests around the country has led to sales of large timber tracts in east Texas which may be converted to other uses. Fire suppression, fire ant and Chinese tallow invasion are also threats. Much of the best remaining bottomland hardwood habitat is threatened by potential reservoir construction.

Rare Plants and Communities: Plant endemism ranks relatively low, though the region supports 22 rare species and 27 endemics. The longleaf pine savannahs have been reduced from approximately 1.5 million acres historically to 50,000 acres today. Many of the acid seeps and pitcher plant bogs have been converted to other uses.

Rare Animals: The Pineywoods and the Gulf Coast ecoregions share one of the world's most diverse, highly threatened mussel populations. Reptiles of concern include the Louisiana pinesnake, alligator snapping turtle and timber rattlesnake. Amphibians are declining generally. Birds of concern are the red-cockaded woodpecker, Bachman's sparrow and other grassland savannah nesters and winterers. The endangered Louisiana black bear may be attempting to naturally recolonize and the conservation of bottomland forests is critical to their return.

Priorities: Longleaf pine savannahs and other unique plant communities, including bogs, hardwood slope forests and baygalls should be preserved and restored where possible. Conservation and restoration of remaining bottomland hardwood habitat is also important for many wildlife species.

Tier III –Tertiary Priority Ecoregions for TPWD Efforts

Post Oak Savannah
Percent of land under Wildlife Management Plans = 11.18%
Percent of Ecoregion in Public and Nonprofit Conserved Land = 1.13%

Conserved Status: This ecoregion ranked medium in conserved status because only a small percentage is public or non-profit conservation land.

Threats: The Post Oak Savannah ranked relatively low in threats overall. The primary threats are fragmentation and land conversion, especially from the damming of springs, streams and rivers. Other threats include fire ant infestation and fire suppression in both oak savannahs and pitcher plant bogs.

Rare Plants and Communities: Endemism in the plants of this ecoregion ranks lower than in others, though the area supports 17 rare species and 65 endemics. Many highly specialized plant habitats such as blowout sandhills, clay-pan savannahs, pitcher plant bogs, Catahoula and Oakville sandstone outcrops, chalk glades and limestone prairies support numerous rare plants, which are not found on public land.

Rare Animals: There are several species of concern in the region including loggerhead shrikes, painted buntings, spotted skunks, the Brazos water snake and the Houston toad.

Priorities: Conservation efforts in this region should focus on areas that support many of the region's unique species and communities such as mesic hardwood woodlands, bogs, sandhills and bottomland hardwoods.

Rolling Plains
Percent of Ecoregion under Wildlife Management Plans = 6.51%
Percent of Ecoregion in Public and Nonprofit Conserved Land = 0.49%

Conserved Status: The ecoregion ranked low in conserved status with a relatively small amount of public and non-profit conservation land and a medium percentage of land under wildlife management plans.

Threats: This region ranked medium in threats including land fragmentation and conversion. Exotic species such as saltcedar exist along many miles of riverbank.

Rare Plants and Communities: The only rare plant endemic to this region, the Texas poppy-mallow, is associated with the mesquite grasslands and Havard shin oak communities.

Rare Animals: Low forests on limestone out-pockets are important habitat for the endangered black-capped vireo. Both the federally listed Concho and Brazos water snakes occur. The state listed Texas kangaroo rat also survives in this region.

Priorities: This region is a prime candidate for restoration efforts and many species would benefit from restoration of grasslands and riparian forests. Protection of the Texas poppy-mallow and high quality examples of communities such as Havard oak-tallgrass, sandsage-midgrass, cottonwood tallgrass, types of grasslands and woodlands is also important.

Trans-Pecos
Percent of Ecoregion under Wildlife Management Plans = 8.74%
Percent of Ecoregion in Public and Nonprofit Conserved Land = 7.56%

Conserved Status: This ecoregion is the most conserved of all ecoregions, but the conserved lands are not evenly distributed across the region. The desert grasslands of the region are poorly conserved, as are much of the forests along the Rio Grande

and plant communities around springs.

Threats: Threats in this region are the lowest of any ecoregion but include persistent drought and groundwater withdrawals that have damaged many existing spring-associated communities. Expansion of human activities in the El Paso region will negatively impact habitats in the surrounding region.

Rare Plants and Communities: The region is one of Texas' botanically richest and most unique. Approximately one of every 12 plant species occur nowhere else in Texas. The Trans-Pecos supports three times the number of rare plants than any other region. Much of the banks of the Rio Grande are choked with saltcedar, making the protection of the
rare patches of cottonwood-willow and velvet ash willow communities important. Many springs and their associated cienegas and creeks contained numerous rare plants, but most have dried out. Of the few springs that remain, only three are permanently conserved.

Rare Animals: This region has the highest percentage of vertebrate species of concern. The bird, mammal and insect faunas are rich and unique. Rare birds include the golden eagle, the common black hawk, elf and flammulated owls, peregrine falcon, Montezuma quail and others. Mammals include the black-tailed prairie dog, kit fox, desert bighorn, pronghorn antelope, Mexican black bear and the hooded skunk. This is by far the most herpetologically diverse ecoregion. Species of concern include the Chihuahuan mud turtle and the dunes sagebrush lizard.

Priorities: The high desert grasslands, spring communities and riparian woodlands along the Rio Grande need additional conservation action.

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Texas Coastal Wetlands

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Prairie Pothole and Marsh Wetlands

A prairie pothole complex on the Ingleside Sand in Calhoun County. (WAYNE WENTWORTH, TEXAS PARKS AND WILDLIFE)

Where Are They?

The term "pothole" is used up and down the coast to refer rather loosely to any freshwater depression. The difference between a pothole and a marsh is mostly size -marshes occur in larger and generally less well-defined depressions than potholes. This section is limited to freshwater depressions that occur on the Lissie and Beaumont Geological Formations, and the Ingleside Sand (see below and wetland types map). "Pothole" appears to be the most common term on the coast for these depressions, but usage varies widely. In the Beaumont outcrop in Willacy County, for example, the depressions are commonly referred to as lagunas or lagunillas.

Prairie potholes and marshes occur on the prairie from just west of Beaumont to the Rio Grande. These wetlands once covered vast expanses of prairie before urbanization and agriculture destroyed most of them. Approximately 30 percent of the prairies was once wetlands. On the upper coast, potholes and marshes occur in complexes with pimple mounds (small hummocks 1-2 feet tall) and intermound flats. The pattern of mounds and wetlands is often quite intricate with abundant interfingering of uplands and wetlands. Pothole/marsh complexes in the Coastal Bend and lower coast regions have somewhat less relief than those of the upper coast.

An example of a prairie pothole in Matagorda County. The small knoll is a pimple mound. (JOHN JACOB)

This complex pattern, formed thousands of years ago by ancient rivers and bayous, and modified through time by climatic (especially wind) and biotic forces, is an irreplaceable geological legacy. Once these complexes are gone, there is no replacing them. The chance confluence of the many unique factors responsible for the evolution of these wetland complexes is unique to them, and makes them a "chance-medley" we cannot repeat. We understand very little about the complex role this wetland pattern plays in coastal prairie ecology.

Because of extensive land leveling for agriculture, there are very few intact complexes left with the full range of relief, from high pimple mounds to deep potholes. Some of the best remaining complexes are in urban fringe areas. Unfortunately the same areas are now under greatest threat from development.

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Geology and Soils

The most extensive prairie potholes and marshes are found on the Lissie and Beaumont Geological Formations. These potholes are remnants of the rivers that laid down the great floodplain and delta sediment deposits that make up most of the coastal plain, but the original morphology has been greatly modified by wind and other agents. The riverine nature of these scars is sometimes quite obvious, while in other places it is more obscure. The wetlands with the most obvious riverine features are found on the Beaumont Formation and range in age from 15,000 to more than 30,000 years old, while the potholes on the Lissie Formation are for the most part more than 100,000 years old. The Katy Prairie west of Houston is one of the more well known prairies on the Lissie Formation with abundant pothole

Soil-landscape diagram from the Jackson County Soil Survey. The Cieno (pothole) and Texana (ridge) soils represent a prairie pothole complex. Pimple mounds (Fordtran soils) occur on ridges or

wetlands.

in the potholes. (REDRAWN FROM THE JACKSON COUNTY SOIL SURVEY)

Soil Profile of a Prairie Pothole Wetland

(Cieno Soil Series, Prairie Pothole, Jackson County)

The surface soil to a depth of about 25 inches is a dark grayish brown sandy clay loam with brownish iron coatings along old root channels and cleavage faces. The subsoil from 25 to 60 inches is a light brownish gray sandy clay loam with brown iron stains. The soil is neutral in the upper part and moderately alkaline in the lower part.

This soil is ponded with water for periods ranging from a few weeks to several months in the winter and early spring.

(from the Jackson County Soil Survey)

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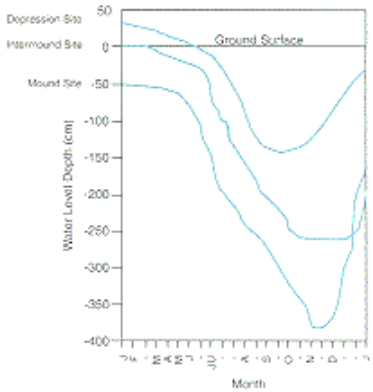
Hydrology

Prairie potholes and marshes are inundated by direct precipitation and by runoff from surrounding flats. Groundwater may be a factor in many potholes, particularly those on the Ingleside Sand (see below), but its role is not well understood. Hydrology in pothole complexes is very diverse, with pronounced changes occurring within just a few feet. Deeper potholes can remain saturated for more than 6 months out of the year, while adjacent pimple mounds may be nearly semi-arid for most of the year. Almost every intermediate hydrologic state will be found associated with potholes and marshes of varying depths and surrounding elevations. This hydrologic complexity translates into high habitat and biological diversity.



Soil water table hydrographs for a prairie pothole site in Harris County, Texas. The lines represent the depth of the water table (or depth of inundation) throughout the year. (ADAPTED FROM GRIFFIN ET AL 1998)

Hydrology changes markedly in these wetlands as one moves down the coast. Many potholes on the upper coast remain inundated for several months out of the year, with six months of wetness not uncommon in the deeper potholes. Most Coastal Bend and lower coast potholes, on the other hand, may remain saturated for only a few weeks to perhaps a month or so at a time.

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Vegetation

Potholes and marshes typically have concentric zones or belts of different habitat types. These habitats are determined by elevation and hydrology; that is, the amount and permanence of the water in each zone. The more permanent potholes may have floating and submerged plants like water lilies, pondweeds, southern naiad, and duckweed in the open water zone. The emergent zone might include cattails, bulrushes, burheads, arrowheads, and common reed. A still higher woody zone may include trees and shrubs like black willow, buttonbush, rattlebush and coffee bean, baccharis, Chinese tallow-tree (an introduced invader) on the upper and mid-coast, and retama on the mid- and lower coast.

The edges of less permanently flooded potholes and marshes might have bushy bluestem and various other grasses, spikerushes, rushes, and sedges as well as the shrubs and trees mentioned above.

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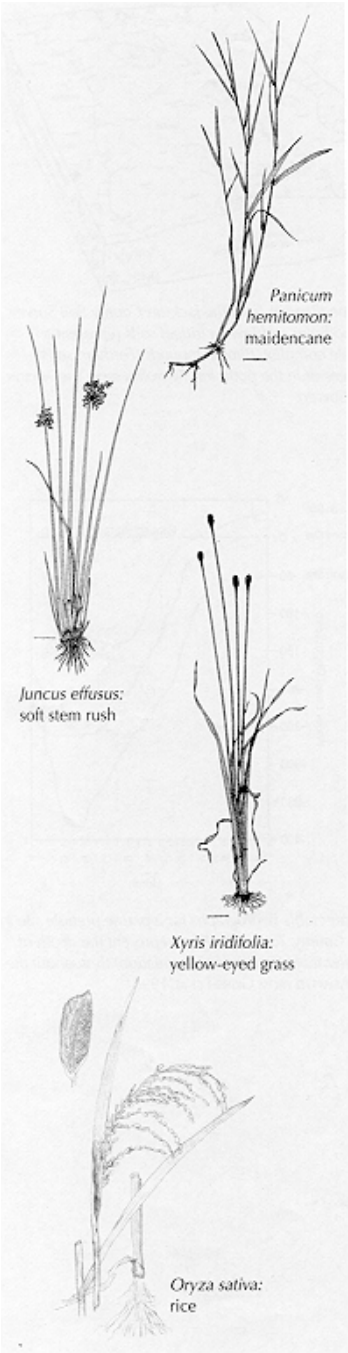
Animals

Pothole/marsh wetlands and wetland/upland complexes play host to a very diverse fauna because of the great variety of habitats. Reptiles and amphibians include alligators, Gulf Coast ribbon snakes, cottonmouth



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moccasins, red-eared sliders, southern leopard frogs, bullfrogs, and green treefrogs. Birds include rails, cranes, all wading birds, dabbling ducks, coots, common moorhens, snipe, blackbirds and grackles, shorebirds like killdeer, marsh and sedge wrens, swamp sparrows, and most all migrating songbirds. Almost all resident animals use the ponds to drink. During drought, all wildlife concentrates near the more permanent potholes.

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Threats

Agriculture was once the greatest cause of the loss of prairie potholes and marshes. Urban sprawl is probably the cause of greatest loss today. Federal wetland regulatory protection has not prevented the loss of these wetlands. The cumulative loss has been significant. On the Texas coastal plain, freshwater marshes have decreased by 29 percent since the mid 1950s, a net loss of more than 235,000 acres!

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Ecological Functions and Human Values

In the spring, pothole/marsh wetlands are especially important to birds migrating across the western Gulf of Mexico. These habitats are the first source of freshwater encountered by migrants and are heavily used by songbirds, shorebirds and waterfowl and other waterbirds. These birds represent an important economic resource for coastal cities and towns. Birdwatching is a rapidly growing segment of the nature tourism industry. Coastal communities with the foresight to protect and promote these habitats will reap great long-term economic benefits. To destroy these wetlands is to "kill the goose that lays the golden egg."

These habitats are also important to resident wildlife, particularly in the semiarid coastal regions and in times of drought. They also provide water and forage for livestock.

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Special Pothole and Marsh Areas

Rice Fields

An aerial view of a coastal rice field. (DAN MOULTON)

Most of the prairie potholes and marshes have been greatly modified by farming, principally for rice from Victoria to Beaumont. While rice farming has greatly modified the wetlands through land-leveling, many of the potholes remain, even if somewhat shallower than before modification. Rice is farmed only 1 year out of 3, with the other two years fallow or resting. Because of the flooding that accompanies rice cultivation and the rest or fallow period, these farmed potholes retain much of their wetland character, with a moderate soil seed bank of native wetland plants. More recent practices involving laser and water leveling, unfortunately, level the potholes completely.

Rice fields can themselves be considered a type of wetland because the fields remain flooded for significant periods. Rice fields are by far, at about 1.5 million total acres, the most abundant type of wetlands on the Texas coast. In addition to the grain, rice fields also provide other benefits to wildlife and people. The huge wintering waterfowl populations, particularly geese, enjoyed by Texas hunters and bird watchers are quite dependent on the rice farming industry. Rice fields also provide habitats for large numbers of invertebrates such as insects and crayfish. These attract herons, egrets and other wading birds, sandpipers, plovers and other shorebirds, gulls and terns, mammals, reptiles, and amphibians.

Even rice field wetlands face threats. Urban and suburban sprawl eliminates farmland of all kinds as developmental pressures drive up land values. However, the most serious threat to rice farming now seems to be the changing markets and subsidies that rice farmers have come to rely on. Much rice acreage will probably be converted to other crops that will not provide wetlands or support waterfowl. This does not bode well for a large segment of North American ducks and geese.

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Ingleside Sand Freshwater Depressions

The Ingleside Sand is a remnant of an ancient barrier island or strandplain system that faced the coast during a previous period of high sea level (about 50,000 to 75,000 years ago). A strandplain is a mainland shoreline built seaward by a series of accumulated sandy beach ridges. During this period, this strandplain was somewhat analogous to the barrier islands that line the coast today, but the effects of wind and other geomorphic agents have greatly modified the original ridge and swale topography. Highs and lows are found on the Ingleside Sand, but they are much less elongate than those found on the barrier islands today.

Ingleside Sand pothole in the Aransas National Wildlife Refuge (JOHN JACOB)

The Ingleside Sand is especially evident along the Coastal Bend region from south of Corpus Christi Bay north to Matagorda Bay. The Encinal (Flour Bluff), Live Oak (Aransas Pass and Rockport), Blackjack and Lamar (Aransas National Wildlife Refuge), and Calhoun (Seadrift-Port O'Conner Ridge) Peninsulas are the remnants of the ancient barrier sands.

Vegetation in the Ingleside depressions is frequently similar to the vegetation found in nearby prairie potholes. The soils as a rule are much sandier, very similar to the present-day barrier island complexes, except that the Ingleside soils frequently have a layer with more clay below 30-40 inches. Groundwater may be a more important factor in these wetlands than in nearby prairie potholes of the Beaumont Geological Formation. Rainwater rapidly penetrates the sandy soils, and the claypan acts to hold the water much as a cistern would.

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Lower Coast Potholes and Marshes

Lower coast pothole and marsh depressions occur in a semi-arid environment. A complex geologic unit that includes some Sand Sheet wetlands and Beaumont and Lissie-aged potholes has been lumped into one map unit, the Prairie Potholes-Lower Coast. Very little descriptive work has been done on these wetlands. The hydroperiod or time that these wetlands are wet is less than that of potholes to the north and east, but is definitely long enough for wetland vegetation to have developed in these depressions.

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MATAGORDA COUNTY. Matagorda County (G-24) is in the Coastal Prairie region of Texas, bounded on the north by Wharton County, on the east by Brazoria County and the Gulf of Mexico, on the west by Calhoun and Jackson counties, and on the south by the Gulf of Mexico and Tres Palacios, Matagorda, and East Matagorda bays. The center of the county lies at 28°54' north latitude and 95°59' west longitude; Bay City, the county's seat of government and largest city, is four miles north of the center of the county at the convergence of State highways 35 and 60, fifty air miles southwest of Houston. The name Matagorda, Spanish for "thick brush," was derived from the canebrakes that formerly lined the shore. Crossed by the once highly flood-prone Colorado River, which bisects it from north to south, the county extends across 1,612 square miles of mostly open prairie. With the exception of a slight undulation in the north, most of the county is level, with elevations ranging from sea level to seventy feet. Part of Matagorda Peninsula, a narrow barrier island formed less than 5,000 years ago, runs northeast and southwest for sixty-five miles from the mouth of Caney Creek in the eastern part of the county to Pass Cavallo on the west. The peninsula protects Matagorda Bay and is cut in half by the Colorado River channel twenty-four miles from the pass. Major watercourses in the county include Caney, Peach, Peyton's, Turtle, Cash's, and Big and Little Boggy creeks, the Trespalacios and Colorado rivers, Live Oak and Linville bayous, and Little Robbins Slough. Along the rivers the soils are brownish to reddish, cracking and clayey to loamy, and along the coast soils are sandy. In the rest of the county light-colored, shallow loam covers clayey subsoils; some areas, particularly in the coastal marshes, have gray to black, cracking, clayey soils. Temperatures in the county vary from an average low of 44° F in January to an average high of 92° F in July. The growing season averages 295 days per year. Live oak, post oak, pin oak, pecan, ash cottonwood, elm, red cedar, and mulberry grow in the county's forests; mesquite[qv] and prickly pear have invaded the Bay Prairie in patches where the land has been overgrazed. The area harbors a variety of wildlife, including bobcats, coyotes, otters, white-tailed deer, and numerous smaller mammals, as well as oysters, shrimp, fish, snakes, and waterfowl. A number of protected wildlife habitats, including Big Boggy National Wildlife Refuge, the Mad Island Wildlife Management Area,

the Runnels Family Mad Island Marsh, and the Nature Conservance, are located in the county. In 1982, 80 percent of Matagorda County was in farms and ranches, and of this, 28 percent was cultivated. The county derives 67 percent of its agricultural receipts from crops, especially rice, sorghum, soybeans, wheat, hay, and cotton. Potatoes, peaches, and pecans were also grown there. Cattle ranching has been important to the local economy. Mineral resources include salt domes, brine, petroleum, and natural gas. In 1982, 97,440,000,000 cubic feet of gas well gas, 6,781,000,000 cubic feet of casinghead gas, and 2,903,000 barrels of petroleum were produced in the county. The Colorado Barge Canal, completed in 1959, extends fifteen miles along the Colorado River from the Gulf Intracoastal Waterway to a turning basin below Bay City and links the county to deep water at Freeport and Galveston. In the 1990s the county was served by the Union Pacific, Southern Pacific, and Santa Fe railroads.

Archeological research has revealed a pattern of relatively dense occupation near inland water sources in the upper Texas coastal region, and projectile points from the early Paleo-Indian period (10,000-6,000 B.C.) have been found thinly scattered along the Texas coastal plain. By the time of European exploration in the early 1500s, the central section of the Texas coast, including Matagorda County, was home to several linguistically related subgroups of the hunter-gatherer Karankawa Indians. By the eighteenth and nineteenth centuries the shifting of tribal territories further north forced other tribes, notably the Tonkawa Indians of Central Texas, toward the coast and into Karankawa territory. Alonso Álvarez de Pineda mapped the Texas coastline in 1519, but the first recorded European expedition into the Texas interior was conducted by Álvar Núñez Cabeza de Vaca, who sometime after 1528 probably passed through what later became Matagorda County. Guido de Lavazares landed at Matagorda Bay in 1558, surveyed the northern Gulf Coast, and claimed the area for King Charles V. In 1690 Manuel José de Cárdenas y Magaña mapped Matagorda Bay as part of the Llanos-Cárdenas expedition, and the Alarcón expedition[qv] passed through what is now Matagorda County between 1718 and 1719. As early as 1820 plans were made to establish a port at the site of the future town of Matagorda, but none developed, since silt deposited in the bay by the Colorado River made a port impractical at that time. Settlement by Anglo-Americans began in 1822, when the schooner *Only Son* landed immigrants for Stephen F. Austin's colony at the mouth of the Colorado. Some of the first white residents of what is now Matagorda County were soldiers sent to protect the new settlers from the Karankawa Indians. Austin gave grants in the area to fifty-two families, principally from New York, and in 1827 received permission to settle 300 more within thirty leagues of the coast in areas where settlement had previously been forbidden by the Mexican government. The town of Matagorda, at the mouth of the Colorado River, was founded in 1829 after Austin had convinced the Mexican government that a military post was needed to protect incoming settlers. The town quickly flourished, and settlement proceeded inward from the coast, initially along Caney Creek. A custom house established at Matagorda in 1831 was maintained until the Texas Revolution. Steamers and sailing vessels approached within six miles of the town on Matagorda Bay; other county transportation was also largely by water. The municipality of Matagorda, which comprised the southeast corner of

the original Austin grants, was established in 1834 while the area remained under Mexican control.

In events leading up to the Texas Revolution, according to some sources, members of the district of Mina at the Convention of 1832 were actually people from the Matagorda area rather than what became Bastrop County. The District of Matagorda was represented at the Convention of 1833, and Matagordans took an active part in both the councils and subsequent fighting. A local Committee of Public Safety drew up a formal pledge to protect the citizens of Goliad, and troops were sent to aid James W. Fannin. After the war, in 1836, Matagorda County was organized as one of the first twenty-three counties by the Republic of Texas; Matagorda was designated as the county seat. The area's culture reflected the southern backgrounds of many of its inhabitants. Baptist education began at Matagorda around 1829, an Episcopal congregation was established in the area in 1838, and the area's first Methodist congregation was established in 1839. The county's first newspaper, the *Tribune*, appeared in 1837. A keel boat was reported on the Colorado in 1838, and a ferry known as Cayce's (later called Elliotts) was established in 1849 west of Bay City. As Texas's second major seaport and a port of entry for Texas immigrants from 1840 to 1865, Matagorda rapidly developed transportation and industry. The town had a gristmill in 1859, and the largest sugar mill in the state was built there sometime before 1860. By 1850 there were 2,124 people living in the county, including 913 whites, 1,208 slaves, and 3 free blacks. According to the agricultural census, almost 59,000 acres were in farms in the county that year, including 8,500 acres considered "improved." More than 103,000 bushes of corn, 1,394 thousand-pound hogsheads of sugar, 1,613 bales of cotton, and 60 pounds of rice were produced in the county that year. While cash crops already constituted an important part of the local economy, livestock also played a significant role: almost 32,000 cattle, and more than 2,100 sheep, were also reported in the county that year. The production of cotton rapidly expanded in the county during the 1850s. On the east side of the Colorado, alluvial soils made up of stream deposits provided bottomlands hospitable to plantations, while west of the Colorado the land was used almost exclusively by stockraisers and small farmers. Between 1850 and 1855 a number of slaves were brought into the county, largely by slaveholders from Georgia, South Carolina, and Virginia, to work on large plantations in the bottomlands of the Colorado River and Caney Creek. The region between Matagorda and Brazoria, forty miles away, came to be known as "Old Caney" and was noted for its production of cotton and sugar. Meanwhile, as the profitable plantation economy encouraged planters to bring more black slaves into the area, the county's minority white population took various steps to ensure their control. Citizens established a curfew for slaves and free persons of color as early as 1850, and in 1852 Elder Noah Hill was employed to serve as a missionary to slaves in the county. The need to protect their control over their slaves was also used by white citizens in 1856 to justify expelling the county's entire Mexican population. As one newspaper item contended, the Mexicans in the county were known to "hang around the plantations, taking the likeliest negro girls for wives....they often steal horses, and these girls, too, and endeavor to run them to Mexico. We should rather have anticipated an appeal to Lynch law, than the mild course which has been adopted." By 1858 roughly 30

percent of the improved acreage in the county was used to raise cotton, 6 percent was devoted to sugar, and 20 percent to corn; sea-island cotton was grown on Matagorda Peninsula during this period. In the late 1850s major towns in the county included Matagorda, with 1,200 residents, and Tres Palacios (also known simply as Palacios), which was located west of the Colorado on a high point of land between Matagorda and Tres Palacios bays. By 1860 there were 3,454 people, including 2,107 slaves, living in Matagorda County. Almost 159,000 acres in the county was in farms, and 21,000 acres were reported to be improved. That year the county's plantations and farms produced 8,454 bales of cotton, 507 hogsheads of cane sugar, and 144,000 bushels of corn. John Duncan, one of the county's many wealthy planters, owned real property valued at $150,000 and personal property valued at $128,000, as well as seventy-five slaves and 3,000 cattle. Another planter, James B. Hawkins, had real property valued at $100,000 and personal property valued at $60,750, along with his 101 slaves. While cash crops, especially cotton, had helped to provide this prosperity, cattle remained an important part of the economy in 1860. Almost 38,000 cattle were reported in the county that year, and a cattle company formed in 1849 continued to engage in a lively commerce that had grown between Matagorda Bay, New Orleans, Mobile, and other Gulf points; this trade lasted until the Civil War.

Although the county's voters supported John Bell (the relatively moderate candidate of the Constitutional Union Partyqv) in the presidential election of 1860, the county overwhelmingly supported secession from the union (136 to 8) in a special election held in February 1861. Several Confederate camps, posts, and garrisons were established in the area, and the county shared others with nearby Brazoria County. Capt. E. S. Rugeley's C.S.A. Company was garrisoned at Fort Matagorda, and in 1862 twenty-two soldiers died crossing the bay to skirmish with Union gunboats offshore. In 1863 Confederate soldiers stationed at Matagorda drove cattle off the peninsula, a popular winter pasture, to keep them from being captured by Union troops. DeCrow's Battery was on the southwestern tip of Matagorda Peninsula to guard the east channel to Matagorda Bay. Maj. Gen. John B. Magruder's orders for fortifications at the mouth of Caney Creek to stop invasion by federal forces resulted in 1864 in the construction of an earthen fort called Fort Caney. The fort was made up of four east bank garrisons-forts Ashbel Smith, Hawkins, Rugeley, and Sandcliff-which were later bombarded. Union troops preparing to build a fort in 1864 were repelled by fifty-seven local volunteers. The Confederate gunboat, the *John H. Carr*, was anchored at Matagorda, along with the *Lizzie Lake*, a stern wheeler, and a transport called the *Luck Guinn*. No Union troops entered the county during the war, but the Union's blockade of the Texas coast restricted foreign cotton trade, crippled the commerce of the port at Matagorda, and severely damaged the local economy. Land values and the county's tax base declined after the Civil War and the subsequent emancipation of the slaves. Taxable wealth in the county declined from $2,727,256 (of which $1,095,400 represented the value of slaves) in 1860, to only $1,028,815 by 1866. Farm acreage in the county declined by 30 percent between 1860 and 1870, and the area's cotton-growers, undercut during the war by the Union blockade, never really recovered during this period; in 1870 only 1,590 bales were produced in Matagorda County. There were 3,377 people living in the area that year, a population slightly smaller than

before the Civil War began. Almost two-thirds (2,120) of the county's residents were black; twelve Mexicans and three American Indians were also reported in the area that year. Though many of the county's wealthy planters had left the area, others remained and engaged in the cattle trade. The agricultural census reported over 93,000 cattle in the county in 1870, along with about 8,500 sheep. The Stabler Patent Beef Packing Plant, which began canning beef in 1866, and a hide and tallow factory established near the coast before 1870 are evidence of the importance of the county's beef industry during this period.

Though cotton production in the area began to revive after 1870, Matagorda County's economy and population grew slowly until last years of the nineteenth century. From 1875 to 1880 financial difficulties plagued the county government, which was forced to resort to script to finance its activities. There were few towns and little commerce in the area at that time, and the rich farm lands along Caney Creek held the majority of the population; progress awaited the development of improved roads. Steamships of the Morgan Lines maintained a station at Palacios in the 1880s, but the once-thriving port of Matagorda declined, losing its competition with Lavaca and Indianola as a port. About 3,400 acres in the county were planted in cotton in 1880, and 4,307 acres were devoted to the fiber by 1890. Meanwhile, the number of cattle in the area declined significantly: fewer than 20,000 cattle were reported in the county in 1880 and 27,000 in 1890. That year there were 3,985 people living in the county, including 2,524 blacks; post offices had been established at Culver, Elliott, Hardeman, Matagorda, Plader, and Tres Placios. One-fourth of the county's 378 farms were operated by tenants. The county's agricultural economy developed more rapidly during the 1890s, as people from the north-central and central western states moved into the area to take up farming. Bay City was founded in 1894, and because of its location near the center of the county it replaced Matagorda as the county seat. The influx of new immigrants increased land values but discouraged ranching, though the county's herds were improved with Hereford and Durham cattle strains. Cotton acreage in the county almost tripled during the 1890s, and by 1900 12,000 acres in the county were planted in the fiber. That year there were 448 farms and ranches in the county, and the population had increased to 6,097.

Matagorda County's social and political life in the late nineteenth century was marked by racial tension and conflict. The Ku Klux Klan, an organization dedicated to restricting the social and political activities of the newly freed slaves, was active in the area during Reconstruction. Nevertheless at least some area blacks remained active in local politics, and the county consistently supported the Republican tickets in presidential elections between 1872 and 1896. One of the most violent episodes in the county's history occurred in 1887, when the black community known as the Vann Settlement, or the King Vann African Settlement, was attack by armed white vigilantes from Matagorda, Wharton, Brazoria, and Fort Bend counties. According to one local history, the incident convinced the area's black population "that they had best remain in the background and leave the government of the county to the whites." A White Man's Union Association[qv] was formed in the county by 1894. Though a majority of the county's voters supported Republican William McKinley in 1896, the number of Republican ballots

in the county dropped off dramatically in elections held over the next twenty years. McKinley had won 561 votes in 1896, for example, but Theodore Roosevelt was able to win only ninety Republican ballots in the county in 1904. The area's Democrats had apparently reestablished their control by driving blacks from the political process. In the late nineteenth century the county's economy had been based on corn, cattle, and cotton, but after 1899, when the Matagorda County Rice and Irrigation Company was founded, canal building and the production of rice helped to diversify and invigorate the local economy. Rice plantations grew up along the railroad for fifteen miles above Bay City, which by 1912 was one of the leading rice markets in the state. At first, water dammed up by a raft of debris blocking the mouth of the Colorado River was used to irrigate the rice fields. By 1916 there were eleven irrigation plants, capable of irrigating 286,000 acres in the county, and 235 miles of canals had been built. Farmers turned increasingly to rice production after the boll weevil attacked the central Gulf Coast area in the early 1900s; in 1910, 34 percent of the county's improved acreage was in rice, while less 1 percent was planted in cotton and corn. Sorghum, sudan grass, sugar cane, sweet and Irish potatoes, peanuts, and feed crops were also grown in the area that year, and 27,400 cattle and 46,236 poultry were reported. Though cotton cultivation rebounded in the county during the 1910s, rice acreage continued to expand. By 1920, 38,000 acres in the county were planted in rice, and more than 46,000 acres were planted in cotton. By 1925, 60,000 acres in the county were planted in rice. Much of the agricultural growth of the previous two decades was reversed during the late 1920s, however. In 1930 only 7,452 acres in the county were planted in rice and only 24,000 acres were planted in cotton, a drop of almost 50 percent since 1920. The number of farms and ranches in the county grew to 1,116 by 1910, to 1,616 by 1920, and to 1,673 by 1930. Increasing numbers of the area's farmers did not own their own land, however. Tenants operated 37 percent of the farms in Matagorda County in 1910, 40 percent by 1920, and 60 percent by 1930.

Railroad construction in Matagorda County during the early twentieth century had helped to encourage development by tying the area to national markets and encouraging immigration. From 1900 to 1902 the New York, Texas and Mexican Railway extended its line from Wharton into northeastern Matagorda County, serving Pledger, Podo, Ashwood, Sugar Valley, Grovedale, and Van Vleck on its way to Bay City; it then built west to Cortes, Markham, and Midfield. After Jonathan Edwards Pierce and others donated land, the railroad angled south through Blessing and Pheasant Switch on its way to Palacios on the coast. The railroad later became part of the Southern Pacific. An extension of this line, known as the Hawkinsville Tap, passed from Van Vleck southeast to Rugeley, Cedar Lane, and Gainesmore, reaching Hawkinsville by 1903 and remaining in service until 1932. Meanwhile the Cane Belt Railroad had entered the county from Eagle Lake in 1901, passing through Bay City and stimulating the growth of Wadsworth as it moved south to its terminus at Matagorda on the coast. This line shipped sulphur from Gulf Hill, six miles east of Matagorda, from 1919 until the 1920s, when deposits were depleted and both shipping and the community at Matagorda began to decline. Around 1905 the Saint Louis, Brownsville and Mexico Railway extended its tracks west from Bay City through Buckeye and Blessing and east through Allenhurst and Hasima on its way

to Houston. It also constructed a spur from Buckeye to the Tres Palacios Rice and Irrigation Company, to Tres Palacios, and to Collegeport. While the town of Matagorda was the only major town in the county in 1890, by 1913 the railroads had helped to establish or expand many towns and villages, including Bay City, Palacios, Blessing, Collegeport, Markham, Midfield, Wadsworth, Van Vleck, Pledger, and Sargent. Bay City, located at the junction point of all three railroad lines, flourished after 1900. Buckeye was on the St. Louis, Brownsville and Mexico, and Hasima was in the eastern part of the county on the Matagorda-Brazoria line. Gainesmore was on Caney Creek with navigable deep water, and Hawkinsville was in the southeastern part of the county. The economic development of the county was also encouraged by other improvements in the area's transportation network. Around 1902 the Elliott Ferry was replaced by a bridge, and by 1916 the county had 500 miles of roads, half built since 1914. A major improvement in water transportation came with the removal of the massive log jam or raft that extended from the mouth of the Colorado River forty-six miles upstream, trapping sediments and preventing the Colorado from building a delta. Floods on the river occurred in 1913 and 1922, as logs accumulated, alternating with dry years that damaged area rice crops. Efforts to remove the raft had begun as early as 1836, but it was finally blasted to cut a navigation channel in 1929. A large flood that year removed remaining debris.

The discovery of oil and sulphur in the county also helped to diversify the local economy during this period. Oilmen struck gas at Big Hill in 1901, and by 1913 there were producing oilfields at Markham, Clemville, and Big Hill. The Texas Gulf Sulphur Company began mining sulphur in 1919 and founded a company town at Gulf. Meanwhile, manufacturing played only a limited role in the area's economy; in 1920, for example, the twenty-seven manufacturing establishments in Matagorda County employed fewer than 1,000 workers. In 1926 the Texas National Guard established Camp Palacios (later renamed Camp Hulen for its first commanding general) as a summer training site. Between 1900 and 1920 the population of Matagorda County more than doubled, as land speculators helped to attract immigrants to the area. There were 13,589 people living in the area by 1910 and 16,589 by 1920. The area's population continued to grow during the 1920s, and by 1930, 17,678 people lived in the county. Immigration into the area during the early twentieth century fundamentally altered the county's racial composition. More than two-thirds of the county's residents had been black, but by 1930 blacks constituted under 26 percent of the area's residents. A significant increase in the Hispanic population had also occurred by 1930; that year 1,993 residents of Mexican descent were reported in the county.

Cotton cultivation in Matagorda County continued to decline during the Great Depression of the 1930s. By 1940 only 17,000 acres in the area were devoted to the fiber. Rice cultivation in the area revived somewhat, however, so that by 1940, 16,000 areas were planted in that crop. Cropland harvested in the county increased 20 percent during the 1930s, rising from 50,000 acres in 1929 to 62,000 acres in 1940. Meanwhile, the area's petroleum industry continued to grow; Edgar B. Davis, for example, developed oil resources at Buckeye. Almost 1,929,000 barrels of crude were produced in the county in 1938. The county's topography also changed during this period. By 1936 the Colorado River had built a

delta across Matagorda Bay to Matagorda Peninsula, cutting the bay into its present eastern and western sections. That same year a channel was dredged through the new delta from the Gulf of Mexico to the town of Matagorda; thereafter, Matagorda was no longer on the coast. In spite of the depression, the county's population continued to grow during the 1930s, and by 1940 there were 20,066 people living in the area. In 1940 a channel was dredged from the Gulf Intracoastal Canal[qv] for a deep-water port at Palacios. In 1940 Camp Hulen was taken over by the federal government as an Anti-Aircraft Replacement Training Center; after the beginning of World War II Palacios Army Air Base was established, and part of Matagorda Peninsula became a bombing range. German prisoners of war were housed in the county during the war at installations in Palacios and Bay City; about 400 Germans were interned in the Bay City camp. Some of the prisoners were leased to local rice farmers for field work, while others toiled as cotton choppers, painters, and carpenters. Oil production in the county began to increase significantly during World War II, and as it generally continued to grow for more than twenty years after, the industry became a mainstay of the local economy. Almost 4,563,000 barrels of crude were produced in the county in 1944, more than 6,912,000 barrels in 1948, almost 5,701,000 barrels in 1956, and more than 7,013,000 barrels in 1965. Though oil remained an important component of the local economy during the 1970s and 1980s, production fell off significantly. About 4,780,000 barrels were produced in the county in 1974, 3,323,000 barrels in 1978, and 2,903,000 barrels in 1982; fewer than 1,605,000 barrels were produced in the county in 1990.

Partly because of farm consolidations and mechanization the number of farms in the county steadily declined in the decades after World War II, dropping to 1,329 by 1960, to 902 by 1970, and to 703 by 1980. Nevertheless the area's population grew during this period, rising to 21,559 by 1950, to 25,744 by 1960, to 27,913 by 1970, and to 37,828 by 1980. Much of this growth can be attributed to the area's petroleum resources and to new industries, which began to move to the area in the 1960s. In 1956 the Colorado River Industrial Development Association was organized to encourage economic development of counties along the Colorado. In the 1960s a Celanese Corporation plant was established at Bay City for access to raw materials and the Intracoastal Waterway. Plants owned by Conoco and E. I. DePont de Nemours Company (Occidental Chemical after 1987) followed, along with a Marathon Oil Company gasoline refinery and several plants producing natural gas and other gases. Meanwhile, the area's agricultural sector remained important to the local economy. By the 1970s the county was a leading cattle-producing area, and significant amounts of cotton, grain sorghums, soy beans, and corn were grown there; the area was the third largest rice producer in the state after Wharton and Jefferson counties. The demographic profile of the community continued to evolve. By 1982 the population was 20 percent Hispanic, 14 percent black, 20 percent of English descent, and 16 percent of German or Irish descent. Many people still engaged in farming, but 10 percent were employed in the construction industry, and more than half the population resided in either Bay City or Palacios. A total of 782 businesses operated in the county in 1982, and 12 percent of the labor force was employed in manufacturing. The fishing industry and fine recreational facilities for hunting also helped to diversify the economy. Meanwhile, most of the area's railroad

trackage was no longer used. Though most of the spurs had been abandoned by the 1980s, the Missouri-Pacific's main customer was the Celanese Corporation in southwest Bay City. The Palacios branch of the Texas and New Orleans Railroad was last used in the 1970s when it shipped supplies for the construction of South Texas Nuclear Project, a twin-reactor plant managed by Houston Lighting and Power Company. The STNP began operations at Bay City in 1988 and supplied electricity to Houston, San Antonio, Austin, and Corpus Christi. In the early 1990s the fear of leaks in the nuclear plant led to its closure for several months. In the 1990s the Houston-Galveston Area Council provided regional planning to guide unified development in the county and nearby areas.

The voters of Matagorda County supported the Democratic candidates in virtually every presidential election between 1900 and 1948; the only exception occurred in 1928, when Republican Herbert Hoover carried the county. The county's loyalties began to shift in the early 1950s, however, and the Republican candidates received most of the county's votes in all but three of the presidential elections between 1948 and 1988. The only Democratic candidates to win in the county during this period were Lyndon B. Johnson in 1964, Hubert Humphrey in 1968, and Jimmy Carter in 1976. In 1992 a plurality of the county's voters supported Republican George Bush over Democrat Bill Clinton and Ross Perot, the independent candidate. In 1990 there were 36,928 people living in Matagorda County, slightly fewer than in 1980. That year almost half of the county's residents lived in Bay City (1990 population: 18,170), the county seat and a center of petrochemical production in the area. Other communities included Palacios (4,148), Markham (1,206), and Van Vleck (1,534). Major tourist attractions included fishing and water sports, an October rice festival, and a March fair. The Texas Independence Trail runs through Matagorda County, and an annual cattle drive across the Colorado River to summer pastures on Matagorda Peninsula, which began in 1919 still drew tourists in 1994. Palacios celebrates a Valentine Parade and Pageant in February, July 4th Boat Races, and a Bayfest in November. Bay City holds a county fair, the Rodeo and Parade in March, an October Rice Festival, and a Christmas Tour of Homes and Christmas Lighted Parade in December.

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BRAZORIA COUNTY. Brazoria County, on the prairie of the Gulf Coast at the mouth of the Brazos River in Southeast Texas, is bordered by Matagorda, Fort Bend, Harris, and Galveston counties. It covers an area of 1,407 square miles. Its highest altitude, Damon Mound, is 146 feet above sea level. The center of the county lies at approximately 29°10' north latitude and 95°26' west longitude, near the county seat, Angleton. Other principal towns include Alvin, Amsterdam, Brazoria, Damon, Pearland, Rosharon, West Columbia, Holiday Lake, Old Ocean, Bailey's Prairie, Iowa Colony, Bonney, Hillcrest Village, Brookside Village, Danbury, Liverpool, Manvel, and Sweeny; the towns that constitute Brazosport include Clute, Freeport, Quintana, Oyster Creek, Jones Creek, Lake Jackson, Richwood, and Surfside Beach. Key county roads include State highways 6, 35, 36, and 288, and railroad service is provided by the Union Pacific and Burlington Northern Santa Fe railroads. The annual rainfall is fifty-two inches, and the mean annual temperature is 69° F. Hurricanes and floods are common in the region, among the most notable being the hurricanes of 1854, 1900, 1909, 1915, 1932, 1941, Hurricane Carla in 1961, and the floods of 1899, 1913, 1915, 1929, and 1940. Soils in the county are chiefly alluvial loams and clays, and are highly productive when well drained. The growing season averages 309 days a year. In 1982, between 61 and 70 percent of the land was considered prime farmland. The principal streams flowing through Brazoria County into the Gulf of Mexico include the Brazos and San Bernard rivers, Oyster Creek, Bastrop Bayou, and Chocolate Bayou. The Gulf Intracoastal Waterway crosses Brazoria County near the coast. The Brazos River divides the county into two sections; the western one-third is covered by hardwoods, and the rest is generally prairieland. Abundant groves of pin oak, cedar, live oak, mulberry, hackberry, ash, elm, cottonwood, and pecan trees grow in the river and creek bottoms, while cordgrasses, bunchgrasses, and sedges predominate in the coastal marshes. When settlers first arrived, wildlife was abundant, including deer, bear, turkey, and fish. Two major national wildlife refuges, the Brazoria and San Bernard, are close to the Gulf Coast in Brazoria County. In 1947 the county ranked fourth in state timber production. More recently, the petrochemical industry and mineral resources including oil, gas, sulfur, salt, lime, sand, and gravel, concentrated in the

Damon Mound-West Columbia-Freeport area, have dominated the county economy. Magnesium is also extracted locally from seawater.

Before Anglo-American colonization, the region was occupied by Karankawa Indians. Archeological excavations have revealed some of the shell middens and campsite refuse of this nomadic people, who exploited maritime and mainland resources on a seasonal basis as early as a.d. 450. Skirmishes with colonists, including the battle of Jones Creek in 1824, resulted in expulsion of most of the Indian population to the area south of the Rio Grande by 1850.

In 1528 Spanish explorer Álvar Núñez Cabeza de Vaca landed on the Isle of Mal Hado (Island of Evil Destiny), possibly San Luis Island. Scholars agree that his party probably crossed Oyster Creek, Old Caney Creek, and the Brazos and San Bernard rivers, roaming the area that became Brazoria County looking for provisions. Spanish soldiers under Alonso De León, governor of Coahuila, passed through the region in search of the La Salle expedition in 1689, and Joaquín de Orobio y Basterra came in 1727 searching for possible French intruders in the Trinity River area. In an effort to forestall French or English incursions, the Spanish began to occupy Texas in the eighteenth century, but entered the future Brazoria County chiefly to trade with Indians or search for stolen horses. Though expeditions on the Trinity probably traveled through for missionary purposes in the 1750s, the area was not settled by the Spanish. Similarly, early American military expeditions did not reach the future county, though a popular tradition suggests that pirate Jean Laffite used the mouth of the Brazos as a rendezvous and buried treasure along its banks.

Though the alluvial bottomlands of the county's rivers attracted settlement by Americans as early as 1820, the passengers of the schooner *Lively* who landed at the mouth of the Brazos in December 1821 passed on to Richmond. The area was first populated when Stephen F. Austin selected it for his proposed settlement, and eighty-nine of Austin's Old Three Hundred had grants in what is now Brazoria County by 1824. The earliest communities were Velasco (at the site of present Surfside), East Columbia (originally known as Bell's Landing or Marion), Columbia (later West Columbia), and Brazoria. Quintana and Liverpool were also settled before 1832. In 1835 Mary Austin Holley observed, "The rage is now for making towns," but many new towns, including George L. Hammeken's thriving community on San Luis Island, failed to survive.

Brazoria County became part of the Victoria district when Austin's original San Felipe district was divided in two in 1826. In 1832 the legislature of Coahuila separated Brazoria Municipality from San Felipe and made Brazoria its capital. Brazoria Municipality was the scene of the battle of Velasco on June 26, 1832, and witnessed other agitation against Mexican rule. In 1833 county residents suffered both flood and cholera, but in 1834 population in the municipality reached 2,100, and prosperity returned. A decision was made to change the name of the municipality from Brazoria to Columbia, to make Columbia the seat of government, and transfer some territory to Matagorda Municipality. At the time, the largest settlements in the future county were Brazoria, with 500 residents, Velasco with 100, and Bolivar with fifty. As early as the mid-1830s, cotton farms produced more than 5,000 bales annually, and plantation

owners in the area became some of the wealthiest in Texas. On March 1, 1835, a meeting near Brazoria led to the establishment of the first Masonic lodge in Texas, Holland Lodge No. 36 (*see* FREEMASONRY).

When Stephen F. Austin declared against Santa Anna at another meeting in Brazoria on September 8, 1835, Texans began to prepare for a revolution. Agitation for independence led to the formation of committees of public safety and public meetings to discuss the impending break. After the convention at San Felipe and engagements at Gonzales, Goliad, and Bexar, volunteer companies were organized and a provisional government approved on November 13, 1835. Henry Smith[qv] of Brazoria County served as the first provisional governor. Formation of a permanent council soon thereafter brought the inauguration of mail routes throughout the area. Rebellion grew in 1835 and 1836, culminating in the Texas Declaration of Independence.

Citizens of the county contributed men and means to the Texas Revolution and participated in the Runaway Scrape. After his capture at the battle of San Jacinto on April 21, 1836, Santa Anna and members of his army were taken to Velasco, then the location of the provisional government. Here Santa Anna signed the Treaties of Velasco with the Republic of Texas on May 14, 1836. Columbia, the seat of the ad interim government, served as the capital of the republic when sessions of the first Texas Congress met in October 1836. During the first session Stephen F. Austin died and was buried at Peach Point. Houston became the capital.

Under the provisional government, Texas accepted the constitution that made its first counties from former municipalities. Brazoria County, among the first, took its name from the Brazos River when the Congress of the republic established it on March 24, 1836. Brazoria, which became county seat when the county was organized on December 20, 1836, served until 1896, when Angleton replaced it. The establishment of Fort Bend County in 1837 and of Galveston County in 1838 drew the present county boundaries, and the towns of Columbia, Velasco, and Brazoria were incorporated by the Congress of the republic in 1837.

According to some sources, the last shipment of African Americans brought as slaves into North America arrived at the mouth of the San Bernard River in 1840. At the time, the community of Brazoria had an estimated population of 800 and Columbia of 300; 80 slaveholders in the county owned a total of 1,316 slaves. Yellow fever and flooding in 1843 and 1844 slowed growth, but the annexation of Texas to the United States in 1845 and the Mexican War had little effect on residents of Brazoria County, mostly farmers. By 1847 Brazoria County had 1,623 white inhabitants and 3,013 slaves. In 1852 the county produced 7,329 hogsheads of sugar, the most of all Texas counties.

During pioneer days, the Brazos River was the chief artery by which immigration, communication, and commerce penetrated Texas from the Gulf. Small boats regularly navigated as far as East Columbia, and customhouses were located at Brazoria and Velasco. By 1840, Buffalo Bayou and the growing town of Houston had begun to draw commerce away from the Brazos, but freight and passenger service between

Brazoria, other Brazos River ports, and Galveston was established by 1842, and a canal from the Brazos mouth to West Galveston Bay was completed by 1857 (*see* GALVESTON AND BRAZOS NAVIGATION COMPANY).

Between 1849 and 1859 plantation life in Brazoria County flourished, and the county became the wealthiest in Texas, with a typically Southern society based on slavery. Agriculture was the foundation of the county's early economy, and some of the state's largest and most prosperous sugar and cotton plantations grew up along the rivers and deeper creeks on which crops could be shipped by barges. Plantations in the county between 1850 and 1860 numbered forty-six, including nineteen sugar, sixteen cotton, and three that produced both sugar and cotton. Before the war, these plantations produced an average of 7,000 to 8,000 hogsheads of sugar annually, and up to three-fourths of the state's output in 1857. Many planters raised cattle, and some cultivated oranges, lemons, and other fruits. Each of twenty-six county residents owned more than $100,000 in property by the year 1860; the foremost planter was John H. Herndon, whose real property was valued at more than $1.6 million and personal property at more than $106,000. In that year Brazoria County had 2,027 white, 5,110 black slave, and six free black residents; by 1864, when slaves numbered 5,125, their value was only slightly less than the county's 283,151 acres of land. Town life was subordinated to plantation life, and Old Velasco and Quintana served as Gulf seaports and resort centers for antebellum plantation society. Later, the two towns declined in importance as plans for an intracoastal canal to divert trade developed, and in 1875 and 1900 both were almost destroyed by hurricanes. Other transportation in the period was provided by the Houston Tap and Brazoria Railroad, chartered in 1856 and built by planters to connect East Columbia with Houston markets and with the Buffalo Bayou, Brazos and Colorado Railroad at Pierce Junction. After the Civil War, this railroad became the property of the International-Great Northern.

Residents of Brazoria County cast more than 99 percent of their votes for secession, 527 for and two against. During the Civil War, the Dance Brothers gun works manufactured weapons, companies were organized for the Confederate Army, and women were left to run the plantations. Fortifications built at Velasco and Quintana weathered Union attacks in 1862. Confederate blockade runners operated along the coast, and some cotton was shipped overland by mule and wagon to Mexico. Though the county suffered little physical damage in the war, the presence of federal troops and loss of profit from cotton crops in 1864 brought increasing hardship. Some plantations were destroyed, and agricultural production declined sharply with the freeing of the slaves. David G. Mills alone lost 313 slaves as a result of emancipation. County land was valued at more than $3 million in 1860, but its value had declined to less than $2 million by 1866. During the same period, total property value in the county fell from almost $7 million to less than $3 million. Many plantations were divided into smaller farms or turned into pastures; others eventually became part of the Ramsey, Retrieve, Clemens, and Darrington state prison farms (*see* PRISON SYSTEM). In 1870 only a single Brazoria County resident, farmer William Bryan, had a prewar level of wealth, with real property valued at $100,000 and personal property worth $20,000. As conditions worsened, some Brazoria countians moved to

Mexico, where they organized settlements in the Tuxpan River valley in Vera Cruz.

Brazoria County had been primarily Democratic in politics from annexation to the Civil War, but voted Republican throughout Reconstruction because the majority of voters were newly franchised freedmen. The county supported Rutherford B. Hayes, James A. Garfield, James G. Blaine, Benjamin Harrison, and William McKinley in the national elections from 1876 to 1900. During Reconstruction, federal troops were stationed at Brazoria and Sandy Point. A Freedmen's Bureau agent arrived in the county in 1865, the Union League organized and registered black voters by the mid-1870s, and voters elected black legislator George T. Ruby as early as 1870 and Nathan H. Haller as late as 1894. Such organizations as the Ku Klux Klan, San Bernard Rifles, and Prairie Rangers attempted to maintain the supremacy of whites in the county in opposition to Reconstruction measures, though some former slaves succeeded in attaining positions of wealth and leadership. The White Man's Union ultimately disfranchised black voters, however, and removed local politics from the hands of carpetbaggers and freedmen. From 1895 until the 1950s, the Taxpayers Union worked to assure "the fact that this is a white man's country and that white supremacy must obtain," and held primaries in which only whites could vote (*see* WHITE PRIMARY). Leaders posted notices that African Americans elected to office could not serve, and in the 1890s placed guards around the courthouse to enforce their edict. In presidential elelctions from 1900 to 1952 the county's voters generally favored Democratic candidates, though they did support Republicans Theodore Roosevelt, Warren G. Harding, and Herbert Hoover. After 1956, when Republican Dwight D. Eisenhower, carried the county, the area began to trend more Republican, though Democrats did take the area in 1964 and 1968. After 1972, when Republican Richard M. Nixon won most of the county's votes, the county voted Republican in virtually every presidential election through 2004. The only exception was 1976, when Democrat Jimmy Carter carried the county. Third-party candidates usually received little assistance from Brazoria County, though in 1944, 1948, 1980, and 1992 they won a significant percentage of the vote. In 1990 half the county's residents were registered voters.

Between 1870 and 1880 the population in Brazoria County grew from 7,527 to 9,774, largely due to the arrival of federal soldiers and other Northerners, foreign immigrants, and Confederate soldiers from Texas and the Old South. S. A. Hackworth, a white Republican, bought land in Wharton, Fort Bend, and Brazoria counties and sold it to blacks in the 1870s and 1880s. By the 1890s Columbia was the largest town in the county, followed by Brazoria, Velasco, Quintana, Sandy Point, and Liverpool, and new towns had been founded—Alvin, Angleton, and Pearland. In 1898, at the end of the Spanish-American War, Adm. George Dewey acquired 65,000 acres of land in Brazoria County.

Economic recovery came slowly in the post-Civil War era. The principal crops were corn, grains, sweet and Irish potatoes, fruits, wild grapes, and cotton and sugar for export. Sugar production, reduced in the early years of Reconstruction, burgeoned with the use of convict labor by 1871, but never again reached earlier levels. By 1867 the value of livestock, chiefly

cattle, nearly equalled that of agriculture. When cattlemen found northern markets shut off in the late 1860s, hide and tallow factories were established along the Brazos River; Brazoria County packed $100,000 worth of canned beef in 1870. Figs were introduced in the Alvin area around the turn of the century and became an important crop. Four canneries were later built in the community. Live oak moss was ginned at Angleton.

Though the Galveston and Brazos Navigation Company was chartered as early as 1850, major improvements in transportation began only in the 1870s, starting with a canal across Galveston Bay, completed with the help of the federal government. By 1905 workers completed jetties to deepen the water in the harbors at Velasco and Quintana, and in part of what became the Gulf Intracoastal Waterway. The Brazos River Harbor Association was founded in 1925, and by 1929 Brazos River diversion reduced the problem of sanding in the channel and opened the harbor at Freeport. Railroad transportation improved. The Houston and Brazos Valley Railroad reached Velasco by 1907, the Sugar Land Railroad was serving plantations along Oyster Creek by 1916, and the St. Louis, Brownsville, and Mexico Railway established service to Brazoria by 1937. All were later acquired by the Missouri Pacific system, and more recently by the Southern Pacific. Major state highway construction in the county was done in the 1920s and 1930s, though State Highway 288 was not completed until later.

The value of Brazoria County agriculture rose steadily after Reconstruction, and the majority of residents earned their livelihood from the soil until the late 1930s. The use of mules declined with widespread use of tractors after 1925, and the number of farms increased steadily to a maximum of 3,065 in 1940. Houston Lighting and Power service reached the county in 1927. But by 1930 the effects of the Great Depression were obvious. Whereas fewer than a third of county farmers were tenants in 1880, by 1930 tenants constituted a majority, a condition that lasted until the 1950s. Between 1900 and 1930 Brazoria County was described as a cattle-raising area, with some oil and sulfur production, dairying, and diverse farming. The dairy industry, centered around Alvin, peaked between 1910 and 1930, and cotton culture in 1920. Corn culture concentrated near Sweeny, Brazoria, Damon, Danbury, and Angleton, stock farming around Alvin, truck farming in the Sweeny area, figs and poultry near Alvin and Angleton, and pecans around Sweeny and East Columbia.

Rice culture enhanced the economy. Farmers near Danbury and elsewhere started planting rice after 1900 and began to dig rice canals in 1935. From a total of 6,000 acres planted in the crop in 1903, planting grew to 16,000 acres by 1940. In 1948 favorable growing conditions made Brazoria County the nation's number-one rice producing area, with a crop valued at more than $10 million. The average yield per acre almost doubled between 1956 and 1970; an average of 53,000 acres was planted during those years. Rice and grain exports comprised 65,000 tons in 1968; American Rice, Incorporated, at Brazosport, shipped 350,000 tons of rice in 1990.

Brazoria County mineral development began at West Columbia oilfield[qv]

as early as 1901. Oil production started at Brazoria in 1902, reached 12,500,000 barrels in 1921, declined during the depression, and then resumed. Brazoria County ranked fourth among Texas counties in 1946, with 29,308,106 barrels produced. Sulfur deposits at Bryan Mound, Hoskins Mound, and Stratton Ridge Dome were first mined in 1912, and soon made the county first in United States production of sulfur. The Freeport Sulphur Company employed 800 persons at Bryan and Hoskins Mound in 1930 and extracted 2,000 tons of sulfur daily. By 1944 the firm had extracted 552,000 long tons of ore (*see* SULFUR INDUSTRY). The county's contribution to World War I came from factories at Brazoria, Sweeny, and Hasima that produced live oak nails for shipbuilding.

Brazoria County manufacturing was relatively unimportant as late as 1940, when it employed only 166 persons. During the 1940s, however, the number of manufacturing jobs increased rapidly. As the depletion of Bryan Mound sulfur deposits brought an end to the area's principal industry, Dow Chemical Company, drawn to natural resources at Freeport, came in 1939 and soon gave rise to the Brazosport[qv] industrial and port community. After the Japanese attack on Pearl Harbor in 1941, members of the Texas National Guard manned newly established Dow facilities, while the company constructed 2,300 dwelling units in less than two months for its workers. By 1945 exports from Brazosport amounted to 117,610 tons. Another effect of World War II on the county took the form of camps for prisoners of war, which housed German soldiers and members of Rommel's Afrika Corps for a time. A second phase of industrialization began in the 1950s as "customer companies," including Monsanto and processors of chemical fertilizers, established operations nearby to make use of Dow products. Industrial development attracted more workers, including people from East Texas and some African Americans from nearby communities, while real estate developments produced such new Brazosport communities as Lake Jackson. Transportation, meanwhile, included by 1949 the Gulf, Colorado and Santa Fe Railway and the Missouri Pacific, which operated the Houston and Brazos Valley, the St. Louis, Brownsville and Mexico, the International-Great Northern, and the Texas and New Orleans. The county population grew from 27,069 in 1940 to 46,413 in 1950, and continued to expand. By 1982, at which time 17,800 persons were employed in 2,785 business establishments in Brazoria County, three decades of further growth had more than tripled the population to 185,244.

Small farms in Brazoria County increased through the 1930s and 1940s, and farmers increasingly raised crops as tenants rather than landowners. By 1945 agribusiness had appeared; fewer than 7 percent of all farms accounted for almost 70 percent of farm income, and more than 50 percent of farms made less than $1,000 annually. At the same time, the county ranked eighth in Texas cattle production, with 69,437 head, and farmers turned to the Brahman breed. Overall farm production peaked in the 1950s, with 130,000 acres of cropland harvested. County farmers owned almost 82,000 cattle by 1960, and by 1968 cattle outnumbered people. Roughly 60 percent of the county's agricultural income derived from rice in the 1970s, and 40 percent from livestock and poultry; cotton, soybeans, and grain increased in importance by the latter part of the decade. By 1976 the county had forty-eight oil and gas fields, including

Old Ocean, Chocolate Bayou, Damon Mound, Hastings, Bryan Mound, Danbury, Manvel, and West Columbia. In the late twentieth century petroleum and mineral production and marketing, together with other extraction and manufacturing and the chemical industry, continued to shape the county's development and the lives of local farmers and ranchers. More than 2,549,000 barrels of oil and 44,831,552 cubic feet of gas-well gas were produced in the county in 2004; by the end of that year 1,270,790,962 barrels of oil had been taken from county lands since 1902. Magnesium from sea water, which ranked Brazoria County first in the nation's production, along with oyster shell, sulfur, and salt, was manufactured at Freeport and Velasco. The shrimping industry grew at Freeport after World War II. In 1967, 610 boats harvested 14,000,000 pounds of shrimp; the 1971 catch was 160 times larger than that in 1970, and the harvest doubled again by 1972. Both fishing and the recreation industry, which grew up after 1960, fostered ongoing development on the Gulf Coast.

By the 1980s the county had 186 manufacturing establishments that employed almost 18,000 workers. In the 1990s, when the county had more than 41,000 acres of rice in production, the chief agricultural products were rice, cattle, cotton, corn, small grains, forage, and truck crops, with some sorghum, soybeans, and horses. The Brazoria-Galveston Soil Conservation District promoted adequate drainage to allow cultivation.

The population of Brazoria County became more homogeneous during the twentieth century. After 1900 the white population grew steadily. By 1920, as blacks began to leave for employment in northern cities, the county had twice as many white as black residents. A typical county resident at the turn of the century was born either in the lower South or within the state of Texas. Native whites comprised 62.9 percent of the total population in 1930, and grew to 71.4 percent in 1940. Mexican Americans increased in the 1930s, especially around Alvin, where they were employed as farm laborers. The county population, 23,114 in 1930, increased steadily but predominantly in urban areas after 1940, and rose almost 57 percent between 1970 and 1980. Of a total population of 182,244 in 1982, almost 68 percent were native Texans, 13,152 were African American, and 22,679 Hispanic.

Brazoria County's first school was established in 1827, Brazoria Academy in 1839, Alvin Normal School in 1890, and the University of South Texas in 1897. By 1900 eight independent school districts with 200 teachers and forty school buildings served the county's 6,000 pupils. Alvin Community College, founded in the late 1940s, enrolled 3,900 students in 1990. Brazosport College began in 1968. Common-school districts expanded significantly around 1920, suffered declining enrollments during the Great Depression, but grew again by 1940 as the northern county population increased with the rapid growth of Houston, and the southern and central parts of the county grew through the influence of increasing industrialization. New independent school districts became necessary. In 1935 the county had twenty-seven schools for whites and twenty-eight for blacks, and in 1940 Pearland had the only first-class high school among the common-school districts. In 1950 only 23 percent of the county population had completed high school, but by

1982 more than 65 percent had done so. College graduates numbered almost 14 percent that year.

In 2000 the census counted 241,767 people living in Brazoria County. About 66 percent were Anglo, 23 percent were Hispanic, and 9 percent were African American. Almost 80 percent of residents age twenty-five and older had four years of high school, and more than 19 percent had college degrees. In the early twenty-first century petroleum and chemical production, tourism, and agribusiness were the key elements of the area's economy. In 2002 the county had 2,455 farms and ranches covering 613,891 acres, 55 percent of which were devoted to pasture, 37 percent to crops, and 7 percent to woodlands. In that year local farmers and ranchers earned $47,422,000, with crop sales accounting for $24,824,000 of that total. Cattle, hay, rice, beans, sorghum, nursery plants, corn, and cotton were the chief agricultural products. Over 19,271,000 cubic feet of pinewood and over 3,680,000 cubic feet of hardwood were harvested in the county in 2003.

Angleton (2000 population, 18,130) is the county's seat of government and Pearland (37,640) its largest city. Brazosport (59,440) is a community of nine cities, including Brazoria, Clute, Freeport, Jones Creek, Lake Jackson, Oyster Creek, Quintana, Richwood, and Surfside Beach. Other towns include West Columbia (4,255), Sweeny (3,624), Manvel (3,046), Brookside Village (1,960), Danbury (1,611), Holiday Lakes (1,095), Bailey's Prairie (694), Damon (535), Danciger (357), and Bonney (384). Brazoria County offers water sports, fishing, hunting, and other recreation, along with historic sites including Varner-Hogg Plantation State Historical Park. The county celebrates a San Jacinto Festival at West Columbia and the Spring Fling at Clute in April; a Mexican Fiesta at Pearland and Youth Rodeo and Frontier Days at Alvin in May; a Fishing Fiesta at Freeport, a Fireworks Display at Alvin, and the Great Texas Mosquito Festival and Parade at Clute in July; a Founders Day Celebration at Pearland in September; and a County Fair and Rodeo at Angleton and the Bluegrass and Gospel Fall Festival at Brazoria in October.

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Summary of Lower Colorado (K) Region

The Lower Colorado Regional Water Planning Area is composed of all or parts of 14 counties, stretching from Mills County in the Hill Country southeast to Matagorda County on the Gulf Coast (Figure K.1). Most of the region lies in the Colorado River Basin. Major cities in the region include Austin, Bay City, Pflugerville, and Fredericksburg. The largest economic sectors in the region include agriculture, government, service, manufacturing, and retail trade. The manufacturing sector is primarily concentrated in the technology and semiconductor industry in the Austin area. Oil, gas, as well as petrochemical processing, and mineral production, are found primarily in Wharton and Matagorda counties near the coast. The members of the Lower Colorado Planning Group are listed on the last page of this summary.

Population and Water Demands

In 2010, just over 5 percent of the state's total population is projected to reside in the Lower Colorado Region, and between 2010 and 2060 its population is projected to increase by nearly 100 percent to 2,713,905 (Figure K.2). Water demands, however, are projected to increase less significantly. By 2060, the region's total water demand is projected to increase by 21 percent, from 1,078,041 acre-feet in 2010 to 1,301,682 acre-feet (Figure K.3). Agricultural irrigation water use accounts for the largest share of demands through 2050, but by 2060, municipal demand in all forms (including County-other) is expected to overtake irrigation (Table K.1). Municipal demand is projected to increase by 95 percent from

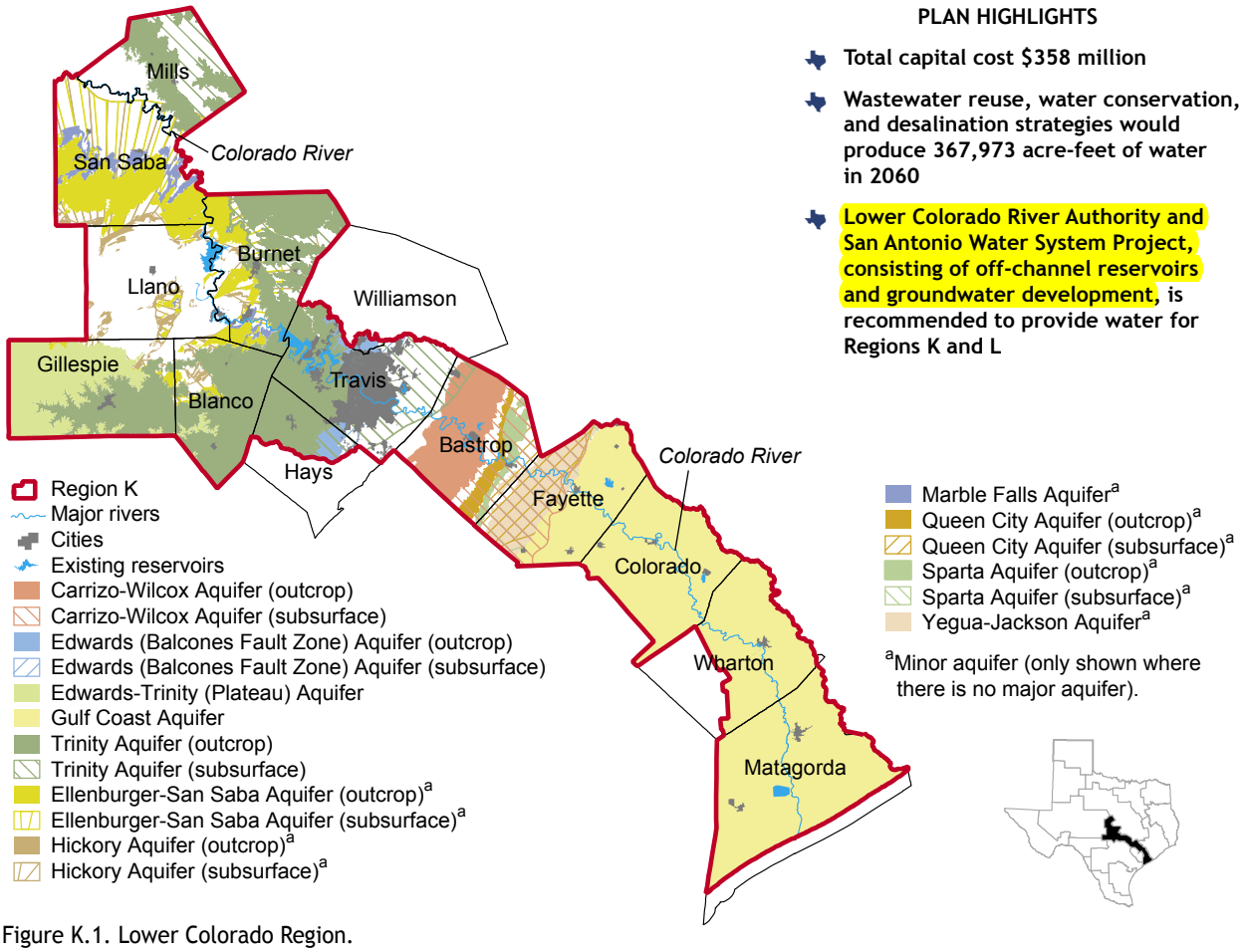


Figure K.1. Lower Colorado Region.

2010 to 2060, rising from 226,437 acre-feet to 442,110 acre-feet. Steam-electric water demand will increase by 45 percent, from 153,522 acre-feet to 222,058 acre-feet in the same time period. Agricultural irrigation demand is expected to decline by 21 percent, from 589,705 acre-feet in 2010 to 468,763 acre-feet in 2060.

Existing Water Supplies

The region has a large number of surface water and groundwater sources available. In 2010, surface water is projected to provide about 77 percent of supplies and groundwater about 23 percent. The principal surface water supply sources are the Colorado River and its tributaries, including the Highland Lakes system. There are 9 reservoirs in the Region K plan from which water supply is calculated. In determining water supply from the Colorado River, the planning group assumed voluntary subordination of its major senior water rights to those in Region F for planning purposes only. Assumptions used to determine existing supplies from the Colorado River have no legal effect. There are 10 major and minor aquifers that supply groundwater to users in the region. The five major aquifers providing groundwater supplies are the Edwards-Trinity (Plateau) and Trinity in the western portion of the region, the Edwards (Balcones Fault Zone) and Carrizo-Wilcox in the central portion, and the Gulf Coast in the eastern portion. The total supply to the planning area is estimated to be 1,182,078 acre-feet in 2010, declining 25 percent to 887,972 acre-feet in 2060, because of reservoir sedimentation and expired water supply contracts (Table K.2).

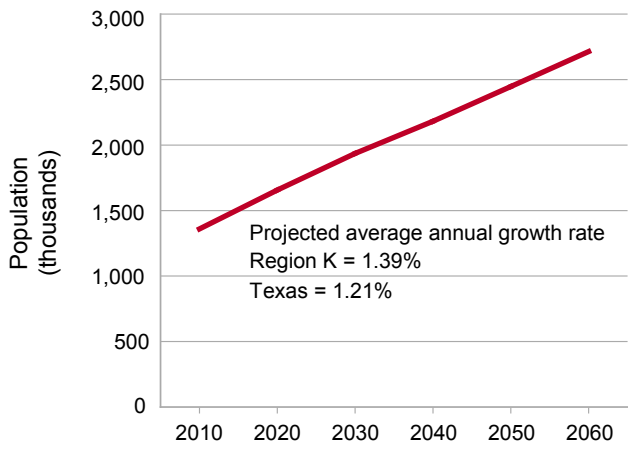


Figure K.2. Projected population for 2010-2060.

Needs

Water user groups in the Lower Colorado Region are anticipated to need 246,055 acre-feet of additional water in 2010 and 557,311 acre-feet by 2060 under drought conditions (Figure K.4, Table K.3). However, about 61 percent of the 2060 needs can be met by renewing current water supply contracts with wholesale providers. All six water use sectors show needs for additional water by 2060. In 2010, the agricultural irrigation sector has the largest needs, 218,550 acre-feet or 89 percent of total. However, in 2060, municipal has approximately half the needs, 277,674 acre-feet, due to population growth over the planning period. Irrigation needs in 2060 decline to 116,320 acre-feet.

Table K.1. Projected water demands for 2010-2060

Category	2010 (acre-feet)	2060 (acre-feet)	Percent change in demand 2010-2060	Percent of overall demand in 2010	Percent change in relative share of overall demand, 2010-2060
Municipal	226,437	442,110	+95	+21	+13
County-other	26,200	42,060	+61	+2	+1
Manufacturing	38,162	85,698	+125	+4	+3
Mining	30,620	27,598	-10	+3	-1
Irrigation	589,705	468,763	-21	+55	-19
Steam-electric	153,522	222,058	+45	+1	+3
Livestock	13,395	13,395	0	+1	0
Region	1,078,041	1,301,682	+21		

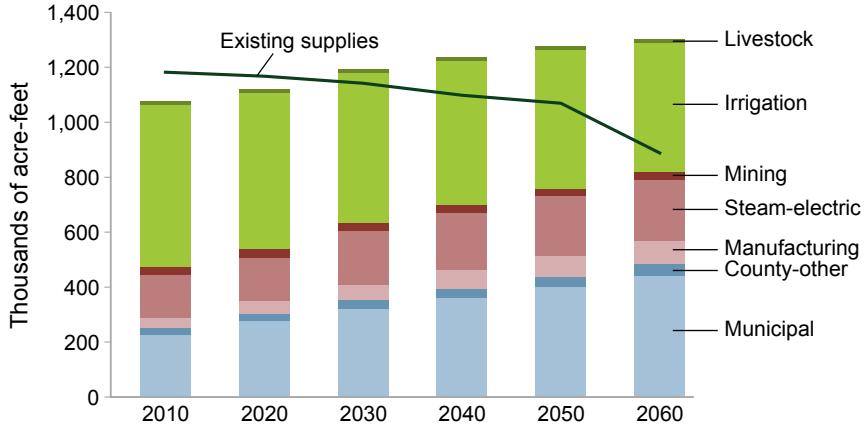
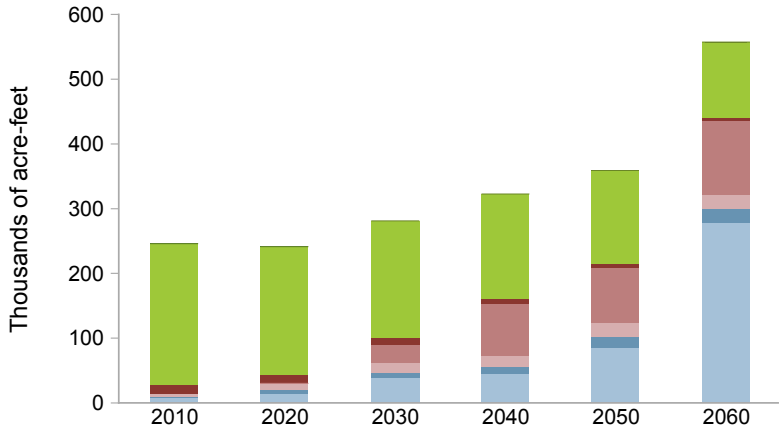


Figure K.3. Projected total water demand and existing water supplies for 2010-2060.



	2010	2020	2030	2040	2050	2060
Livestock	188	188	188	188	188	188
Irrigation	218,550	197,660	179,196	161,554	144,573	116,320
Mining	13,550	13,146	12,366	6,972	5,574	5,794
Steam-electric	0	401	27,720	81,467	86,351	112,867
Manufacturing	4,315	9,617	14,409	16,056	20,297	22,096
County-other	1,805	5,507	8,811	12,241	18,127	22,372
Municipal	7,647	14,817	38,231	43,975	84,469	277,674

Figure K.4. Projected water needs for 2010-2060.

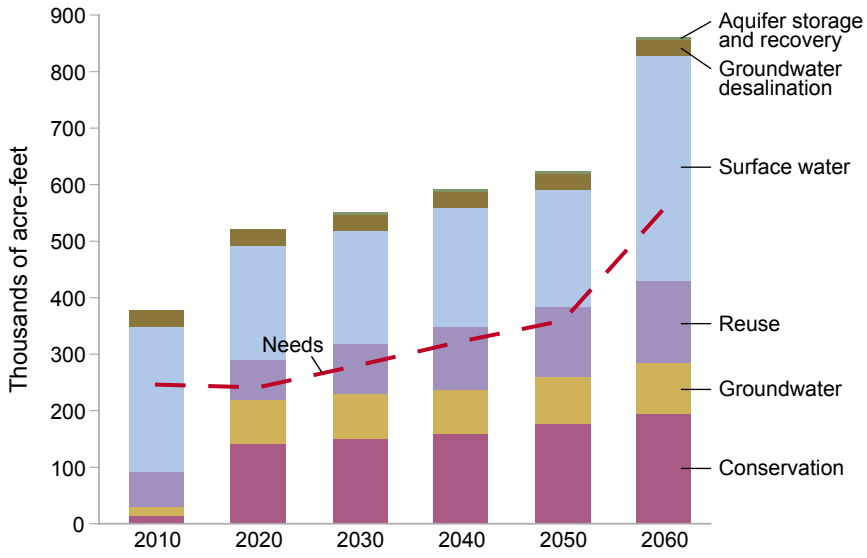


Figure K.5. Recommended water management strategy water supply volumes for 2010-2060.

Table K.2. Existing water supply sources supplies for 2010 and 2060

Water supply source	2010 (acre-feet)	2060 (acre-feet)
Surface water		
Colorado River run-of-river	464,601	471,402
Highland Lakes system	380,106	72,477
Colorado River combined run-of-river irrigation	25,629	25,629
Other local supply	18,378	26,124
Other surface water	26,330	26,807
Surface water subtotal	**915,044**	**622,439**
Groundwater		
Gulf Coast Aquifer	158,936	158,511
Hickory Aquifer	22,920	22,920
Ellenburger-San Saba Aquifer	21,384	21,365
Marble Falls Aquifer	15,147	15,147
Carrizo-Wilcox Aquifer	13,768	13,650
Other groundwater	34,879	33,940
Groundwater subtotal	**267,034**	**265,533**
Region total	**1,182,078**	**887,972**

Note: Water supply sources are listed individually if 10,000 acre-feet per year or greater in 2010.
Only includes supplies that are physically and legally available to users during a drought of record.

Recommended Water Management Strategies and Cost

Water management strategies included in the Lower Colorado Regional Water Plan would provide 861,930 acre-feet of additional water supply by the year 2060 (Figure K.5) at a **total capital cost of $358,174,068** for the region's portion of the project (Appendix 2.1). The primary recommended water management strategy is the Lower Colorado River Authority/San Antonio Water System Project that consists of off-channel reservoirs, agricultural water conservation, additional groundwater development, and new and/or amended surface water rights. The majority of new surface water will be captured in off-channel reservoirs for use by San Antonio, while the groundwater will remain within the region to meet agricultural needs. The costs associated with this project will be paid for by San Antonio and are included in the 2006 Region L Regional Water Plan. There are no unmet needs in the plan.

Conservation Recommendations

Conservation strategies represent 23 percent of the total amount of water resulting from all recommended water management strategies. Water conservation was included as a strategy for every municipal water user group with a need and water use greater than 140 gallons per capita per day. The plan recommends that all nonmunicipal water user groups with needs reduce their water use through conservation by 3, 5, and 7 percent in 2010, 2020, and 2030, respectively.

Ongoing Issues

Region K is concerned that some groups may oppose the Lower Colorado River Authority/San Antonio Water System Project. Feasibility studies for this project are at about the midpoint of the scheduled seven-year time period. The project can not go forward until all studies are completed, the project is found to be feasible, and all statutory and permitting requirements are satisfied.

Select Policy Recommendations

- Provide instream flows and freshwater inflows to bays and estuaries
- Use surface water and groundwater conjunctively for maximum efficiency and to avoid depleting either source
- Achieve sustainable growth, development, and water use
- Promote agricultural and municipal conservation and wastewater reuse

Table K.3. Water needs (acre-feet per year) by county and type of use in years 2010 and 2060

County	Total		Municipal		County-other		Manufacturing		Steam-electric		Mining		Irrigation		Livestock	
	2010	2060	2010	2060	2010	2060	2010	2060	2010	2060	2010	2060	2010	2060	2010	2060
Bastrop	4,420	29,032	—	10,629	—	9,576	8	60	—	8,750	4,293	—	119	17	—	—
Blanco	123	264	—	—	122	263	1	1	—	—	—	—	—	—	—	—
Burnet	1,618	10,120	296	6,584	611	2,615	—	—	—	—	688	898	—	—	23	23
Colorado	62,601	24,972	—	—	105	90	—	—	—	—	8,569	4,867	53,902	19,990	25	25
Fayette	332	33,230	37	2,083	208	16	45	162	—	30,908	—	29	20	10	22	22
Gillespie	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Hays	2,066	18,779	1,307	8,708	759	9,738	—	333	—	—	—	—	—	—	—	—
Llano	805	2,666	740	2,527	—	74	3	3	—	—	—	—	—	—	62	62
Matagorda	97,503	131,554	2	2	—	—	—	13,515	—	52,766	—	—	97,445	65,215	56	56
Mills	697	544	357	357	—	—	1	1	—	—	—	—	339	186	—	—
San Saba	—	5	—	5	—	—	—	—	—	—	—	—	—	—	—	—
Travis	7,825	273,042	3,444	244,504	—	—	4,257	8,013	—	20,443	—	—	124	82	—	—
Wharton	66,601	30,828	—	—	—	—	—	8	—	—	—	—	66,601	30,820	—	—
Williamson	1,464	2,275	1,464	2,275	—	—	—	—	—	—	—	—	—	—	—	—
Region	246,055	557,311	7,647	277,674	1,805	22,372	4,315	22,096	—	112,867	13,550	5,794	218,550	116,320	188	188

SELECT MAJOR WATER MANAGEMENT STRATEGIES

(Dollar amounts are rounded.
See Appendix 2.1 for all recommended strategies and actual costs.)

- *Lower Colorado/San Antonio Water System Project would provide up to 377,000 acre-feet per year for users in Regions K and L*—Implementation by: 2020; Capital Cost: $2 billion (All capital costs are included in 2006 Region L Regional Water Plan).
- *New water pipelines to Hays County (2 strategies)*—Implementation by: 2010; Capital Cost: $13 million.
- *Wastewater reuse by Austin and return flows would produce 144,090 acre-feet per year*—Implementation by: 2010; Capital Cost: $178 million.
- *Desalination of brackish groundwater by South Texas Project Electrical Generating Station would produce 29,568 acre-feet per year*—Implementation by: 2010; Capital Cost: $97 million.

Lower Colorado Planning Group Members and Interests Represented

Voting members during adoption of 2006 Regional Water Plan:

John Burke (Chair), water utilities; Jim Barho, environmental; David Deeds, municipalities; Ronald G. Fieseler, environmental; Rick Gangluff, electric generating utilities; Ronald Gertson, small business; Barbara Johnson, industries; Mark Jordan, river authorities; D.C. (Chris) King, counties; Teresa Lutes, municipalities; Julia Marsden, public; William M. (Bill) Miller, agriculture; Bill Neve, counties; W.R. (Bob) Pickens, other; W.A. (Billy) Roeder, counties; Haskell Simon, agriculture; Harold Streicher, small business; James Sultemeier, counties; Paul Tybor, water districts; Roy Varley, other; Jennifer Walker, environmental; Del Waters, recreation

Former voting members during 2001-2006 planning cycle:

Dede Armentrout, environmental; Steve Balas, agriculture; Stovy Bowlin, water districts; Robert Dickerson, small business; Gerald Hajovsky, counties; Dale Henry, counties; Dennis Jones, municipalities; Jobaid Kabir, river authorities; Quentin Martin, river authorities; Charles Martinez, municipalities; Stanley Reinhard, water districts; Cole Rowland, other (recreation); Mark Smith, industries; Bill Stewart, other (recreation)

Chapter 10

Water Management Strategies

Chapter 10

Water Management Strategies

The planning groups recommended more than 4,500 individual water management strategies to meet water supply needs resulting in a projected total of 9.0 million acre-feet per year of new supplies by 2060. Some of the recommended water management strategies are associated with supplies that are available but not physically connected or legally available.

Surface water management strategies, excluding major reservoirs, are projected to result in 3.3 million acre-feet per year.

Municipal water conservation strategies are projected to result in about 617,000 acre-feet per year by 2060.

Irrigation conservation strategies are projected to result in about 1.4 million acre-feet per year by 2060.

The planning groups recommended 14 new major reservoirs that are projected to generate approximately 1.1 million acre-feet per year by 2060.

Recommended water management strategies relying on groundwater are projected to result in about 800,000 acre-feet per year by 2060.

Recommended water reuse water management strategies are projected to result in about 1.3 million acre-feet per year by 2060.

Desalination projects recommended as water management strategies are projected to result in about 313,000 acre-feet per year by 2060.

The previous chapter demonstrates the need for additional water supplies in Texas. A key goal of regional water planning is to assess and recommend water management strategies to meet those needs. A recommended water management strategy is a specific plan to increase water supply or maximize existing supply to meet a specific need. Water management strategies include

- implementing water conservation and drought management;
- developing new groundwater and surface water supplies;
- expanding and improving management of existing water supplies, such as improving reservoir operations, reallocating reservoir storage space, using groundwater and surface water conjunctively, and conveying water from one area to another;
- water reuse; and
- implementing other, less traditional, approaches such as desalinating seawater and brackish water, controlling vegetation that consumes large volumes of water, practicing land stewardship, and weather modification.

Each of the 16 planning groups identified potentially feasible water management strategies for detailed analyses. As a result of their analyses, planning groups recommended a portfolio of water management strategies tailored to meet each region's water supply needs. Some strategies were carried forward from the prior planning cycle and reassessed due to changing conditions or new information. Other water management strategies considered by planning groups introduced new approaches to meeting water supply needs. In total, the planning groups recommended more than 4,500 individual water management strategies resulting in a total of 9.0 million acre-feet per year of new supplies by 2060.

This chapter provides information about the analyses of potentially feasible water management strategies and the resulting recommended water management strategies in the 2006 Regional

Water Plans and this state water plan. For presentation at the state level, recommended water management strategies in this chapter are categorized as water conservation, new or existing surface water supplies, new or existing groundwater supplies, conjunctive use of groundwater and surface water, water reuse, and desalination. In some cases, subcategories are presented for comparison within a major group.

10.1 Identification and Evaluation of Potential Water Management Strategies

Planning groups systematically evaluated each potentially feasible water management strategy before recommending specific water management strategies to meet water supply needs (Figure 10.1). These potentially feasible water management strategies were then assessed based on a variety of factors, including (1) how much water a strategy could produce and at what costs; (2) how the strategy could impact water quality and the state's water, agricultural, and natural resources; and (3) how reliable the strategy would be in providing water during drought conditions. Other factors considered by some planning groups included regulatory requirements, political and local issues, time requirements to implement a strategy, recreational impacts, and other socioeconomic benefits or impacts. The planning groups also identified how their plans would be consistent with the state's long-term goal of protecting Texas' water, agricultural, and natural resources. After a lengthy evaluation process, each planning group ultimately recommended specific water management strategies to meet identified water supply needs in their planning areas.

10.1.1 Quantity, Reliability, and Costs

Water quantity and reliability were among the key criteria used to assess strategies. Quantity refers to the amount of water that a given strategy would provide to water user groups during drought of record conditions. Reliability is an assessment of the availability of specified water quantities to users over time. If the quantity of water is available to the user all the time, then the strategy

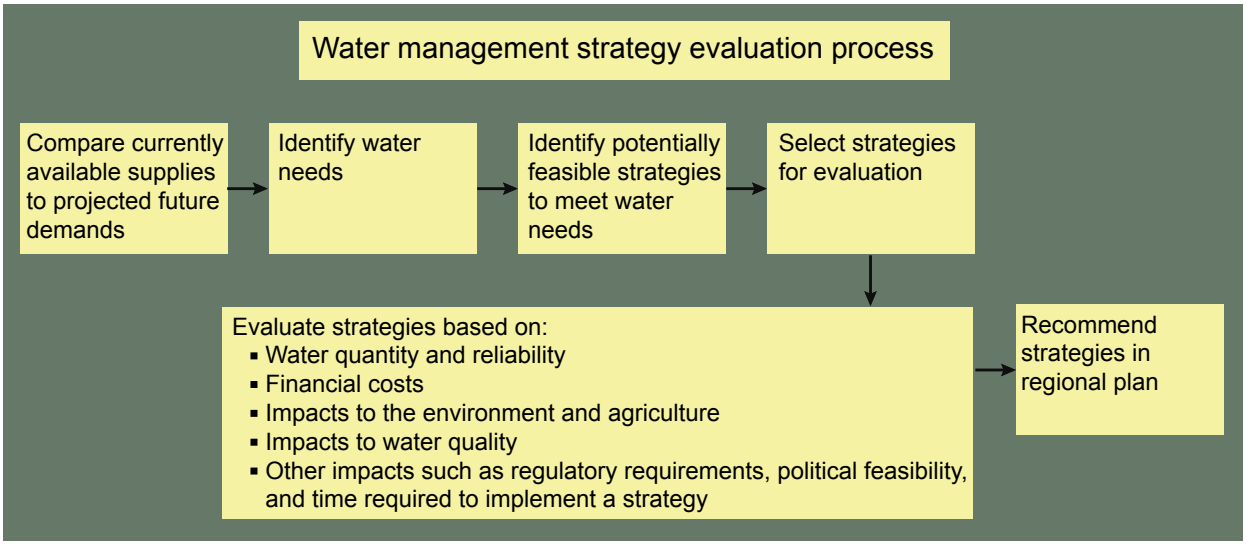


Figure 10.1.Water management strategy evaluation process.

has a high reliability. In contrast, if the quantity of water is contingent on other factors, reliability may be lower.

Financial costs were also an important factor considered when evaluating water management strategies. Planning groups estimated up-front capital requirements and annual costs. Capital costs included both the direct costs of constructing facilities, such as materials, labor, and equipment, and the indirect expenses associated with construction activities, such as costs for engineering studies, legal counsel, land acquisition, contingencies, environmental mitigation, interest during construction, and permitting fees. However, not all strategies have capital costs. For example, water conservation or water transfers using existing infrastructure often do not require up-front capital expenditures.

Annual costs were determined by including both the repayment of borrowed capital funds (debt service), the purchase of power and water, and the operating and maintenance expenses of facilities and water management programs. Debt service is the estimated annual costs of borrowed funds based on total capital costs and a prescribed finance rate and finance period based on the type of water management strategies being evaluated. Operating costs generally consist of labor and materials required to maintain a project in a given year and regular repair and/or replacement of depreciated equipment. Capital, operating, and maintenance costs were reported in year 2002 dollars. Planning groups were also required to consider project costs in terms of discounted present value when evaluating and comparing different strategies. The planning groups reported annual costs, and, thus, the unit cost per acre-foot for each decade for each water management strategy considered. These costs vary according to the type of project and many other factors, including whether or not a given strategy requires capital expenditures and debt service payments.

10.1.2 Impacts to the State's Water, Agricultural, and Natural Resources

Planning groups evaluated the potential impacts of each water management strategy on the state's water, agricultural, and natural resources.

In analyzing the impact of water management strategies on the state's water resources, the planning groups honored all existing water rights and contracts and considered conservation strategies for all water user groups with a water supply need. They also based their analyses of environmental flow needs on the environmental Consensus Planning Criteria or site-specific studies. In addition, planning groups were required to consider water management strategies to meet the water supply needs of irrigated agriculture and livestock production.

Planning groups also determined mitigation costs and quantified impacts for all water management strategies considered. They used a variety of approaches and assessment factors to quantify impacts of water management strategies on water, agricultural, and natural resources. Some used categorical assessments describing impacts as "high," "moderate," and "low." These ratings were based on existing data and the potential to avoid or mitigate impacts to agricultural and natural resources. For example, a "low" rating implied that impacts could be avoided or mitigated relatively

easily. In contrast, a "high" rating implied that impacts would be significant and mitigation requirements would be substantial. Other planning groups used a numerical rating that indicated the level of impact. Many planning groups based their ratings on factors such as the volume of discharges a strategy would produce or the number of irrigated acres lost. Another approach relied on identifying the number of endangered or threatened species listed in a county with a proposed water source. In general, most planning groups relied on existing information for evaluating the impacts of water management strategies on agricultural and natural resources.

10.1.3 Impacts on Water Quality

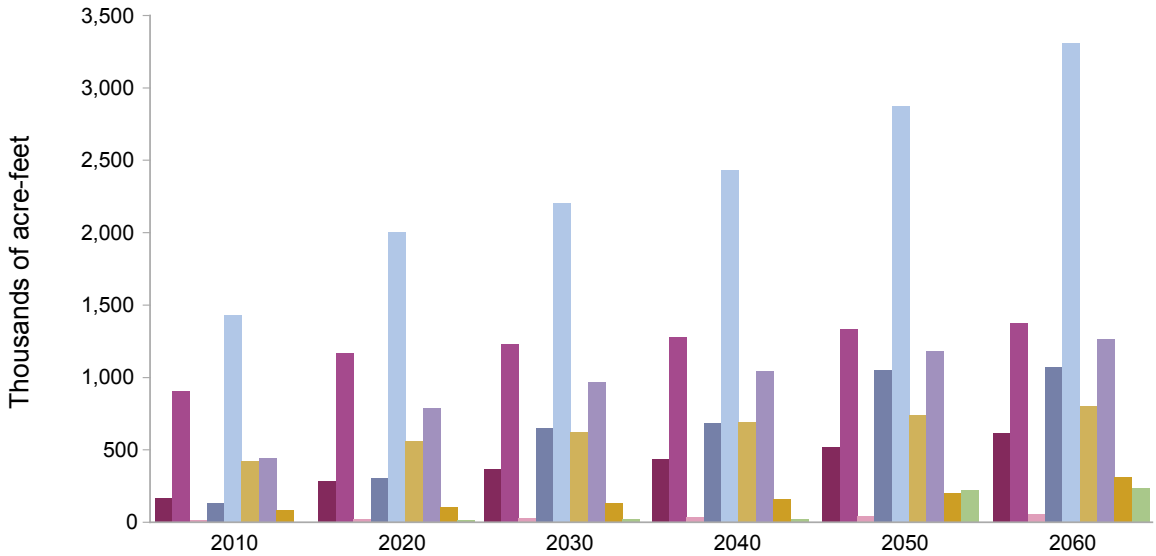
The planning groups also assessed how implementing water management strategies would affect water quality. All the planning groups identified key water quality parameters important for the use of water within their regions. These parameters were generally based on surface and groundwater quality standards and the list of impaired waters maintained and published by the Texas Commission on Environmental Quality. Other sources included water quality parameters and concerns identified by local and regional water management entities and concerns expressed by the public during the planning process. Key water quality parameters considered included bacteria, pH, dissolved oxygen, total suspended solids, temperature, nutrients, total dissolved solids, chlorides, nitrates, mercury, radionuclides, arsenic, salinity, and sediment.

10.2 Overview of Recommended Strategies

Planning groups recommended a variety of water management strategies to help meet needs in the future, including strategies that use water conservation, new or existing surface water supplies, new or existing groundwater supplies, conjunctive use of groundwater and surface water, water reuse, desalination, and land stewardship to provide additional water supplies. These strategies are projected to total 9.0 million acre-feet per year of new supplies by 2060 (Figure 10.2). Many strategies involve water conveyances from the source of water being recommended to meet a water supply need to the place of need (see section 10.2.8).

10.2.1 Water Conservation

Traditionally, water management strategies have focused on bringing water "into the pipe" through dams, reservoirs, and wells. In recent years, however, many communities have begun to focus on "end of the pipe" solutions through a common approach known as water conservation. At a fundamental level, water conservation involves managing existing water supplies to reduce demand and increase effciency of use. In other words, water managers and citizens collectively join forces to use less water in their homes and businesses and on their farms rather than building new projects to supply more of an already scarce resource. For water utilities and their customers, conservation programs are often more economical because they can postpone or eliminate the need for new infrastructure such as dams, wells, pipelines, and water treatment plants.



	2010	2020	2030	2040	2050	2060
Municipal conservation	164,672	286,226	364,924	437,714	519,441	616,679
Irrigation conservation	903,769	1,166,909	1,231,948	1,280,593	1,331,243	1,376,080
Other conservation[a]	10,636	20,276	30,130	37,115	45,128	54,092
New major reservoirs	132,863	306,663	646,993	681,498	1,051,128	1,072,128
Other surface water	1,426,449	2,002,895	2,204,909	2,432,839	2,873,271	3,309,990
Groundwater	424,429	563,081	622,381	691,671	736,609	799,209
Reuse	443,030	788,223	965,593	1,041,433	1,182,441	1,261,579
Desalination	84,295	101,522	130,164	159,922	200,866	312,887
Conjunctive use	1,131	15,244	18,700	18,701	223,090	231,567
Total	3,591,274	5,251,039	6,215,742	6,781,486	8,163,217	9,034,211

[a]Other conservation is associated with manufacturing, mining, and power industries.

Figure 10.2. Total new supply volumes generated by all recommended water management strategies over the planning period.

In recent years, the awareness and understanding of water conservation and water use efficiency has grown significantly in Texas. During the development of the 2006 Regional Water Plans, conservation has become increasingly important as a means to meet water supply needs.

A comparison of the 2007 State Water Plan to the 2002 State Water Plan shows the growing importance of water conservation in Texas. For example, recommended water management strategies for conservation in the 2002 State Water Plan generated 14 percent of the water needed to meet the state's needs in 2050—a total of about 990,000 acre-feet per year. In the 2007 State Water Plan, conservation accounts for nearly 23 percent of required water in 2060—a total of about 2 million acre-feet. These figures represent "active conservation," measures usually initiated by water utilities, individual businesses, residential water consumers, and agricultural producers to reduce water consumption. In addition, Texas will also save large amounts of water through as "passive water conservation." Passive water conservation involves water savings that result from state and federal legislation requiring plumbing manufacturers to sell more water-efficient plumbing fixtures, such as showerheads, faucets, and toilets. Active water conservation is above and beyond passive water conservation. TWDB estimates that passive conservation will reduce municipal water demand by 6.6 percent by 2060, which equals about 587,000 acre-feet, and statewide gallons per capita per day by 11.5 gallons.

Municipal Water Conservation

In state and regional water planning, municipal water conservation strategies focus on reducing residential, commercial, and institutional water use that typically involves water for drinking, cooking, cleaning, sanitation, air conditioning, and outdoor uses, such as landscape irrigation and swimming pools.

Municipal water conservation strategies focus on reducing these types of uses through a variety of social or technological approaches. Social approaches include changing water pricing structures to encourage more efficient water use and creating a greater awareness of the importance of conservation through promotional and educational campaigns. For example, programs such as bill explanation, plant tours, school programs, and educational and outreach activities have proven beneficial. Technological approaches include installing more efficient plumbing fixtures in homes and businesses.

In general, many communities throughout the state have taken great strides in developing municipal water conservation programs. Each city uses water conservation for different reasons. For example, the city of Austin wants to lower demand to meet a growing customer base; Corpus Christi hopes to postpone need for additional supply; El Paso has a limited long-term supply; and San Antonio has a limited existing water supply during drought conditions. However, water conservation is not limited to large cities. Many small- and medium-sized systems are also committed to increasing water use efficiency. To provide a unified conservation message, many smaller systems have partnered with

Table 10.1. Summary of recommended municipal water conservation management strategies in 2060

Region	New supplies from all recommended strategies (acre-feet per year)	New supplies from municipal conservation (acre-feet per year)	Percentage of all new supplies from municipal conservation	Estimated capital costs (millions of dollars)	Average annual unit costs per acre-foot of water [a] (dollars)
A	412,146	4,255	1	0.00	489
B	81,021	1,855	2	0.00	131
C	2,653,248	291,909	11	1.10	421
D	108,742	—	—	—	—
E	137,737	23,437	17	0.00	153
F	239,250	9,727	4	0.00	238
G	736,032	21,406	3	0.00	380
H	1,300,639	100,987	8	0.00	214
I	324,756	1,916	1	0.00	111
J	14,869	55	<1	0.00	419
K	861,930	51,315	6	0.00	209
L	732,779	72,566	10	0.00	442
M	807,587	24,412	3	8.77	141
N	149,496	2,415	2	0.00	333
O	441,511	10,424	2	0.00	863
P	32,468	—	—	—	—
Texas	9,034,211	616,679	7	9.87	234

Note: A dash indicates a value of zero.
[a]Reported figures are an average of unit costs in the first decade of strategy implementation and unit costs in 2060 weighted by the amount of water produced by a given strategy.

neighboring water systems in public-awareness campaigns to increase exposure, limit confusion, and reduce costs.

Municipal water conservation strategies identified by planning groups in their 2006 Regional Water Plans relied heavily on the Water Conservation Implementation Task Force's Best Management Practices Guide and include aggressive plumbing fixture replacement programs, water-efficient landscaping codes, water loss and leak detection programs, education and public awareness programs, rainwater harvesting, and changes in water rate structures. Fifteen of the 16 planning groups recommended municipal water conservation. Fourteen planning groups recommended it as a potential way to meet future municipal water needs (Table 10.1). In total, municipal water conservation strategies make up nearly 617,000 acre-feet (7 percent) of water generated by all recommend strategies by 2060.

When compared to the total volume of water generated by all recommended water management strategies, municipal water conservation strategies are an important source of water in many of the regions with large metropolitan areas, including Region E (17 percent), Region C (11 percent), Region H (8 percent), and Region L (10 percent). As noted previously, capital costs needed for implementing municipal water conservation programs are relatively small, amounting to about $9.9 million. Average operating costs per acre-feet of water generated from municipal water conservation strategies range from $111 per acre-foot in Region I to $863 in Region 0. The statewide average is $234 per acre-foot.

Agricultural Water Conservation

Irrigated agriculture has long been one of Texas' greatest water consumers. For example, irrigation currently accounts for about 60 percent of all water demand in the state, much of which consists of groundwater. By 2060, irrigation water demand is projected to decline to about 40 percent of total water demand in the state. Agricultural irrigation conservation programs have been widely promoted in areas of the state with large concentrations of irrigated crop production, such as the High Plains and Lower Rio Grande Valley.

Twelve of the 16 planning groups recommended agricultural water conservation as water management strategies to meet water needs including

- irrigation water use management, such as irrigation scheduling, volumetric measurement of water use, crop residue management, conservation tillage, and on-farm irrigation audits;
- land management systems, including furrow dikes, land leveling, conversion from irrigated to dry land farming, and brush control/management;
- on-farm delivery systems, such as lining of farm ditches, low pressure center pivot sprinkler systems, drip/micro irrigation systems, surge flow irrigation, and linear move sprinkler systems;
- water district delivery systems, including lining of district irrigation canals and replacing irrigation district and lateral canals with pipelines; and
- miscellaneous systems, such as water recovery and reuse.

In total, irrigation conservation strategies would generate nearly 1.4 million acre-feet of water in 2060, which equals about 37 percent of all irrigation water needs (Table 10.2). When compared to the total volume of water generated by all recommended water management strategies, agricultural water conservation is an important source of water where agriculture is a major economic sector. For example, Region A, Region O, and Region M collectively produce about 80 percent of irrigated crops in the state, with an economic value of around $1.5 billion annually. In total, these three planning groups recommended irrigation conservation strategies that would generate approximately 1 million acre-feet of water by 2060 (76 percent of the total water generated by irrigation conservation strategies in the state). Regions K, H, and J, which also produce substantial amounts of irrigated crops, adopted irrigation conservation strategies generating 222,333 acre-feet by 2060. Estimated capital costs for irrigation con-

Table 10.2. Summary of recommended irrigation water conservation management strategies in 2060

Region	New supplies from all recommended strategies (acre-feet per year)	New supplies from irrigation conservation (acre-feet per year)	Percentage of all new supplies from irrigation conservation	Estimated capital costs (millions of dollars)	Average annual unit costs per acre-foot of water[a] (dollars)
A	412,146	282,549	69	144.97	5
B	81,021	14,607	18	58.50	216
C	2,653,248	3,121	<1	0.00	211
D	108,742	—	—	—	—
E	137,737	—	—	—	—
F	239,250	72,247	30	43.15	51
G	736,032	8,027	1	0.00	154
H	1,300,639	77,881	6	0.62	83
I	324,756	—	—	—	—
J	14,869	1,452	10	<0.01	47
K	861,930	143,000	17	2.90	1
L	732,779	7,477	1	0.00	107
M	807,587	438,011	54	325.40	173
N	149,496	342	<1	0.00	171
O	441,511	327,366	74	353.51	65
P	32,468	—	—	—	—
Texas	9,034,211	1,376,080	15	929.06	77

Note: Dashes indicate a value of zero.
[a]Reported figures are an average of unit costs in the first decade of strategy implementation and unit costs in 2060 weighted by the amount of water produced by a given strategy.

servation are $929 million, and average operating costs per acre-feet of water generated range from $1 per acre-feet in Region K to $216 in Region B.

While many planning groups have adopted agricultural water conservation management strategies as a way to meet agricultural needs, implementing these strategies will be challenging for a variety of reasons. One overarching constraint, however, is economics. For on-farm water conservation practices, the cost per acre-foot for implementation, while lower than other water management strategies, is still cost-prohibitive for many individual farmers. In Region M, surface water rights and cost structures of irrigation districts may also provide disincentives for on-farm conservation. On the other hand, recent increases in energy costs are providing new economic incentives to adopt water conservation practices in areas that rely primarily on groundwater, such as Region A and Region O.

However, the immediate effect on farm income from these increases will limit farmers' abilities to invest in conservation practices that require capital expenditures.

To address economic and technical issues for implementing irrigation water conservation strategies, two large-scale, multiyear agricultural water conservation demonstration projects are underway in Region M and Region O to

- expedite the transfer of available water conservation technology to irrigated farms;
- develop comprehensive data using large-scale demonstration sites;
- assess the cost effectiveness of selected technologies; and
- evaluate and determine the impacts of conservation implementation on crop productivity, reduced irrigation water use, and available water supplies.

TWDB has developed partnerships to implement these projects, which will be used to support and enhance future agricultural conservation efforts. The projects represent major collaborative efforts by producers who volunteer their operations and time to the project to demonstrate cost-effective ways of implementing conservation strategies in the state. Several planning groups have also recommended continued and/or increased funding of federal and state financial and technical assistance for agricultural water conservation programs.

10.2.2 Strategies Using New and Existing Surface Water

Surface water management strategies generally consist of (1) building new reservoirs to impound surface waters or (2) managing existing surface waters through various approaches, such as moving water from one area to another through pipelines, purchasing additional water through contracts with major water providers, obtaining additional water rights, reallocating water in existing reservoirs, and changing the operating framework for a system of reservoirs (that is, system optimization).

In total, surface water strategies would produce about 4.4 million acre-feet of water in 2060 (Table 10.3). This represents a decrease from the 2002 State Water Plan of about 418,000 acre-feet. When compared to the total volume of water produced by all recommended strategies in the 2006 Regional Water Plans, surface water accounts for about 49 percent of the new supply for the state compared to nearly 66 percent in the 2002 State Water Plan. However, in some regions, surface water strategies make up the majority of new water, primarily in the eastern half of the state: Region C (61 percent), Region D (93 percent), Region G (70 percent), Region H (64 percent), Region I (92 percent), Region J (52 percent), and Region N (69 percent). Capital costs for surface water strategies total about $18 billion.

Planning groups recommended 14 new major reservoirs that would generate approximately 1.1 million acre-feet per year by 2060 (Table 10.3, Figure 10.3). These reservoirs account for about 12 percent of new water supplies at a capital cost of about $5 billion, which is 16 percent of total capital costs. The planning groups made the following recommendations:

Table 10.3. Summary of recommended surface water management strategies in 2060

Region	New supplies from all recommended strategies (acre-feet per year)	New supplies from surface water (acre-feet per year)		Percentage of all new supplies from surface water		Estimated capital costs (millions of dollars)		Average annual unit costs per acre-foot of water[a] (dollars)	
		New major reservoirs	Other surface water strategies	New major reservoirs	Other surface water strategies	New major reservoirs	Other surface water strategies	New major reservoirs	Other surface water strategies
A	412,146	—	3,750	—	1	—	72.27	—	1,122
B	81,021	—	51,875	—	64	—	89.08	—	198
C	2,653,248	746,540	874,102	28	33	3,338.57	6,461.72	354	331
D	108,742	—	100,636	—	93	—	4.82	—	362
E	137,737	—	20,000	—	15	—	103.49	—	408
F	239,250	—	90,075	—	38	—	30.12	—	36
G	736,032	36,520	477,101	5	65	89.06	493.58	186	208
H	1,300,639	129,520	707,393	10	54	567.79	4,206.81	223	88
I	324,756	75,700	222,875	23	69	387.11	190.36	643	197
J	14,869	—	7,690	—	52	—	6.65	—	124
K	861,930	—	398,215	—	46	—	15.23	—	66
L	732,779	—	98,214	—	13	—	853.37	—	887
M	807,587	20,643	169,460	3	21	66.55	230.62	537	539
N	149,496	42,005	61,615	28	41	304.21	186.55	684	493
O	441,511	21,200	26,500	5	6	150.76	230.58	688	1,186
P	32,468	—	489	—	2	—	—	—	na
Texas	9,034,211	1,072,128	3,309,990	12	37	4,904.05	13,175.25	374	254

Note: Dash indicates a value of zero and "na" indicates that data are not currently available.
[a]Reported figures are an average of unit costs in the first decade of strategy implementation and unit costs in 2060 weighted by the amount of water produced by a given strategy.

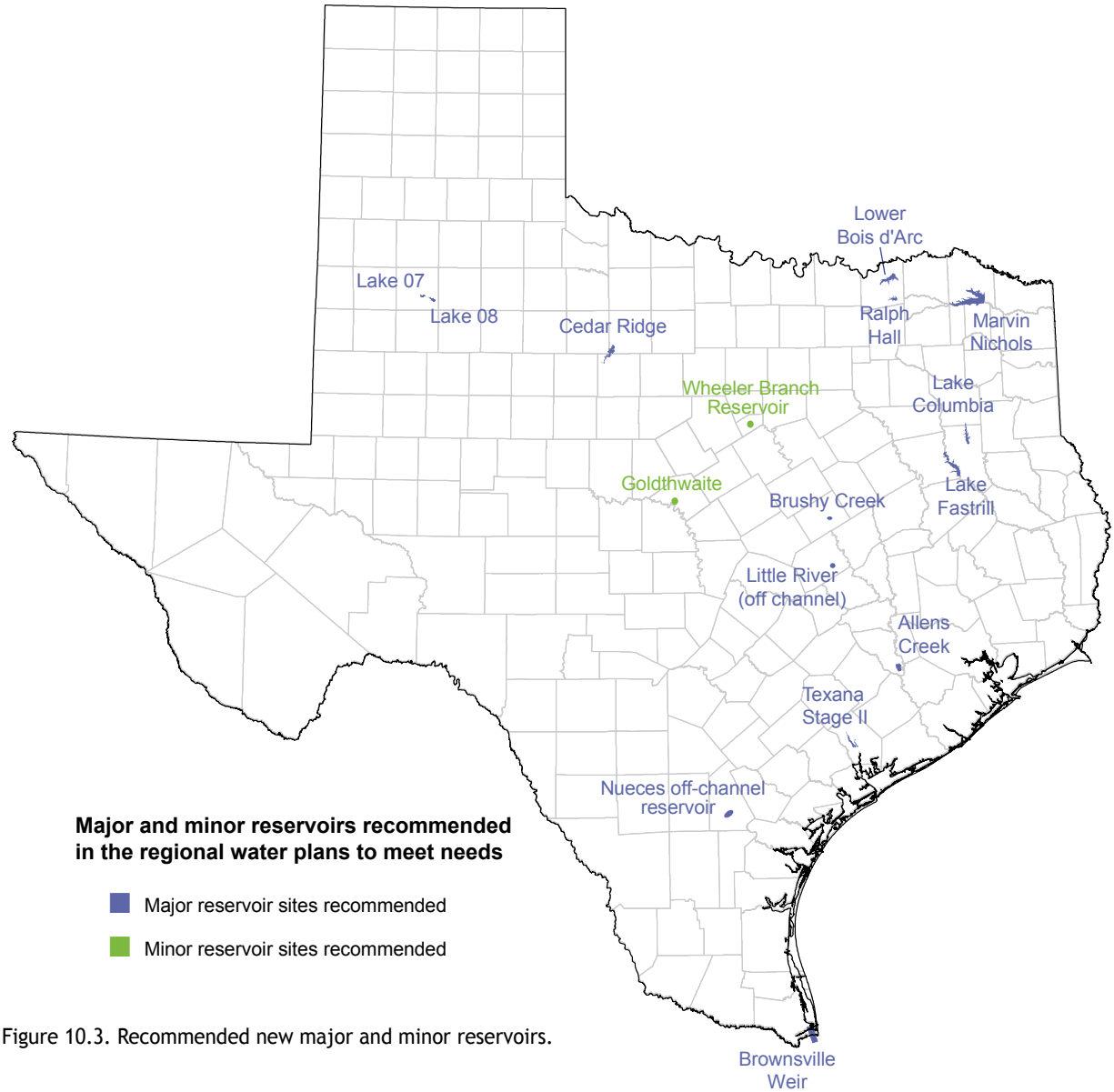


Figure 10.3. Recommended new major and minor reservoirs.

- Region C recommended four major reservoirs providing 28 percent of new supplies for the region in 2060 at a capital cost of about $3.3 billion
- Region G recommended two major reservoirs generating 5 percent of new supplies for the region at a capital cost of about $89 million
- Region H recommended two major reservoirs generating 10 percent of new supplies for the region at a capital cost of about $568 million
- Region I recommended one major reservoir providing 23 percent of new supplies for the region at a capital cost of about $387 million
- Region M recommended one major reservoir generating 3 percent of new supplies for the region at a capital cost of about $67 million
- Region N recommended two major reservoirs producing 28 percent of new supplies for the region at a capital cost of about $304 million
- Region O recommended two major reservoirs generating 5 percent of new supplies for the region at a capital cost of about $151 million

Average unit costs for reservoirs range from $186 per acre-foot in Region G to $688 per acre-foot in Region O. The statewide average unit cost for new major reservoirs is $374 per acre-foot. For other surface water strategies, average unit costs range anywhere from $36 per acre-foot in Region F to $1,186 per acre-foot in Region O, with the lower end reflecting costs of voluntary reallocation and purchases and the higher end representing costs of conveyance infrastructure.

The planning groups had the option of recommending unique reservoir sites and river and stream segments of unique ecological value for designation by the state legislature. A unique reservoir site is a location where a reservoir could be built. A river or stream segment of unique ecological value is a length of stream with distinctive ecological characteristics. Once designated as a unique reservoir site by the legislature, a state agency or political subdivision would not be allowed to purchase land or obtain an easement that would prevent the construction of a reservoir at the site. Similarly, once designated as a unique stream segment by the legislature, a state agency or political subdivision would not be allowed to finance the actual construction of a reservoir on that specific river or stream segment. This 2007 State Water Plan recommends that a total of 19 major and minor reservoir sites be designated by the legislature as unique reservoir sites. The planning groups recommended 11 unique reservoir sites (Figure 10.4), seven of which were recommended water management strategies. The remaining four recommended by planning groups as unique reservoir sites, Ringgold, Tehuacana, Little River, and Bedias, were not recommended as water management strategies to meet water supply needs over this planning horizon. TWDB is recommending eight additional unique reservoirs sites that were recommended by planning groups as water management strategies to meet water supply needs. TWDB's recommended sites include Cedar Ridge, Brushy Creek, Nueces River Off-Channel, Brownsville Weir, Wheeler Branch, and Goldthwaite. Fifteen river and stream segments of unique ecological value were recommended by two planning groups, seven for Region E (Figure 10.5) and eight for Region H (Figure 10.6).

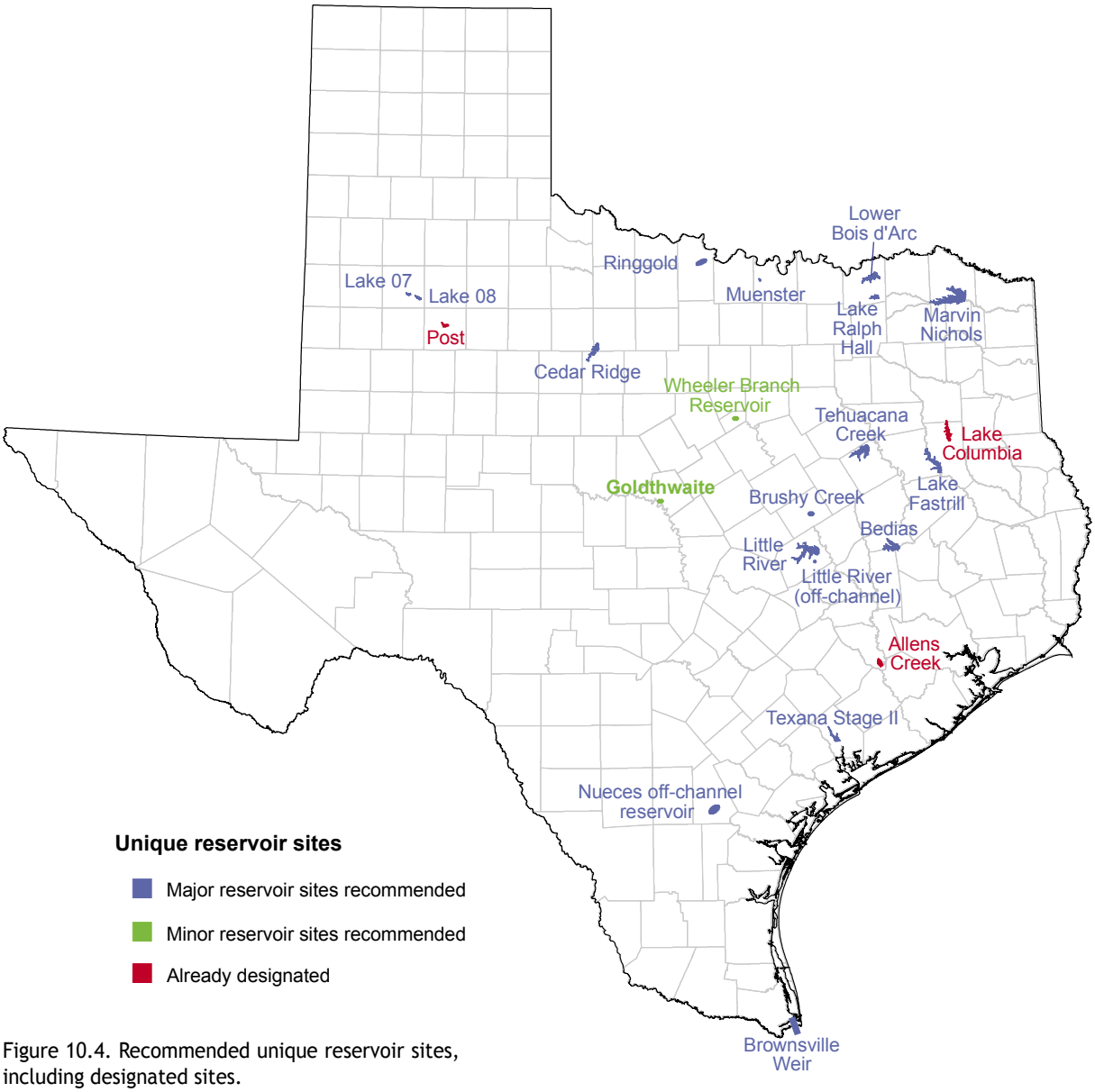


Figure 10.4. Recommended unique reservoir sites, including designated sites.

10.2.3 Strategies Using Groundwater

Recommended water management strategies using groundwater involve one or a combination of the following: (1) installing new wells; (2) increasing pumping from existing wells; (3) installing supplemental wells; (4) temporarily overdrafting of aquifers during drought conditions to supplement water supplies; (5) expanding treatment plants to make groundwater supplies meet water quality standards; and (6) reallocating and/

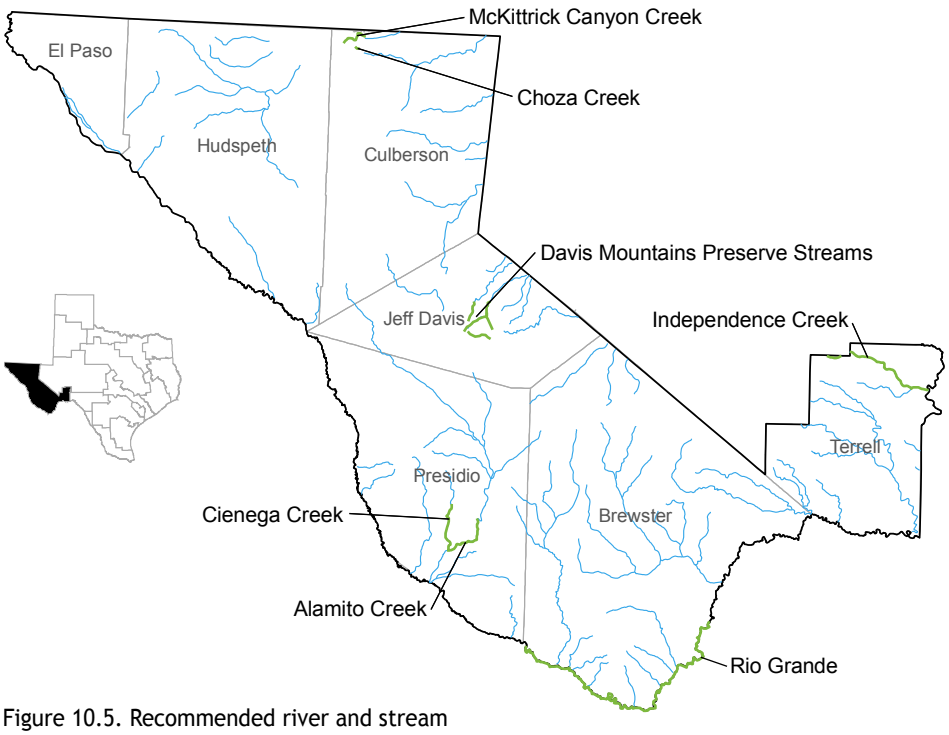


Figure 10.5. Recommended river and stream segments of unique ecological value in Region E.

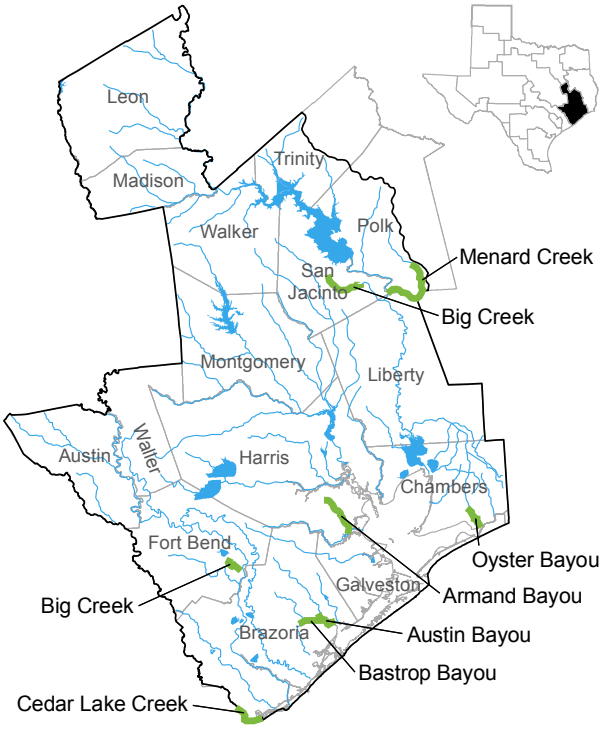


Figure 10.6. Recommended river and stream segments of unique ecological value in Region H.

or transferring groundwater supplies from areas where projections indicate that surplus groundwater will exist to areas with water needs.

Water management strategies relying on groundwater account for about 9 percent of the total projected water volume to be provided by all recommended water management strategies on a statewide basis in 2060, about 0.8 million acre-feet (Table 10.4). This represents an increase of about 20,000 acre-feet in 2050 from the 2002 State Water Plan. In terms of volume, recommended groundwater management strategies are the largest for Region L (206,111 acre-feet per year in 2060) and Region A (117,220 acre-feet per year in 2060). Total capital costs for groundwater strategies amount to about $2.3 billion, and average annual unit costs range from $33 per acre-foot in Region P to $634 per acre-foot in Region D. The statewide average unit cost for groundwater is $260 per acre-foot.

10.2.4 Strategies Using Water Reuse

Water reuse is an increasingly attractive water management strategy to meet water supply needs (see Chapter 8, Water Reuse). On a statewide basis, recommended water reuse strategies will generate about 1.3 million acre-feet in 2060 (Table 10.5), which accounts for about 14 percent

of new water supplies to be provided from all recommended water management strategies. This represents a substantial increase when compared to the 2002 State Water Plan in which reuse made up about 6 percent (about 420,000 acre-feet) of new water supplies in 2050.

On a regional basis, Region C recommended reuse strategies that would produce about 720,000 acre-feet by 2060—nearly 27 percent of new water for the region. Reuse in Region H totals about 170,000 acre-feet per year by 2060, and regions K, L, and M collectively recommended over 240,000 acre-feet per year by 2060. Estimated capital costs for reuse strategies amount to about $4.0 billion, and average annual unit costs range from $100 to $1,259 per acre-foot of water generated, with a statewide average of $248 per acre-foot.

10.2.5 Strategies Using Desalination

Simply put, desalination is converting saline water to usable water. Today, desalination technology has been proven both reliable and cost effective in areas where water is scarce. Eight planning groups recommended desalinating brackish groundwater or seawater as a water management strategy. In total, recommended desalination projects would create about 313,000 acre-feet per year of new water supplies by 2060, with 44 percent of this water coming from seawater desalination and 56 percent coming from brackish groundwater desalination (Table 10.6). Desalination accounts for about 3 percent of all new water supplies from recommended water management strategies in 2060. Capital costs to implement recommended desalination water management strategies total about $2.6 billion. Average annual costs per acre-foot range from $768 to $1,390 for seawater desalination and $429 to $953 for brackish groundwater desalination.

10.2.6 Strategies Using Conjunctive Use

Conjunctive use water management strategies involve the combined use of groundwater and surface water in a way that optimizes the beneficial characteristics of each source. An example

Table 10.4. Summary of recommended groundwater management strategies in 2060

Region	New supplies from all recommended strategies (acre-feet per year)	New supplies from groundwater (acre-feet per year)	Percentage of all new supplies from groundwater	Estimated capital costs (millions of dollars)	Average annual unit costs per acre-foot of water[a] (dollars)
A	412,146	117,220	28	343.34	193
B	81,021	1,550	2	5.09	590
C	2,653,248	12,639	<1	449.53	96
D	108,742	7,806	7	27.76	634
E	137,737	26,191	19	36.78	204
F	239,250	38,270	16	251.83	490
G	736,032	41,075	6	86.71	443
H	1,300,639	90,993	7	173.15	122
I	324,756	21,589	7	32.36	183
J	14,869	5,672	38	7.72	120
K	861,930	95,742	11	65.45	93
L	732,779	206,111	28	713.96	399
M	807,587	31,416	4	43.98	359
N	149,496	20,535	14	48.34	537
O	441,511	50,421	11	43.99	136
P	32,468	31,979	98	0.00	33
Texas	9,034,211	799,209	9	2,329.99	260

[a]Reported figures are an average of unit costs in the first decade of strategy implementation and unit costs in 2060 weighted by the amount of water produced by a given strategy.

of conjunctive use is when water providers use surface water as their primary source of water supply and groundwater to meet peak day needs or to supplement supply during times of drought. Region K, Region L, and Region G recommended conjunctive use strategies in their regional water plans. New supplies provided from these recommended water management strategies in Region L would total about 180,000 acre-feet per year by 2060. This includes water provided from the Lower Colorado River Authority and San Antonio Water System Water Project that is projected to generate 150,000 acre-feet of new water supplies by 2060 through conjunctive use of groundwater from the Gulf Coast Aquifer and surface water

Table 10.5. Summary of recommended water reuse management strategies in 2060

Region	New supplies from all recommended strategies (acre-feet per year)	New supplies from water reuse (acre-feet per year)	Percentage of all new supplies from water reuse	Estimated capital costs (millions of dollars)	Average annual unit costs per acre-foot of water[a] (dollars)
A	412,146	2,700	1	1.83	100
B	81,021	11,134	14	49.60	761
C	2,653,248	722,320	27	2,952.01	113
D	108,742	300	<1	0.00	na
E	137,737	18,109	13	45.84	249
F	239,250	12,710	5	100.89	627
G	736,032	81,728	11	103.68	320
H	1,300,639	165,865	13	256.45	561
I	324,756	2,676	1	3.6	214
J	14,869	—	—	—	—
K	861,930	144,090	17	178.06	268
L	732,779	51,676	7	189.31	449
M	807,587	45,781	6	52.39	559
N	149,496	250	<1	1.50	725
O	441,511	2,240	1	29.75	1,259
P	32,468	—	—	—	—
Texas	9,034,211	1,261,579	14	3,964.91	248

Note: Dash indicates a value of zero and "na" indicates that data are not currently available.
[a] Reported figures are an average of unit costs in the first decade of strategy implementation and unit costs in 2060 weighted by the amount of water produced by a given strategy.

supplies from the Colorado River. In Region G, conjunctive use strategies would produce about 54,000 acre-feet per year of new supplies by 2060. Capital costs for both regions are about $2.8 billion, and average annual unit costs are $749 per acre-foot in Region G and $1,244 per acre-foot in Region L.

10.2.7 Strategies Using Land Stewardship

One of the suggested water management strategies emerging in this round of water supply planning is voluntary land stewardship. There is a relationship between the condition of a watershed and the quality and quantity of water that percolates to aquifers or runs off to streams and rivers. In some parts of the state, it is thought that improving the condition of the watershed's vegetative cover can help clean and increase the amount of water for human use and the environment. Land stewardship practices that help control nuisance vegetation, maintain and restore suitable vegetation in riparian areas, reseed with native plants, maintain open space land and wildlife habitat, conserve wetlands, and control erosion through reduction of overgrazing will promote the health and efficiency of the state's watersheds and should be encouraged.

A component of land stewardship that has garnered much attention is brush control, which involves reducing vegetation that consumes large volumes of water that would otherwise recharge aquifers or flow in rivers and streams in many areas of the state. Region G recommended brush control as a water management strategy to meet irrigation needs; however, potential supplies generated by brush control are difficult to quantify and, as a result, are not included in their regional total.

10.2.8 Major Conveyances

To deliver water to areas with needs, several new water conveyance systems are included as a component of many water management strategies. These conveyance systems connect existing waters sources that are not currently physically available to a water user. Although determining precise conveyance routes was beyond the level of detail required for regional water planning, the general location of the recommended conveyance structures illustrates that most of the water supplies will be conveyed to larger urban areas of the state (Table 10.7, Figure 10.7).

Detailed information on planning group recommended water management strategies are included in Chapter 2, Appendix 2.1, and Volume III.

Table 10.6. Summary of recommended desalination water management strategies in 2060

Region	New supplies from all recommended strategies (acre-feet per year)	New supplies from desalination (acre-feet per year)		Percentage of all new supplies from desalination		Estimated capital costs (millions of dollars)		Average annual unit costs per acre-foot of water[a] (dollars)	
		Seawater desalination	Brackish desalination	Seawater desalination	Brackish desalination	Seawater desalination	Brackish desalination	Seawater desalination	Brackish desalination
A	412,146	—	—	—	—	—	—	—	—
B	81,021	—	—	—	—	—	—	—	—
C	2,653,248	—	—	—	—	—	—	—	—
D	108,742	—	—	—	—	—	—	—	—
E	137,737	—	50,000	—	36	—	502.74	—	953
F	239,250	—	16,221	—	7	—	131.45	—	599
G	736,032	—	—	—	—	—	—	—	—
H	1,300,639	28,000	—	2	—	255.70	—	1,300	—
I	324,756	—	—	—	—	—	—	—	—
J	14,869	—	—	—	—	—	—	—	—
K	861,930	—	29,568	—	3	—	96.54	—	429
L	732,779	84,012	5,662	11	1	891.32	93.41	1,390	903
M	807,587	7,902	69,962	1	9	15.94	342.47	768	537
N	149,496	18,200	—	12	—	248.92	—	1,341	—
O	441,511	—	3,360	—	1	—	10.05	—	506
P	32,468	—	—	—	—	—	—	—	—
Texas	9,034,211	138,114	174,773	2	2	1,411.88	1,176.66	1,351	671

Note: Dash indicates a value of zero.

[a]Reported figures are an average of unit costs in the first decade of strategy implementation and unit costs in 2060 weighted by the amount of water produced by a given strategy.

Table 10.7. Major water conveyances proposed by planning groups

ID	Conveyance from	To
1	Potter County	Amarillo
2	Roberts County	Amarillo
3	Palo Duro Reservoir	Hansford, Hutchinson, and Moore counties
4	Wichita Falls	Electra
5	Lake Kemp/Diversion System	Archer, Clay, and Wichita counties
6A	Toledo Bend Reservoir	Lake Fork
6B	Lake Fork	Cooper Lake then Lake Lavon
6C	Lake Fork	Lake Tawakoni then Cedar Creek Reservoir
7A	Marvin Nichols Reservoir	Lake Lavon
7B	Lake Lavon	Lewisville Lake
7C	Lewisville Lake	Eagle Mountain Lake
8A	Hugo Lake in southeast Oklahoma	Lavon Lake
8B	Lake Lavon	Lewisville Lake
8C	Lewisville Lake	Eagle Mountain Lake
9	Lake Wright Patman	Dallas Water Utilities
10	Richland-Chambers and Cedar Creek reservoirs	Tarrant Regional Water District
11	Lower Bois d'Arc Reservoir	North Texas Municipal Water District
12	Lake Fork	Dallas Water Utilities
13	Lake Texoma	North Texas Municipal Water District
14	Lake Ralph Hall	Denton and Collin counties
15	Lake Fastrill	Dallas Water Utilities
16	Lake Palestine	Dallas Water Utilities
17	Trinity River near Crandall	Lake Lavon
18	Hudspeth and Culberson counties	Dell City then El Paso
19	Winkler County	Odessa
20	Winkler County	Midland
21	Capitan Reef Aquifer	Odessa
22	Concho and McCulloch counties	San Angelo
23	Brazos River at Johnson County	Johnson County
24	Lake Whitney	Hill County
25	Brazos River at Grimes County	Grimes County
26	Milam County	Lake Granger
27	Lake Travis	Williamson County
28	Lake Fork	Rusk County
29	Kerr County	Kerrville
30	Lower Colorado River	Bexar County
31	Lower Guadalupe River	Hays and Kendall counties
32	Gonzales and Wilson counties	Bexar County
33	Bastrop, Caldwell, and Fayette counties	Hays County
34	Gonzales County/Lake Dunlap	Guadalupe and Bexar counties
35	Desalination plant	Bexar County
36	Wilson County	Bexar County
37	Choke Canyon Reservoir	Lake Corpus Christi
38	Corpus Christi	San Patricio County
39	Lower Colorado River	Lake Texana
40	Lake Alan Henry	Lubbock
41	Lubbock	Constructed wetlands on tributary of White River

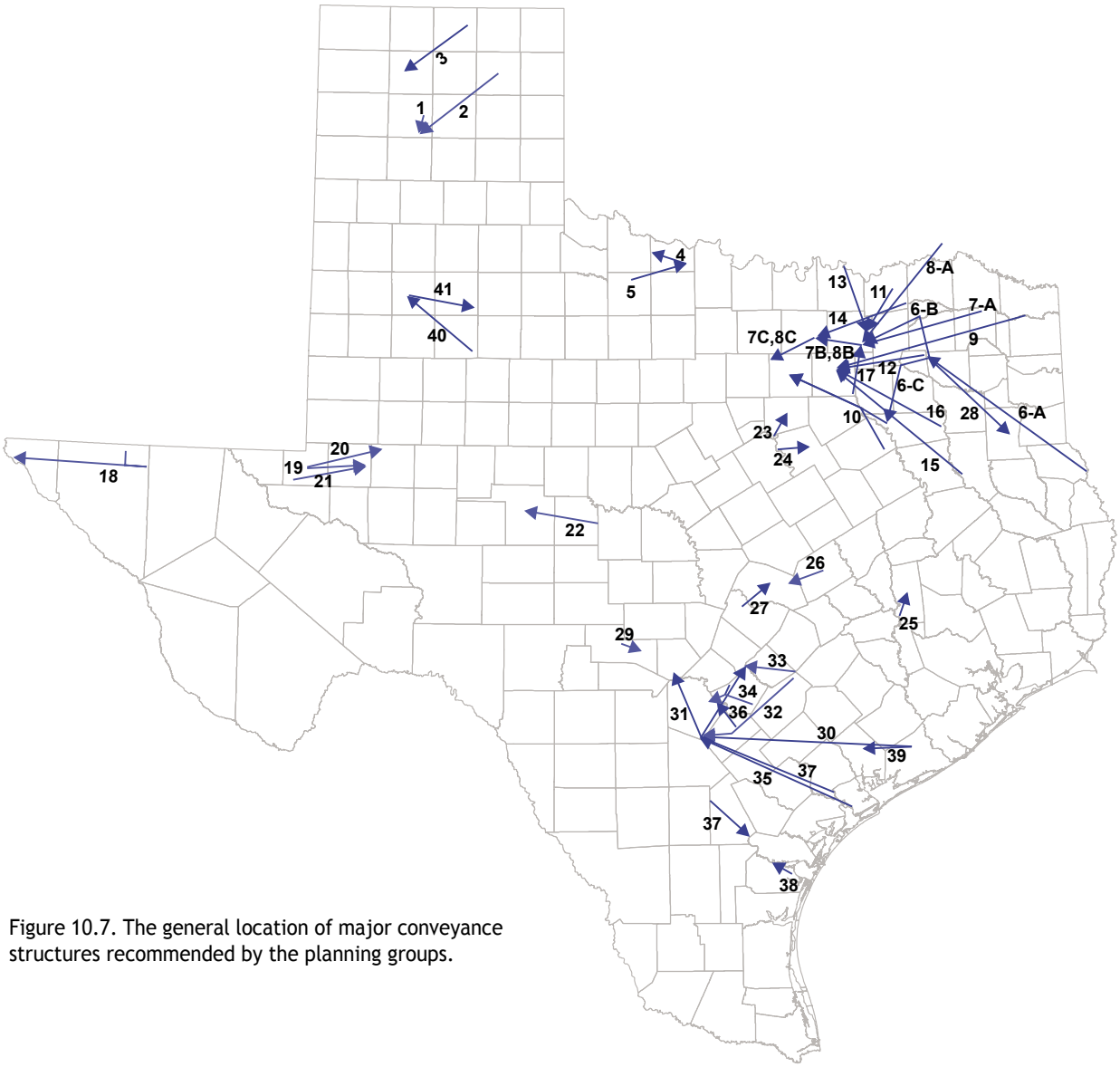


Figure 10.7. The general location of major conveyance structures recommended by the planning groups.

In Your Area
Citizens' Advisory Committees
Texas Corridors
New Toll Roads
Congestion Relief
Safer Roads & Evacuations
Economic Opportunities
Connecting Communities
Local Control
Better Air Quality
Project Funding Options
Stay Informed
Events & Public Hearings
Question or Comment?
News
e-Newsletters
Podcast
FAQs
Sitio en Español

I-69/TTC - Tier One DEIS

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The I-69/TTC Tier One Draft Environmental Impact Statement (DEIS) was released for public review and comment on November 9, 2007. Use the links below to view the DEIS; visit the Environmental Studies and Maps page to learn more about the DEIS and the I-69/TTC environmental process. Please click on document title to see a document description.

View Detailed Maps of Recommended Preferred Alternative (narrowed study area)

Volume 1

Draft Environmental Impact Statement

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Appendix I

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Galveston District Projects

Mouth of the Colorado River / Colorado River Locks

- Main Page
  - Mouth of Colorado River
  - GIWW Mods - Colorado River Locks
  - Modeling Efforts
  - What are our plans

The Mouth of the Colorado River and the Colorado River Locks/GIWW projects are closely entwined not only by proximity but also by the impacts that changes in these projects can have on one another. Variable environmental conditions such as river discharge rates and tides complicate the interaction further. While these projects fall under separate authorities with different regulations, both projects must be included in any analysis. This has led to some confusion concerning study purposes, authority, and scope. The following web pages document the background of both projects, the study progress and describes the models that have been developed to better understand issues associated with the projects and the impacts proposed measures will have on the projects.

This is an official US Government webpage. This webpage is intended to provide information of general interest to the public. The information contained herein is accurate as of the date of publication.

Technical Assistance

For technical difficulties with this website please contact the webmaster.

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Updated: December 09, 2005

U.S. ENVIRONMENTAL PROTECTION AGENCY

Facility Registry System (FRS)

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Facility Detail Report

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FRS

FORMOSA POINT COMFORT PLANT

201 FORMOSA DRIVE
POINT COMFORT, TX 77978
EPA Registry Id: 110018925957

Legend

- Selected Facility
- EPA Facility of Interest
- State/Tribe Facility of Interest

The facility locations displayed come from the FRS Spatial Coordinates tables. They are the best representative locations for the displayed facilities based on the accuracy of the collection method and quality assurance checks performed against each location. The North American Datum of 1983 is used to display all coordinates.

Environmental Interests

Information System	Information System ID	Environmental Interest Type	Data Source	Last Updated Date	Supplemental Environmental Interests:
AIR FACILITY SYSTEM	4805700015	AIR MAJOR ()	AIRS/AFS	09/29/2009	**ICIS**-ENFORCEMENT/COMPLIANCE ACTIVITY
AIR FACILITY SYSTEM	4805700026	AIR MAJOR ()	AIRS/AFS	07/22/2009	
COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION AND LIABILITY INFORMATION SYSTEM	TXN000606638	SUPERFUND	CERCLIS		
FACILITY RESPONSE PLANS	R6-TX-00580	OIL CONTROL	FRP		
INTEGRATED COMPLIANCE INFORMATION SYSTEM	10622	FORMAL ENFORCEMENT ACTION	ICIS	01/18/2001	**ICIS**-06-1995-0007 FORMAL ENFORCEMENT ACTION **ICIS**-06-1995-0032 FORMAL ENFORCEMENT ACTION **ICIS**-06-1995-0144 FORMAL ENFORCEMENT ACTION
INTEGRATED COMPLIANCE INFORMATION SYSTEM	35898	FORMAL ENFORCEMENT ACTION	ICIS	07/14/2000	**ICIS**-06-1995-0369 FORMAL ENFORCEMENT ACTION **ICIS**-06-1995-0370 FORMAL ENFORCEMENT ACTION **ICIS**-06-2000-0886 FORMAL ENFORCEMENT ACTION
					ICIS-06-1995-0369 FORMAL ENFORCEMENT ACTION **ICIS**-06-1995-0370

INTEGRATED COMPLIANCE INFORMATION SYSTEM	35898	ENFORCEMENT/COMPLIANCE ACTIVITY	ICIS	07/06/2005	FORMAL ENFORCEMENT ACTION **ICIS**-06-2000-0886 FORMAL ENFORCEMENT ACTION
INTEGRATED COMPLIANCE INFORMATION SYSTEM	600015829	ENFORCEMENT/COMPLIANCE ACTIVITY	ICIS	04/16/2007	
INTEGRATED COMPLIANCE INFORMATION SYSTEM	6680061	FORMAL ENFORCEMENT ACTION	ICIS	10/05/2004	**ICIS**-HQ-2004-5042 FORMAL ENFORCEMENT ACTION
NATIONAL COMPLIANCE DATABASE	D06#VI-605C(T)	COMPLIANCE ACTIVITY	NCDB		
NATIONAL COMPLIANCE DATABASE	D11#T-HQ-2004-0011	COMPLIANCE ACTIVITY	NCDB		
NATIONAL COMPLIANCE DATABASE	I06#1993051833711	COMPLIANCE ACTIVITY	NCDB		
NATIONAL COMPLIANCE DATABASE	I06#1993051833712	COMPLIANCE ACTIVITY	NCDB		
NATIONAL COMPLIANCE DATABASE	I06#19930518TX0111	COMPLIANCE ACTIVITY	NCDB		
NATIONAL COMPLIANCE DATABASE	I11#20030703SC 2	COMPLIANCE ACTIVITY	NCDB		
NATIONAL EMISSIONS INVENTORY	NEI6976	CRITERIA AND HAZARDOUS AIR POLLUTANT INVENTORY	NEI		
NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (ICIS-NPDES)	TX0085570	ICIS-NPDES MAJOR	ICIS	08/30/2005	**ICIS**-ENFORCEMENT/COMPLIANCE ACTIVITY
PERMIT COMPLIANCE SYSTEM	TX0085570	NPDES MAJOR	NPDES PERMIT	07/07/2004	
RACT/BACT/LAER CLEARINGHOUSE	2182	AIR MAJOR	RBLC		
RACT/BACT/LAER CLEARINGHOUSE	2183	AIR MAJOR	RBLC		
RACT/BACT/LAER CLEARINGHOUSE	2367	AIR MAJOR	RBLC		
RACT/BACT/LAER CLEARINGHOUSE	2368	AIR MAJOR	RBLC		
RACT/BACT/LAER CLEARINGHOUSE	2370	AIR MAJOR	RBLC		
RACT/BACT/LAER CLEARINGHOUSE	2371	AIR MAJOR	RBLC		
RACT/BACT/LAER CLEARINGHOUSE	25140	AIR MAJOR	RBLC		
RACT/BACT/LAER CLEARINGHOUSE	25486	AIR MAJOR	RBLC		
RACT/BACT/LAER CLEARINGHOUSE	25504	AIR MAJOR	RBLC		
RESOURCE CONSERVATION AND RECOVERY ACT INFORMATION SYSTEM	TX0000888164	CESQG (ACTIVE)	NOTIFICATION (RCRA)	04/25/2008	
RESOURCE CONSERVATION AND RECOVERY ACT INFORMATION SYSTEM	TXT490011293	CORRECTIVE ACTION (ACTIVE)	RCRAINFO	01/14/2010	**ICIS**-06-2006-3410 FORMAL ENFORCEMENT ACTION
RESOURCE CONSERVATION AND RECOVERY ACT INFORMATION SYSTEM	TXT490011293	HAZARDOUS WASTE BIENNIAL REPORTER (ACTIVE)	RCRAINFO	12/31/2007	**ICIS**-06-2006-3410 FORMAL ENFORCEMENT ACTION
RESOURCE CONSERVATION AND RECOVERY ACT INFORMATION SYSTEM	TXT490011293	LQG (ACTIVE)	NOTIFICATION (RCRA)	01/14/2010	**ICIS**-06-2006-3410 FORMAL ENFORCEMENT ACTION
RESOURCE CONSERVATION AND RECOVERY ACT INFORMATION SYSTEM	TXT490011293	TSD (ACTIVE)	NOTIFICATION (RCRA)	01/14/2010	**ICIS**-06-2006-3410 FORMAL ENFORCEMENT ACTION
RISK MANAGEMENT PLAN	100000125429	RMP REPORTER	RMP REPORTING FORM	02/16/2006	
SECTION SEVEN TRACKING SYSTEM	085374TX001	PESTICIDE PRODUCER	SSTS		
TOXIC RELEASE INVENTORY SYSTEM	77978FRMSPPOBOX	TRI REPORTER	TRI REPORTING FORM	06/26/2009	
					PERMIT-1484 AIR OPERATING PERMITS **PERMIT**-1484 AIR PROGRAM **PERMIT**-17030 AIR NEW SOURCE PERMITS **PERMIT**-17030 AIR PROGRAM **PERMIT**-17158 AIR NEW SOURCE PERMITS **PERMIT**-17158 AIR PROGRAM **PERMIT**-19166 AIR NEW SOURCE PERMITS **PERMIT**-19166 AIR PROGRAM **PERMIT**-19167 AIR NEW SOURCE PERMITS **PERMIT**-19167 AIR PROGRAM

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TEXAS COMMISSION ON ENVIRONMENTAL QUALITY - AGENCY CENTRAL REGISTRY	RN100218973	STATE MASTER	TX-TCEQ ACR		AIR NEW SOURCE PERMITS **PERMIT**-52259 AIR PROGRAM **PERMIT**-52859 AIR NEW SOURCE PERMITS **PERMIT**-52859 AIR PROGRAM **PERMIT**-56837 AIR NEW SOURCE PERMITS **PERMIT**-56837 AIR PROGRAM **REGISTRATION**-74103 AIR NEW SOURCE PERMITS **REGISTRATION**-74103 AIR PROGRAM **REGISTRATION**-75974 AIR NEW SOURCE PERMITS **REGISTRATION**-75974 AIR PROGRAM **PERMIT**-76044 AIR NEW SOURCE PERMITS **PERMIT**-76044 AIR PROGRAM **PERMIT**-76305 AIR NEW SOURCE PERMITS **PERMIT**-76305 AIR PROGRAM **PERMIT**-7699 AIR NEW SOURCE PERMITS **PERMIT**-7699 AIR PROGRAM **REGISTRATION**-78089 AIR NEW SOURCE PERMITS **REGISTRATION**-78089 AIR PROGRAM **REGISTRATION**-78769 AIR NEW SOURCE PERMITS **REGISTRATION**-78769 AIR PROGRAM **REGISTRATION**-78946 AIR NEW SOURCE PERMITS **REGISTRATION**-78946 AIR PROGRAM **REGISTRATION**-79567 AIR NEW SOURCE PERMITS **REGISTRATION**-79567 AIR PROGRAM **REGISTRATION**-79826 AIR NEW SOURCE PERMITS **REGISTRATION**-79826 AIR PROGRAM **REGISTRATION**-80198 AIR NEW SOURCE PERMITS **REGISTRATION**-80198 AIR PROGRAM **REGISTRATION**-81027 AIR NEW SOURCE PERMITS **REGISTRATION**-81027 AIR PROGRAM **REGISTRATION**-81109 AIR NEW SOURCE PERMITS **REGISTRATION**-81109 AIR PROGRAM **SOLID WASTE REGISTRA**-82613 HAZARDOUS WASTE PROGRAM **SOLID WASTE REGISTRA**-82613 INDUSTRIAL AND HAZARDOUS WASTE GENERATION **REGISTRATION**-83308 AIR NEW SOURCE PERMITS **REGISTRATION**-83308 AIR PROGRAM **REGISTRATION**-83326 AIR NEW SOURCE PERMITS **REGISTRATION**-83326 AIR PROGRAM **REGISTRATION**-83489 AIR NEW SOURCE PERMITS **REGISTRATION**-83489 AIR PROGRAM **REGISTRATION**-83608 AIR NEW SOURCE PERMITS **REGISTRATION**-83608 AIR PROGRAM **REGISTRATION**-83763 AIR NEW SOURCE PERMITS

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					UIC **PERMIT**-WDW402 UNDERGROUND INJECTION CONTROL **PERMIT**-WDW403 UIC **PERMIT**-WDW403 UNDERGROUND INJECTION CONTROL **PERMIT**-WQ0002436000 NPDES PERMIT **PERMIT**-WQ0002436000 WASTEWATER **REGISTRATION**-86288 AIR PROGRAM **REGISTRATION**-84730 AIR PROGRAM **REGISTRATION**-86396 AIR PROGRAM **REGISTRATION**-86403 AIR PROGRAM **REGISTRATION**-85100 AIR PROGRAM **REGISTRATION**-84589 AIR PROGRAM **REGISTRATION**-84788 AIR PROGRAM **REGISTRATION**-86398 AIR PROGRAM **REGISTRATION**-85081 AIR PROGRAM **PERMIT**-87363 AIR PROGRAM **REGISTRATION**-88447 AIR PROGRAM
TEXAS COMMISSION ON ENVIRONMENTAL QUALITY - AGENCY CENTRAL REGISTRY	RN102353018	STATE MASTER	TX-TCEQ ACR		**REGISTRATION**-61453 UNDERGROUND STORAGE TANK PROGRAM **REGISTRATION**-61453 PETROLEUM STORAGE TANK REGISTRATION
TEXAS COMMISSION ON ENVIRONMENTAL QUALITY - AGENCY CENTRAL REGISTRY	RN104939830	STATE MASTER	TX-TCEQ ACR		**PERMIT**-TXR15BF87 NPDES STORMWATER PERMIT **PERMIT**-TXR15BF87 STORMWATER

Additional EPA Reports: MyEnvironment Enforcement and Compliance Cleanups in My Community Site Demographics Watershed Report

Standard Industrial Classification Codes (SIC)

Data Source	SIC Code	Description	Primary
AIRS/AFS	1321	NATURAL GAS LIQUIDS	
TX-TCEQ ACR	2821	PLASTICS MATERIALS, SYNTHETIC RESINS, AND NONVULCANIZABLE ELASTOMERS	
RBLC	2821	PLASTICS MATERIALS, SYNTHETIC RESINS, AND NONVULCANIZABLE ELASTOMERS	
AIRS/AFS	4922	NATURAL GAS TRANSMISSION	
NCDB	2821	PLASTICS MATERIALS, SYNTHETIC RESINS, AND NONVULCANIZABLE ELASTOMERS	
FRS	2821	PLASTICS MATERIALS, SYNTHETIC RESINS, AND NONVULCANIZABLE ELASTOMERS	
ICIS	4225	GENERAL WAREHOUSING AND STORAGE	
AIRS/AFS	2812	ALKALIES AND CHLORINE	
RBLC	2821	PLASTICS MATERIALS, SYNTHETIC RESINS, AND NONVULCANIZABLE ELASTOMERS	
AIRS/AFS	2821	PLASTICS MATERIALS, SYNTHETIC RESINS, AND NONVULCANIZABLE ELASTOMERS	
ICIS	2861	GUM AND WOOD CHEMICALS	
FRS	4412	DEEP SEA FOREIGN TRANSPORTATION OF FREIGHT	
TRIS	2831		
TX-TCEQ ACR	2821	PLASTICS MATERIALS, SYNTHETIC RESINS, AND NONVULCANIZABLE ELASTOMERS	
PCS	2821	PLASTICS MATERIALS, SYNTHETIC RESINS, AND NONVULCANIZABLE ELASTOMERS	
TRIS	2869	INDUSTRIAL ORGANIC CHEMICALS, NOT ELSEWHERE CLASSIFIED	

National Industry Classification System Codes (NAICS)

Data Source	NAICS Code	Description	Primary
TRIS	325181	ALKALIES AND CHLORINE MANUFACTURING.	
RMP	325211	PLASTICS MATERIAL AND RESIN MANUFACTURING.	
FRS	486210	PIPELINE TRANSPORTATION OF NATURAL GAS.	
RMP	482111	LINE-HAUL RAILROADS.	
FRS	325181	ALKALIES AND CHLORINE MANUFACTURING.	
FRS	325211	PLASTICS MATERIAL AND RESIN MANUFACTURING.	
RMP	483111	DEEP SEA FREIGHT TRANSPORTATION.	
RCRAINFO	325211	PLASTICS MATERIAL AND RESIN MANUFACTURING.	
FRS	486910	PIPELINE TRANSPORTATION OF REFINED PETROLEUM PRODUCTS.	
TX-TCEQ ACR	325181	ALKALIES AND CHLORINE MANUFACTURING.	
TRIS	325199	ALL OTHER BASIC ORGANIC CHEMICAL MANUFACTURING.	
TX-TCEQ ACR	325211	PLASTICS MATERIAL AND RESIN MANUFACTURING.	
TRIS	325211	PLASTICS MATERIAL AND RESIN MANUFACTURING.	
FRS	211112	NATURAL GAS LIQUID EXTRACTION.	
RMP	325181	ALKALIES AND CHLORINE MANUFACTURING.	
FRS	325191	GUM AND WOOD CHEMICAL MANUFACTURING.	
RCRAINFO	325211	PLASTICS MATERIAL AND RESIN MANUFACTURING.	
NEI	325211	PLASTICS MATERIAL AND RESIN MANUFACTURING.	

Facility Mailing Addresses

FRS	4011	RAILROADS, LINE-HAUL OPERATING	
NPDES	2821	PLASTICS MATERIALS, SYNTHETIC RESINS, AND NONVULCANIZABLE ELASTOMERS	
ICIS	2821	PLASTICS MATERIALS, SYNTHETIC RESINS, AND NONVULCANIZABLE ELASTOMERS	
TRIS	2821	PLASTICS MATERIALS, SYNTHETIC RESINS, AND NONVULCANIZABLE ELASTOMERS	
RBLC	2821	PLASTICS MATERIALS, SYNTHETIC RESINS, AND NONVULCANIZABLE ELASTOMERS	
ICIS	4613	REFINED PETROLEUM PIPELINES	
TX-TCEQ ACR	2812	ALKALIES AND CHLORINE	
FRS	2812	ALKALIES AND CHLORINE	
NEI	2821	PLASTICS MATERIALS, SYNTHETIC RESINS, AND NONVULCANIZABLE ELASTOMERS	
NCDB	2869	INDUSTRIAL ORGANIC CHEMICALS, NOT ELSEWHERE CLASSIFIED	

Facility Codes and Flags

EPA Region:	06
Duns Number:	626617351
Congressional District Number:	14
Legislative District Number:	14
HUC Code/Watershed:	12100401 / CENTRAL MATAGORDA BAY
US Mexico Border Indicator:	NO
Federal Facility:	NO
Tribal Land:	NO

Alternative Names

Alternative Name	Source of Data
FORMOSA PLASTICS CORP	NCDB
FORMOSA PLASTICS CORP. TEXAS	TRI REPORTING FORM
FORMOSA PLASTICS CORP-POINT COMFORT	NOTIFICATION (RCRA)
FORMOSA PLASTICS TEXAS	RBLC
FORMOSA PLASTIC	TX-TCEQ ACR
POINT COMFORT CRYOGENIC GAS PLANT	AIRS/AFS
FORMOSA PLASTIC CORP.	RBLC
FORMOSA HYDROCARBONS COMPANY, INC.	AIRS/AFS
POINT COMFORT	ICIS
FORMOSA UTILITY VENTURE LTD &	NPDES PERMIT
FORMOSA PLASTICS CORP.	RBLC
FORMOSA PLASTICS TEXAS	RBLC
POINT COMFORT FACILITY	FRP
FORMOSA PLASTICS SVPC PROJECT CONSTRUCTION ACTIVITIES	TX-TCEQ ACR
FORMOSA PLASTICS CORP USA	NPDES PERMIT
FORMOSA PLASTICS CORPORATION	RBLC
FORMOSA PLASTICS PLANT EXPLOSION	CERCLIS
FORMOSA PLASTICS CORPORATION	AIRS/AFS

Organizations

Affiliation Type	Name	DUNS Number	Information System	Mailing Address
OWNER	FORMOSA UTILITY VENTURE, LTD.		NPDES	View
OWNER OPERATOR	SUN COAST RESOURCES, INC.		TX-TCEQ ACR	View
MAILING ADDRESS	FORMOSA UTILITY VENTURE LTD &		NPDES	View
OWNER	FORMOSA PLASTICS CORPORATION TEXAS		RCRAINFO	View
OWNER	FORMOSA PLASTICS CORP	039944004	SSTS	View
OPERATOR	FORMOSA PLASTICS CORPORATION, TEXAS		TX-TCEQ ACR	View
OWNER	FORMOSA PLASTICS CORPORATION TEXAS		RCRAINFO	View
	FORMOSA PLASTICS			

Affiliation Type	Delivery Point	City Name	State	Postal Code	Information System
FACILITY MAILING ADDRESS	PO BOX 700	POINT COMFORT	TX	77978	RCRAINFO
OWNER/OPERATOR	201 FORMOSA DRIVE	POINT COMFORT	TX	779780000	RMP
FACILITY MAILING ADDRESS	PO BOX 700	POINT COMFORT	TX	77978	TRIS
OWNER	& FORMOSA PLASTICS CORPORATION	POINT COMFORT	TX	779780700	NPDES
PUBLIC CONTACT	PO BOX 700	POINT COMFORT		77978	RBLC
PUBLIC CONTACT	201 FORMOSA DR., PO BOX 700	POINT COMFORT	TX	77978	RBLC
OPERATOR	101 FORMOSA DR SHORE TANK FARM	POINT COMFORT	TX	77978	RCRAINFO
MAILING ADDRESS	201 FORMOSA DR	POINT COMFORT	TX	77978	TX-TCEQ ACR
FACILITY MAILING ADDRESS	201 FORMOSA DRIVE	POINT COMFORT	TX	77978	FRP
OWNER OPERATOR	PO BOX 689	EL CAMPO	TX	774370689	TX-TCEQ ACR
FACILITY MAILING ADDRESS	P.O. BOX 700	POINT COMFORT	TX	77978	AIRS/AFS
MAILING ADDRESS	FORMOSA PLASTICS CORPORATION	POINT COMFORT	TX	77978	NPDES
OWNER	& FORMOSA PLASTICS CORPORATION	POINT COMFORT	TX	779780700	PCS
OWNER	PO BOX 700	POINT COMFORT	TX	77978	RCRAINFO
OWNER	122 C STREET, NW, STE 740	WASHINGTON	DC	20001	SSTS
OPERATOR	PO BOX 700	POINT COMFORT	TX	779780700	TX-TCEQ ACR
PRIMARY MAILING ADDRESS	FORMOSA PLASTICS CORPORATION	POINT COMFORT	TX	77978	PCS
REGULATORY CONTACT	PO BOX 700	POINT COMFORT	TX	77978	RCRAINFO
OPERATOR	PO BOX 700	POINT COMFORT	TX	77978	RCRAINFO
FACILITY MAILING ADDRESS	PO BOX 700	POINT COMFORT		77978	SSTS
OWNER OPERATOR	PO BOX 700	POINT COMFORT	TX	779780700	TX-TCEQ ACR
OWNER	PO BOX 550	EL CAMPO	TX	774370550	TX-TCEQ ACR

Contacts

Affiliation Type	Full Name	Office Phone	Information System	Mailing Address
COMPLIANCE CONTACT	HEATHER SIMON	5129877000	AIRS/AFS	
PUBLIC CONTACT			RBLC	
PUBLIC CONTACT	JOHN T. HYAK	361-987-7455	RBLC	View
PUBLIC CONTACT	JIM SHEPHARD	3619877701	TRIS	
REGULATORY CONTACT	MATT BROGGER	3619877468	RCRAINFO	View
COGNIZANT OFFICIAL	R.P. SMITH, VP/GEN. MGR.	3619877000	PCS	
PUBLIC CONTACT			RBLC	
PUBLIC CONTACT			RBLC	
PUBLIC CONTACT	W. KEN MOUNGER	512-987-7000	RBLC	View
COMPANY OFFICIAL	RANDY SMITH	3619877000	SSTS	

OPERATOR	CORPORATION TEXAS		RCRAINFO	View
OWNER	FORMOSA PLASTICS CORPORATION TEXAS		RCRAINFO	View
OPERATOR	FORMOSA PLASTICS CORPORATION TEXAS		RCRAINFO	View
OPERATOR	FORMOSA PLASTICS CORPORATION TEXAS		RCRAINFO	View
OPERATOR	FORMOSA PLASTICS CORPORATION TEXAS		RCRAINFO	View
PARENT COMPANY 1	FORMOSA PLASTICS CORPORATION, USA	39944004	RMP	
OWNER/OPERATOR		056312770	TRIS	
OWNER OPERATOR	FORMOSA PLASTICS CORPORATION, TEXAS		TX-TCEQ ACR	View
OWNER	MAURITZ & COUEY TRANSPORTATION, L.L.C.		TX-TCEQ ACR	View
OPERATOR	FORMOSA PLASTICS CORPORATION TEXAS		RCRAINFO	View
OWNER/OPERATOR	FORMOSA PLASTICS CORPORATION, TEXAS	56312770	RMP	View
OWNER	FORMOSA UTILITY VENTURE, LTD.		PCS	View
OWNER	FORMOSA PLASTICS CORPORATION TEXAS		RCRAINFO	View
PARENT ORGANIZATION	FORMOSA PLASTICS CORP USA	039944004	TRIS	

PUBLIC CONTACT			RBLC	
PUBLIC CONTACT			RBLC	
RESPONSIBLE PARTY	RANDALL P. SMITH	3619877000	RMP	
COMPLIANCE CONTACT	MR. JOHN BLOOM	5129877467	AIRS/AFS	
PUBLIC CONTACT			RBLC	
CONTACT	DAVID HILL	(512)987-7000	FRP	
REGULATORY CONTACT	MATT BROGGER	3619877468	RCRAINFO	View
EMERGENCY CONTACT	SHANE BURGIN	3619877465	RMP	
PUBLIC CONTACT	JOHN T. HYAK	361-987-7455	RBLC	View

Query executed on: FEB-25-2010

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Superfund Site Information

Site Documents

Data Element Dictionary (DED)

Order Superfund Products

Superfund Site Progress Profile
ALCOA (POINT COMFORT)/LAVACA BAY (EPA ID: TXD008123168)

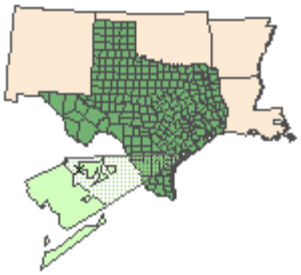
This profile provides you with information on EPA's cleanup progress at this Superfund site. This information includes: Site Location, Cleanup Progress Summary, Cleanup Impact Summary, Contamination, and Cleanup Progress. Please use the links and the "More Details..." box to find more details on this site.

The data and content on this page were last updated on Wednesday, February 24, 2010.

More Details...

- More In-Depth Site Details (EPA Regional Content)
- Site Contacts (EPA Cleanup Managers, etc.)
- Additional Site Documents
- Other Names for this Site (Aliases)
- View GPRA Measures at this Site (see glossary)

Site Location



Get an interactive map

EPA Region 6 >
Serving Louisiana, Arkansas, Oklahoma, New Mexico, Texas and 66 tribes

Site Address: POINT COMFORT, Texas 77979

County: CALHOUN

U.S. Congressional District: 14

Population within one mile: 5,001-10,000

Cleanup Progress Summary

Construction Complete

Physical cleanup activities have been completed.

view detailed list of cleanup activities at this site >>

The National Priorities List (NPL) is the list of the most hazardous sites across the U.S. and its territories.

This site is on the NPL and is known as a Final NPL site (see glossary).

Potentially Responsible Parties (PRPs) were involved in the cleanup effort (see glossary).

Superfund law requires that EPA give communities information about site progress and plans so that they can be

Cleanup Impact Summary

At each site, EPA assesses the risk to humans and the environment and determines the best approach to address the risk. During initial site studies and cleanup, EPA determines if current human exposures to contaminants are under control and takes actions to control any possible human exposures until cleanup has been completed. Once complete, cleanup provides long-term human health and environmental protection at the site.

OK Current human exposures at this site are under control

see glossary definition for "Human Exposure Environmental Indicator Measure." >>

At each site with known ground water contamination, EPA documents whether ground water contamination is below protective risk-based levels or, if not, whether the migration of contaminated ground water is stabilized.

OK Contaminated ground water migration is under control

see glossary definition for "Contaminated Ground Water Migration Environmental Indicator Measure." >>

actively involved in site cleanup decisions. Learn more about community involvement at this site >>

Contamination

Contaminants (i.e., hazardous substances, pollutants or contaminants) can be found in several different types of materials on the site including soil and other solid-based media and water or another liquid-based medium (see glossary).

The contaminants listed via the links below are considered the contaminants of concern (see glossary) to be addressed by cleanup actions at the site.

Contaminated Media: Sediment, Soil

EPA classifies contaminants found into groups or types (listed below). To view all contaminants of concern at the site click on the "view contaminants of concern at this site" link.

Types of Contaminants: Metals, PAH

see glossary definition for "types of contaminants" >>

view contaminants of concern at this site >>

ATSDR ToxFacts information on contaminants EXIT disclaimer

^^ back to top | view glossary >>

Cleanup Progress

Major Site Cleanup Milestones

see glossary definitions for major site cleanup milestones >>

Proposed to the NPL	Listed as Final on the NPL	1st Cleanup Action Initiated	Final Remedy Selected	Construction Complete	Deleted from the NPL
06/23/1993	02/23/1994	08/17/1998	12/20/2001	07/23/2007	

Cleanup Activities At This Site

see glossary definitions for cleanup activities >>

There are many stages of cleanup, including site study, remedy selection, remedy design, remedy construction, and post-construction. Activities undertaken early in the cleanup process focus on understanding problems at the site while those taken later in the cleanup process focus on physically

addressing those problems identified.

Many NPL sites are large and complicated. These sites are often broken up into smaller areas to make cleanup easier and more manageable. These areas are called “Operable Units” or OUs (see glossary).

The chart below shows the different types of activities that are underway or complete at each of the cleanup areas (operable units) at the site. Some activities apply to the entire site; EPA assigns these activities to the site-wide operable unit (designated as OU 0).

Cleanup Areas (Operable Units)	Removal *	Study and Remedy Selection	Remedy Design	Remedy Construction	Post-Construction
OU 1		12/20/2001	03/01/2005	08/22/2007	
OU 0	06/05/2001				

Complete Underway

view activities details >> view OU details >>
more in-depth site details (EPA Regional Content)

* At many sites an action, called a “Removal Action” (see glossary), must be taken to eliminate immediate and near-term threats to human health and the environment. Removal actions do not occur at all sites.

Community Involvement

The goals of the Superfund community involvement (CI) program are to: 1) keep communities affected by sites informed throughout the cleanup process, 2) provide opportunities for communities to comment and offer their input about site cleanup plans, and 3) facilitate the resolution of community issues tied to a site. EPA accomplishes these goals by providing communities different tools and resources to support their site involvement. These resources include independent technical assistance so community members can understand the technical aspects of a site, a public forum for community members to present and discuss their needs and concerns related to the Superfund decision making process, and a job training program to encourage employment of local workers. These are just some of the CI program's resources; to learn more, go to http://www.epa.gov/superfund/community/.

To find out more about community involvement activities at this Superfund site and how you can become involved in site cleanup/reuse decisions, view a list of contacts for this site >>.

Land Reuse

EPA places a high priority on land revitalization as an integral part of its Superfund response program mission, so EPA tries to select cleanup options that encourage and support future use of a site. Sites made ready for use are deemed "Site-wide Ready for Anticipated Use" (see glossary), which means, in part, that all cleanup goals have been achieved for both current and reasonably anticipated future land use.

This site currently does not meet the criteria for Site-wide Ready for Anticipated Use, however parts of the site may be suitable for reuse.

Post-Construction

Post-Construction (see glossary) is the stage following completion of the remedy construction. It includes, among other things, activities such as operating the remedy to address the contamination (e.g., ground water pump and treat); implementing, monitoring, and enforcing institutional controls; and a review of the implemented remedies at least every five years to ensure they continue to protect human health and the environment.

Institutional controls (see glossary) such as administrative or legal restrictions may also be components of remedies at a site that remain in place post-construction completion.

Sites or portions of sites may be deleted (see glossary) from the National Priorities List when all

cleanup goals have been achieved.

This site has not been deleted from the National Priorities List

^^ back to top | view glossary >>

DISCLAIMER: Be advised that the data contained in these profiles are intended solely for informational purposes use by employees of the U.S. Environmental Protection Agency for management of the Superfund program. They are not intended for use in calculating Cost Recovery Statutes of Limitations and cannot be relied upon to create any rights, substantive or procedural, enforceable by any party in litigation with the United States. EPA reserves the right to change these data at any time without public notice.

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Facility Detail Report

Report an Error

EQUISTAR CHEMICALS LP MATAGOR DA FACILITY

HIGHWAY 60 13M S BAY CITY
BAY CITY, TX 77414
EPA Registry Id: 110006126717

Legend

- Selected Facility
- EPA Facility of Interest
- State/Tribe Facility of Interest

The facility locations displayed come from the FRS Spatial Coordinates tables. They are the best representative locations for the displayed facilities based on the accuracy of the collection method and quality assurance checks performed against each location. The North American Datum of 1983 is used to display all coordinates.

Environmental Interests

Information System	Information System ID	Environmental Interest Type	Data Source	Last Updated Date	Supplemental Environmental Interests:
AIR FACILITY SYSTEM	4832100026	AIR MAJOR ()	AIRS/AFS	08/18/2009	
NATIONAL EMISSIONS INVENTORY	NEI7749	CRITERIA AND HAZARDOUS AIR POLLUTANT INVENTORY	NEI		
NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (ICIS-NPDES)	TX0087173	ICIS-NPDES NON-MAJOR	ICIS	06/03/2009	ICIS-ENFORCEMENT/COMPLIANCE ACTIVITY
PERMIT COMPLIANCE SYSTEM	TX0087173	NPDES NON-MAJOR	NPDES PERMIT	06/03/2009	
RESOURCE CONSERVATION AND RECOVERY ACT INFORMATION SYSTEM	TXD980796643	HAZARDOUS WASTE BIENNIAL REPORTER (ACTIVE)	RCRAINFO	12/31/2007	
RESOURCE CONSERVATION AND RECOVERY ACT INFORMATION SYSTEM	TXD980796643	LQG (ACTIVE)	NOTIFICATION (RCRA)	01/27/2010	
RISK MANAGEMENT PLAN	100000037417	RMP REPORTER	RMP REPORTING FORM	06/17/2004	
TOXIC RELEASE INVENTORY SYSTEM	77483CNCHM13MIL	TRI REPORTER	TRI REPORTING FORM	06/25/2009	

Additional EPA Reports: MyEnvironment Enforcement and Compliance Site Demographics Watershed Report

Standard Industrial Classification Codes (SIC)

Data Source	SIC Code	Description	Primary
NEI	2821	PLASTICS MATERIALS, SYNTHETIC RESINS, AND NONVULCANIZABLE ELASTOMERS	

National Industry Classification System Codes (NAICS)

Data Source	NAICS Code	Description	Primary
NEI	325211	PLASTICS MATERIAL AND RESIN MANUFACTURING.	

TRIS	2821	PLASTICS MATERIALS, SYNTHETIC RESINS, AND NONVULCANIZABLE ELASTOMERS	
NPDES	2821	PLASTICS MATERIALS, SYNTHETIC RESINS, AND NONVULCANIZABLE ELASTOMERS	
AIRS/AFS	2821	PLASTICS MATERIALS, SYNTHETIC RESINS, AND NONVULCANIZABLE ELASTOMERS	
PCS	2821	PLASTICS MATERIALS, SYNTHETIC RESINS, AND NONVULCANIZABLE ELASTOMERS	
FRS	2821	PLASTICS MATERIALS, SYNTHETIC RESINS, AND NONVULCANIZABLE ELASTOMERS	

Facility Codes and Flags

EPA Region:	06
Duns Number:	118495126, 011256893
Congressional District Number:	14
Legislative District Number:	12
HUC Code/Watershed:	12090402 / EAST MATAGORDA BAY
US Mexico Border Indicator:	NO
Federal Facility:	NO
Tribal Land:	NO

Alternative Names

Alternative Name	Source of Data
EQUISTAR CHEMICALS L.P. MATAGORDA FACILITY	TRI REPORTING FORM
EQUISTAR CHEMICALS LP MATAGORDA FACILITY	TRI REPORTING FORM
EQUISTAR CHEMICALS, LP	NPDES PERMIT
LYONDELL PETROCHEMICAL CO	RCRAINFO
LYONDELL PETROLEUM COMPANY	AIRS/AFS
EQUISTAR MATAGORDA PLANT	AIRS/AFS
EQUISTAR CHEMICALS, LP MATAGORDA PLANT	RMP REPORTING FORM

Organizations

Affiliation Type	Name	DUNS Number	Information System	Mailing Address
PARENT COMPANY 1	EQUISTAR CHEMICALS, LP	969557263	RMP	
OWNER	EQUISTAR CHEMICALS, LP		PCS	View
OWNER	EQUISTAR CHEMICALS, LP		PCS	View
MAILING ADDRESS	EQUISTAR CHEMICALS, LP		NPDES	View
OWNER	EQUISTAR CHEMICALS, LP		PCS	View
OPERATOR	EQUISTAR CHEMICALS LP		RCRAINFO	View
OWNER	EQUISTAR CHEMICALS LP		RCRAINFO	View
OWNER	EQUISTAR CHEMICALS, LP		NPDES	View
OPERATOR	EQUISTAR CHEMICALS LP		RCRAINFO	View
OWNER/OPERATOR		118495126	AIRS/AFS	
OPERATOR	EQUISTAR CHEMICALS LP		RCRAINFO	View
PARENT COMPANY 1	EQUISTAR CHEMICALS, LP	969557263	RMP	
PARENT COMPANY 1	EQUISTAR CHEMICALS, LP	969557263	RMP	
OWNER/OPERATOR		118495126	TRIS	
OWNER/OPERATOR	EQUISTAR CHEMICALS, LP	111481511	RMP	View
OWNER	EQUISTAR CHEMICALS LP		RCRAINFO	View
OWNER	EQUISTAR CHEMICALS LP		RCRAINFO	View
PARENT ORGANIZATION	EQUISTAR CHEMICALS LP	969557263	TRIS	

FRS	325211	PLASTICS MATERIAL AND RESIN MANUFACTURING.	
TRIS	325211	PLASTICS MATERIAL AND RESIN MANUFACTURING.	
RMP	325211	PLASTICS MATERIAL AND RESIN MANUFACTURING.	
RCRAINFO	325211	PLASTICS MATERIAL AND RESIN MANUFACTURING.	

Facility Mailing Addresses

Affiliation Type	Delivery Point	City Name	State	Postal Code	Information System
OWNER	PO BOX 2100	BAY CITY	TX	77404	RCRAINFO
OPERATOR	PO BOX 2100	BAY CITY	TX	77404	RCRAINFO
OWNER	PO BOX 2100	BAY CITY	TX	774042100	PCS
MAILING ADDRESS	P. O. BOX 2100	BAY CITY	TX	77414	NPDES
FACILITY MAILING ADDRESS	1221 MCKINNEY, #1600	HOUSTON	TX	77253	AIRS/AFS
OWNER	PO BOX 2100	BAY CITY	TX	774042100	NPDES
PRIMARY MAILING ADDRESS	P. O. BOX 2100	BAY CITY	TX	77414	PCS
FACILITY MAILING ADDRESS	PO BOX 2100	BAY CITY	TX	77414	RCRAINFO
REGULATORY CONTACT	PO BOX 2100	BAY CITY	TX	77414	RCRAINFO
FACILITY MAILING ADDRESS	PO BOX 2100	BAY CITY	TX	774042100	TRIS
OWNER/OPERATOR	P.O. BOX 2100	BAY CITY	TX	77414	RMP

Contacts

Affiliation Type	Full Name	Office Phone	Information System	Mailing Address
PUBLIC CONTACT	MICHAEL VANDERSNICK	9792447104	TRIS	
COMPLIANCE CONTACT	BRIAN MEEK	4092447184	AIRS/AFS	
EMERGENCY CONTACT	SHIFT SUPERVISOR	9792447145	RMP	
REGULATORY CONTACT	RONALD SANDERS	9792447175	RCRAINFO	View
RESPONSIBLE PARTY	SHELLY HEUSER	9792447184	RMP	

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Facility Registry System (FRS)

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Facility Detail Report

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CELANESE BAY CITY PLANT

HIGHWAY 3057 10 MILES SOUTHWEST OF BAY CITY
BAY CITY, TX 77414
EPA Registry Id: 110000728062

Legend

- Selected Facility
- EPA Facility of Interest
- State/Tribe Facility of Interest

The facility locations displayed come from the FRS Spatial Coordinates tables. They are the best representative locations for the displayed facilities based on the accuracy of the collection method and quality assurance checks performed against each location. The North American Datum of 1983 is used to display all coordinates.

Environmental Interests

Information System	Information System ID	Environmental Interest Type	Data Source	Last Updated Date	Supplemental Environmental Interests:
AIR FACILITY SYSTEM	4832100005	AIR MAJOR ()	AIRS/AFS	07/22/2009	
INTEGRATED COMPLIANCE INFORMATION SYSTEM	31098	FORMAL ENFORCEMENT ACTION	ICIS	07/30/1997	**ICIS**-06-1988-0508 FORMAL ENFORCEMENT ACTION **ICIS**-06-1995-0388 FORMAL ENFORCEMENT ACTION
NATIONAL COMPLIANCE DATABASE	I06#19950726122291	COMPLIANCE ACTIVITY	NCDB		
NATIONAL COMPLIANCE DATABASE	I06#19950726122292	COMPLIANCE ACTIVITY	NCDB		
NATIONAL EMISSIONS INVENTORY	NEI12063	CRITERIA AND HAZARDOUS AIR POLLUTANT INVENTORY	NEI		
NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (ICIS-NPDES)	TX0006017	ICIS-NPDES MAJOR	ICIS	06/08/2009	**ICIS**-ENFORCEMENT/COMPLIANCE ACTIVITY
PERMIT COMPLIANCE SYSTEM	TX0006017	NPDES MAJOR	NPDES PERMIT	06/08/2009	
RESOURCE CONSERVATION AND RECOVERY ACT INFORMATION SYSTEM	TXD026040709	CORRECTIVE ACTION (ACTIVE)	RCRAINFO	08/27/2009	
RESOURCE CONSERVATION AND RECOVERY ACT INFORMATION SYSTEM	TXD026040709	HAZARDOUS WASTE BIENNIAL REPORTER (ACTIVE)	RCRAINFO	12/31/2007	
RESOURCE CONSERVATION AND RECOVERY ACT INFORMATION SYSTEM	TXD026040709	LQG (ACTIVE)	NOTIFICATION (RCRA)	08/27/2009	
RESOURCE CONSERVATION AND RECOVERY ACT INFORMATION SYSTEM	TXD026040709	TSD (ACTIVE)	NOTIFICATION (RCRA)	08/27/2009	
RISK MANAGEMENT PLAN	100000096932	RMP REPORTER	RMP REPORTING	02/28/2007	

			FORM		
TOXIC RELEASE INVENTORY SYSTEM	77414HCHSTPOBOX	TRI REPORTER	TRI REPORTING FORM	06/29/2009	

Additional EPA Reports: MyEnvironment Enforcement and Compliance Cleanups in My Community Site Demographics Watershed Report

Standard Industrial Classification Codes (SIC)

Data Source	SIC Code	Description	Primary
NPDES	2869	INDUSTRIAL ORGANIC CHEMICALS, NOT ELSEWHERE CLASSIFIED	
AIRS/AFS	2869	INDUSTRIAL ORGANIC CHEMICALS, NOT ELSEWHERE CLASSIFIED	
FRS	2823	CELLULOSIC MANMADE FIBERS	
ICIS	7997	MEMBERSHIP SPORTS AND RECREATION CLUBS	
ICIS	5331	VARIETY STORES	
ICIS	2865	CYCLIC ORGANIC CRUDES AND INTERMEDIATES, AND ORGANIC DYES AND PIGMENTS	
PCS	2869	INDUSTRIAL ORGANIC CHEMICALS, NOT ELSEWHERE CLASSIFIED	
TRIS	2869	INDUSTRIAL ORGANIC CHEMICALS, NOT ELSEWHERE CLASSIFIED	
NEI	2869	INDUSTRIAL ORGANIC CHEMICALS, NOT ELSEWHERE CLASSIFIED	

National Industry Classification System Codes (NAICS)

Data Source	NAICS Code	Description	Primary
TRIS	325199	ALL OTHER BASIC ORGANIC CHEMICAL MANUFACTURING.	
RMP	325199	ALL OTHER BASIC ORGANIC CHEMICAL MANUFACTURING.	
TRIS	325221	CELLULOSIC ORGANIC FIBER MANUFACTURING.	
NEI	325110	PETROCHEMICAL MANUFACTURING.	
FRS	452990	ALL OTHER GENERAL MERCHANDISE STORES.	
TRIS	325000		
RCRAINFO	325199	ALL OTHER BASIC ORGANIC CHEMICAL MANUFACTURING.	

Facility Codes and Flags

EPA Region:	06
Duns Number:	
Congressional District Number:	14
Legislative District Number:	12
HUC Code/Watershed:	12090302 / LOWER COLORADO
US Mexico Border Indicator:	NO
Federal Facility:	NO
Tribal Land:	NO

Facility Mailing Addresses

Affiliation Type	Delivery Point	City Name	State	Postal Code	Information System
REGULATORY CONTACT	PO BOX 509	BAY CITY	TX	77404	RCRAINFO
PRIMARY MAILING ADDRESS	PO BOX 1141	BAY CITY	TX	774041141	PCS
ALTERNATE MAILING ADDRESS	PO BOX 1141	BAY CITY	TX	774041141	PCS
OWNER	PO BOX 1141	BAY CITY	TX	77404	PCS
OWNER/OPERATOR	P.O. BOX 509	BAY CITY	TX	774040509	RMP
FACILITY MAILING ADDRESS	PO BOX 509	BAY CITY	TX	77404	AIRS/AFS
MAILING ADDRESS	PO BOX 1141	BAY CITY	TX	774041141	NPDES
FACILITY MAILING ADDRESS	PO BOX 509	BAY CITY	TX	77404	RCRAINFO
OWNER	PO BOX 819005	DALLAS	TX	78381	RCRAINFO
FACILITY MAILING ADDRESS	PO BOX 509	BAY CITY	TX	77404-0509	TRIS
OPERATOR	PO BOX 509	BAY CITY	TX	77404	RCRAINFO
OWNER	PO BOX 1141	BAY CITY	TX	77404	NPDES

Alternative Names

Alternative Name	Source of Data
HOECHST-CELANESE CHEMICAL GROUP INC	NCDB
CELANESE LTD. BAY CITY SITE	TRIS
CELANESE LTD BAY CITY PLANT	TRI REPORTING FORM
CELANESE LTD	NOTIFICATION (RCRA)
HOECHST CELANESE CHMCL. GROUP, LTD.	AIR VOLUNTARY SUBMISSION
OXEA CORPORATION	NPDES PERMIT

Organizations

Affiliation Type	Name	DUNS Number	Information System	Mailing Address
OWNER/OPERATOR		026040709	AIRS/AFS	
OWNER	OXEA CORPORATION		NPDES	View
OWNER/OPERATOR		026040709	TRIS	
PARENT COMPANY 1	CELANESE LTD.	947592879	RMP	
OWNER	CELANESE LTD		RCRAINFO	View
OWNER	OXEA CORPORATION		PCS	View
MAILING ADDRESS	OXEA CORPORATION		NPDES	View
OPERATOR	CELANESE LTD		RCRAINFO	View
OWNER	CELANESE LTD		RCRAINFO	View
OWNER/OPERATOR	CELANESE CHEMICAL, BAY CITY SITE	26040709	RMP	View
PARENT ORGANIZATION	CELANESE CORP	170204486	TRIS	

Contacts

Affiliation Type	Full Name	Office Phone	Information System	Mailing Address
COMPLIANCE CONTACT	JESSICA NIETO	4092414225	AIRS/AFS	
REGULATORY CONTACT	BILLY CAMPBELL	9792414441	RCRAINFO	View
REGULATORY CONTACT	DANNY MCCASKILL	9792414204	RCRAINFO	View
COGNIZANT OFFICIAL	STEVEN PARKER, SITE DIRECTOR	9792414000	PCS	
RESPONSIBLE PARTY	MICHAEL STONE		RMP	
PUBLIC CONTACT	MARK FRELS	9792414386	TRIS	
EMERGENCY CONTACT	MINDY MCWILLIAMS	9792414159	RMP	

Query executed on: FEB-25-2010

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OXEA CORP BAY CITY PLANT

2001 FM 3057
BAY CITY, TX 77414
EPA Registry Id: 110031389192

Legend

- Selected Facility
- EPA Facility of Interest
- State/Tribe Facility of Interest

The facility locations displayed come from the FRS Spatial Coordinates tables. They are the best representative locations for the displayed facilities based on the accuracy of the collection method and quality assurance checks performed against each location. The North American Datum of 1983 is used to display all coordinates.

Environmental Interests

Information System	Information System ID	Environmental Interest Type	Data Source	Last Updated Date	Supplemental Environmental Interests:
RESOURCE CONSERVATION AND RECOVERY ACT INFORMATION SYSTEM	TXR000077784	CORRECTIVE ACTION (ACTIVE)	RCRAINFO	01/14/2010	**ICIS**-ENFORCEMENT/COMPLIANCE ACTIVITY
RESOURCE CONSERVATION AND RECOVERY ACT INFORMATION SYSTEM	TXR000077784	LQG (ACTIVE)	RCRAINFO	01/14/2010	**ICIS**-ENFORCEMENT/COMPLIANCE ACTIVITY
RESOURCE CONSERVATION AND RECOVERY ACT INFORMATION SYSTEM	TXR000077784	TSD (ACTIVE)	RCRAINFO	01/14/2010	**ICIS**-ENFORCEMENT/COMPLIANCE ACTIVITY
RISK MANAGEMENT PLAN	100000198298	RMP REPORTER	RMP	02/28/2007	
TOXIC RELEASE INVENTORY SYSTEM	77414XCRPB21FM3	TRI REPORTER	TRIS	06/30/2009	

Additional EPA Reports: MyEnvironment Enforcement and Compliance Cleanups in My Community Site Demographics Watershed Report

Standard Industrial Classification Codes (SIC)

No SIC Codes returned.

Facility Codes and Flags

EPA Region:	06
Duns Number:	
Congressional District Number:	
Legislative District Number:	12
HUC Code/Watershed:	12090302 / LOWER COLORADO

National Industry Classification System Codes (NAICS)

Data Source	NAICS Code	Description	Primary
RMP	325199	ALL OTHER BASIC ORGANIC CHEMICAL MANUFACTURING.	
TRIS	325199	ALL OTHER BASIC ORGANIC CHEMICAL MANUFACTURING.	
RCRAINFO	325199	ALL OTHER BASIC ORGANIC CHEMICAL MANUFACTURING.	

Facility Mailing Addresses

US Mexico Border Indicator:	NO
Federal Facility:	NO
Tribal Land:	NO

Alternative Names

Alternative Name	Source of Data
OXEA - BAY CITY PLANT	RMP
OXEA CORPORATION	RCRAINFO

Organizations

Affiliation Type	Name	DUNS Number	Information System	Mailing Address
OPERATOR	OXEA CORPORATION		RCRAINFO	View
OWNER/OPERATOR	OXEA CORPORATION		RMP	View
PARENT COMPANY 1	OXEA CORPORATION		RMP	
OWNER/OPERATOR		792038346	TRIS	
OWNER	OXEA CORPORATION		RCRAINFO	View
OPERATOR	OXEA CORPORATION		RCRAINFO	View
OWNER	OXEA CORPORATION		RCRAINFO	View
PARENT ORGANIZATION	OXEA CORP		TRIS	

Affiliation Type	Delivery Point	City Name	State	Postal Code	Information System
OWNER/OPERATOR	2001 FM 3057	BAY CITY	TX	774041141	RMP
OPERATOR	PO BOX 1141	BAY CITY	TX	77404	RCRAINFO
FACILITY MAILING ADDRESS	P. O. BOX 1141	BAY CITY	TX	77404	TRIS
REGULATORY CONTACT	PO BOX 1141	BAY CITY	TX	77404	RCRAINFO
OWNER	PO BOX 1141	BAY CITY	TX	77404	RCRAINFO
FACILITY MAILING ADDRESS	PO BOX 1141	BAY CITY	TX	77404	RCRAINFO

Contacts

Affiliation Type	Full Name	Office Phone	Information System	Mailing Address
REGULATORY CONTACT	GLADYS GAVRANOVIC	9792414022	RCRAINFO	View
EMERGENCY CONTACT	HUGH D. BILLINGS	9792414300	RMP	
RESPONSIBLE PARTY	HUGH D. BILLINGS		RMP	
PUBLIC CONTACT	JOE ULUH	9792414142	TRIS	

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FRS

TEXAS LIQUID FERTILIZER COMPANY, LTD

FM-1593 SOUTH
POINT COMFORT, TX 77978
EPA Registry Id: 110018939158

Legend

- Selected Facility
- EPA Facility of Interest
- State/Tribe Facility of Interest

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Environmental Interests

Information System	Information System ID	Environmental Interest Type	Data Source	Last Updated Date	Supplemental Environmental Interests:
INTEGRATED COMPLIANCE INFORMATION SYSTEM	6683122	ENFORCEMENT/COMPLIANCE ACTIVITY	ICIS	09/23/2004	
RISK MANAGEMENT PLAN	100000111782	RMP REPORTER	RMP REPORTING FORM	01/31/2005	
TOXIC RELEASE INVENTORY SYSTEM	77978TXSLQFM159	TRI REPORTER	TRI REPORTING FORM	07/06/1994	

Additional EPA Reports: MyEnvironment Enforcement and Compliance Site Demographics Watershed Report

Standard Industrial Classification Codes (SIC)

Data Source	SIC Code	Description	Primary
TRIS	5191	FARM SUPPLIES	
FRS	2873	NITROGENOUS FERTILIZERS	
TRIS	2875	FERTILIZERS, MIXING ONLY	

National Industry Classification System Codes (NAICS)

Data Source	NAICS Code	Description	Primary
TRIS	325311	NITROGENOUS FERTILIZER MANUFACTURING.	
TRIS	325314	FERTILIZER (MIXING ONLY) MANUFACTURING.	

Facility Codes and Flags

EPA Region:	06
Duns Number:	172363590
Congressional District Number:	
Legislative District Number:	
HUC Code/Watershed:	12100401 / CENTRAL MATAGORDA BAY
US Mexico Border Indicator:	NO
Federal Facility:	

Facility Mailing Addresses

Affiliation Type	Delivery Point	City Name	State	Postal Code	Information System
FACILITY MAILING ADDRESS	FM 1593 S., NAVIGATION DISTRICT	POINT COMFORT	TX	77978	TRIS
OWNER/OPERATOR	P.O. BOX 4540	MONROE	LA	71211	RMP

Contacts

Affiliation Type	Full Name	Office Phone	Information System	Mailing Address

Tribal Land:	NO

RESPONSIBLE PARTY	MIKE MORITZ	3619872682	RMP	
PUBLIC CONTACT	KIM COKER	4098268063	TRIS	
EMERGENCY CONTACT	TOM MORGAN	3619872682	RMP	

Alternative Names

Alternative Name	Source of Data
TEXAS LIQUID FERTILIZER CO. POINT COMFORT	TRI REPORTING FORM

Organizations

Affiliation Type	Name	DUNS Number	Information System	Mailing Address
OWNER/OPERATOR	KIM COKER		RMP	View
PARENT COMPANY 1	ABELL CORP.		RMP	
OWNER/OPERATOR	KIM COKER		RMP	View
OWNER/OPERATOR	KIM COKER		RMP	View
PARENT ORGANIZATION	ABELL CORP	043420082	TRIS	

Query executed on: FEB-25-2010

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Global Greenhouse Gas Data

Atmospheric concentrations of greenhouse gases are affected by the total amount of greenhouse gases emitted to and removed from the atmosphere around the world over time. Figure 1 shows a breakdown of global anthropogenic greenhouse gas emissions by each gas measured on a CO_2-equivalent basis.

Related Links

Carbon Dioxide Information Analysis Center

DOE/EIA State Energy Data

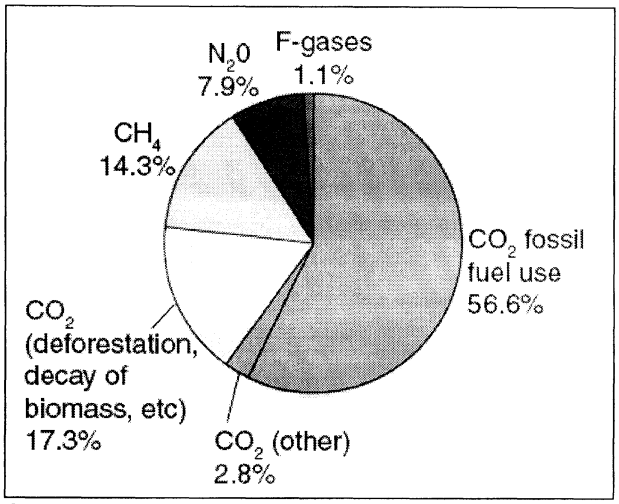
EPA Non-CO2 Gases Site

Gapminder EXIT Disclaimer

National Inventory Submissions EXIT Disclaimer

World Development Indicators EXIT Disclaimer

Figure 1: Global Anthropogenic Greenhouse Gas Emissions in 2004

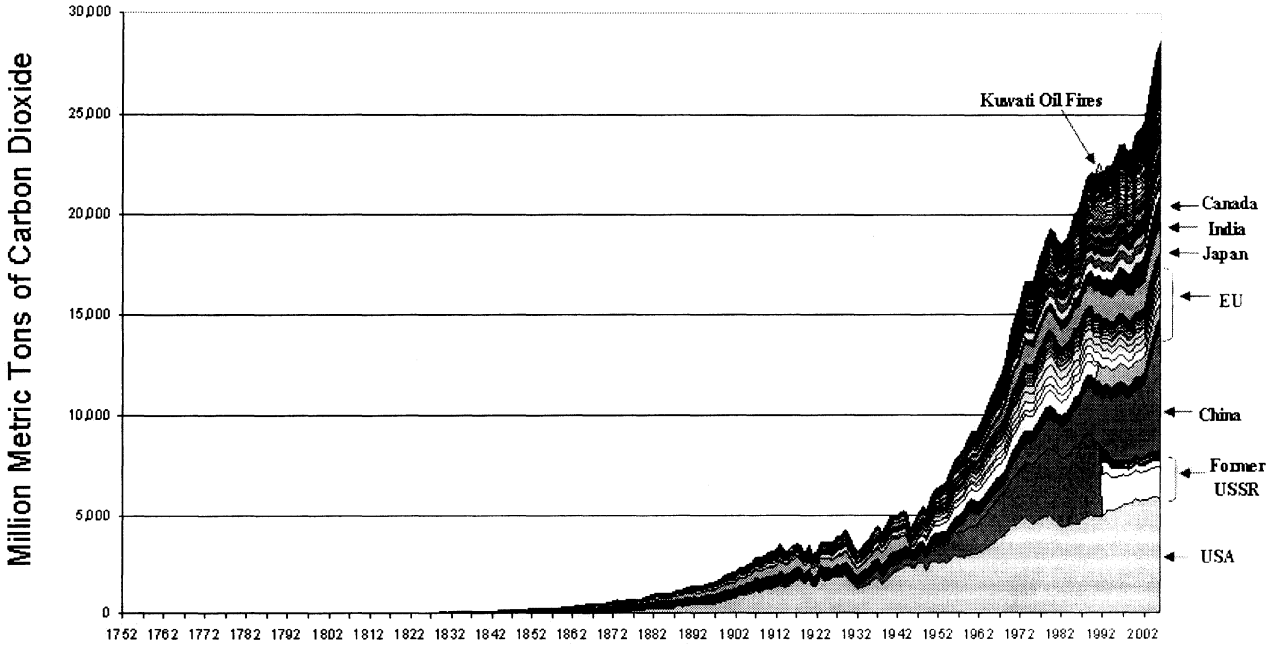


Reference: IPCC 4th Assessment Report:Climate Change 2007: Synthesis Report EXIT Disclaimer

Note: Other CO_2 includes cement production and natural gas flaring.

Figure 2 presents data on the major global sources of carbon dioxide (CO2) emissions by country, from the beginning of the Industrial Revolution to the present.

Figure 2: Global CO_2 Emissions from Fossil-Fuel Burning, Cement Manufacture, and Gas Flaring: 1752-2006

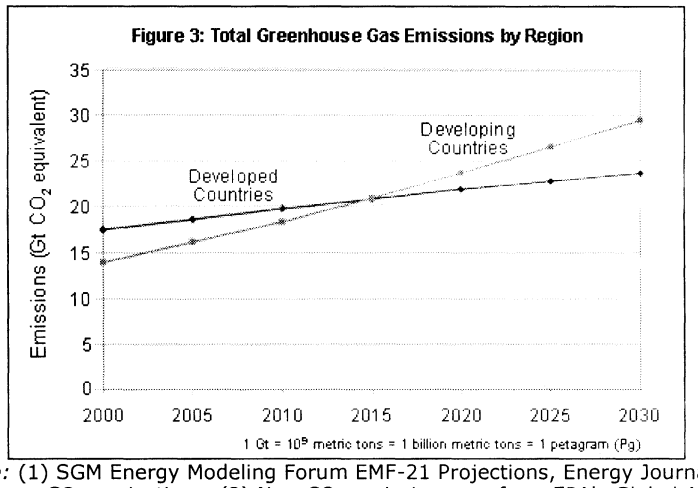


Reference: Carbon Dioxide Information Analysis Center

Subscribers to the World Resources Institute's Climate Analysis Indicators Tool (CAIT) EXIT Disclaimer can draw on existing

greenhouse gas data to generate breakdowns of global emissions by year, country, source and greenhouse gas. In addition, the Intergovernmental Panel on Climate Change synthesizes existing scientific data on global fluxes of greenhouse gas emissions and removals in its assessment reports Exit Disclaimer. These reports provide global data by gas and by type of emission pathway (e.g., general type of source or sink), and include both human and natural emissions.

Figure 3 provides a projection of future greenhouse gas emissions of developed and developing countries. Total emissions from the developing world are expected to exceed those from the developed world by 2015.



Reference: (1) SGM Energy Modeling Forum EMF-21 Projections, Energy Journal Special Issue, in press, reference case CO2 projections. (2) Non-CO2 emissions are from EPA's Global Anthropogenic Emissions of Non-CO2 Greenhouse Gases 1990-2020.

Environmental Impact Statements (EISs)

FERC staff issues Final Environmental Impact Statement for the Proposed Calhoun LNG Terminal and Pipeline Project (Docket Nos. CP05-91-000 and CP05-380-000)
Issued: August 10, 2007

The FERC staff has prepared a final environmental impact statement (EIS) for the Calhoun LNG, L.P and Point Comfort Pipeline Company, L.P.'s (collectively referred to as Calhoun Point Comfort) proposed Calhoun LNG Terminal and Pipeline Project (Project).

The proposed Project would include the construction and operation of a new LNG receiving terminal capable of accommodating about 120 LNG vessels per year, two full containment LNG storage tanks, associated LNG vaporization and processing equipment, approximately 27.1 miles of 36-inch-diameter natural gas pipeline, two approximately 0.5-mile-long 8- and 16-inch-diameter natural gas pipeline laterals, ten natural gas pipeline interconnects, and associated pipeline facilities. These proposed facilities would be constructed and operated in Calhoun and Jackson Counties, Texas and LNG vessels utilizing the terminal would traverse approximately 22 miles of the Matagorda Ship Channel.

The purpose of the proposed Project is to provide facilities necessary to import, store, vaporize, and transport on average about 1.0 billion cubic feet per day of LNG to local industrial customers and existing interstate and intrastate natural gas pipelines.

This final EIS was prepared to satisfy the requirement of the National Environmental Policy Act and was prepared in cooperation with the: U.S. Army Corps of Engineers; U.S. Coast Guard; U.S. Fish and Wildlife Service; National Oceanic and Atmospheric Administration, National Marine Fisheries Service; and the U.S. Environmental Protection Agency.

The FERC staff concludes that if the proposed Project is found to be in the public interest and is constructed and operated in accordance with Calhoun Point Comfort's proposed minimization and mitigation measures as well as our recommended mitigation measures, the potential environmental impacts resulting from proposed Project-related activities would be reduced to environmentally acceptable levels. The FERC staff reached this conclusion based in part on the following:

- Calhoun Point Comfort would construct its LNG terminal on manmade, industrial land owned by the Port of Port Lavaca-Point Comfort;
- Calhoun Point Comfort would minimize impact on soils, wetlands, and waterbodies by implementing the FERC's Plan and Procedures;
- The Matagorda Bay Pilots indicated that they could continue to escort vessels into and out of the MSC in a safe and expeditious manner and that the Project would have minimal impacts on vessel traffic; and
- Safety features would be incorporated into the design and operation of the LNG import terminal and vessels.

The FERC Commissioners will take into consideration staff's recommendations and the final EIS when they make decisions on the Project.

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» Executive Summary PDF

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- » Section 2
- » Section 3
- » Section 4
- » Section 5
- » Additional documents [eLibrary]

Updated: April 17, 2009

4.0 ENVIRONMENTAL ANALYSIS

The environmental consequences of constructing and operating the proposed Project would vary in duration and significance. Four levels of impact duration were considered: temporary, short-term, long-term, and permanent. A temporary impact generally occurs during construction with the resource returning to its preconstruction condition almost immediately afterward. A short-term impact could continue for up to three years following construction. Impact was considered long-term if the resource would require more than three years to recover. A permanent impact could occur as a result of any activity that modifies a resource to the extent that it would not return to preconstruction conditions during the life of the project. We considered an impact to be significant if it would result in a substantial adverse change in the physical environment.

In this section, we discuss the affected environment, general construction and operational impact, and proposed mitigation for each resource. We have also included a brief discussion on the transit corridor for the LNG vessels. Calhoun Point Comfort, as part of its proposal, agreed to implement certain measures to reduce impact. These additional measures appear as bulleted, boldfaced paragraphs in the text. We are recommending that these measures be included as specific conditions to authorizations that the Commission may issue to Calhoun Point Comfort.

Conclusions in this EIS are based on our analysis of the environmental impact and the following assumptions:

- Calhoun Point Comfort would comply with all applicable laws and regulations;
- the proposed facilities would be constructed as described in chapter 2.0 of this document; and
- Calhoun Point Comfort would implement the mitigation measures included in the application and supplemental filings to the FERC.

4.1 GEOLOGIC RESOURCES

4.1.1 Geologic Setting

The proposed Project would be located in the West Gulf Coastal Plain subregion of the Coastal Plain physiographic province (USGS, 2005). This region consists of tertiary and quaternary sedimentary deposits from marine and fluvial sources that have been uplifted and dipped toward the Gulf of Mexico. The region is characterized by a series of increasing depositional plains that range from the shoreline to about 200 miles inland and range in elevation from sea level to about 600 feet above msl. The upper sediments in this region consist of the Pleistocene Beaumont Formation that is underlain by the Pleistocene Lissie Formation.

The Beaumont Formation consists of interbedded layers of clay, sandy clays, and silty and clayey sands that were deposited on the back bay of an ancient barrier island. In the Central Gulf Coast region this formation is composed of up to 90 percent clay with medium to fine grained sands. The Beaumont formation is generally more than 100 feet thick. The underlying Lissie Formation consists of alluvial deposits of sand, silt, clay and small amounts of gravel. About 60 percent of this formation is composed of fine to coarse-grained sand while the remaining

40 percent consists of sandy clay (20 percent) and gravel and clay (10 percent each). The Lissie Formation typically contains very stiff to hard clays, dense to very dense sands, and thin weakly cemented layers of sandstone.

The proposed LNG terminal would be located on a peninsula of fill and spoil material within a bay and estuary system. The fill and spoil material comprising the peninsula is from dredged material that was removed from Lavaca Bay for the construction of the CCND's existing turning basin. As fill and spoil were deposited over time the elevation of the peninsula was raised to about 29 feet above msl. The proposed pipeline would cross the Beaumont formation, which consists of clayey sand and silt deposits and alluvial deposits associated with the Navidad River and Lavaca River floodplains. These alluvial deposits consist of clay, silt, sand, gravel and organic matter that has been deposited by these river systems and reworked by the interaction between the rivers and the associated estuary and bay processes.

Because no bedrock occurs at or near the surface of the LNG terminal site or along the pipeline route, no blasting would be required to construct the LNG terminal or excavate the pipeline trench.

4.1.2 Extractive Resources

There are three primary types of extractive resources potentially found within the project area: oil and gas, lignite and coal, and mineral and gravel. No lignite, coal, mineral, or gravel extraction operations have been identified in the project area.

Oil and gas production occurs within the project area. Several production wells occur in Cox Bay and are supported by small wellhead platforms. None of these wells are within 1,500 feet of the LNG terminal site.

Calhoun Point Comfort reviewed TRRC maps and found one dry oil or gas well within the construction footprint of the LNG terminal and another within the proposed KM-Tejas interconnect site (MP 12.0). Twelve oil or gas wells were identified within 150 feet of the pipeline construction right-of-way. Of these wells, eight are dry and the remaining four may be operational. The four potentially operational wells are near MPs 11.3, 17.6, 19.0, and 19.4 and would be between 0.9 and 147.9 feet from the construction right-of-way. Construction of the LNG terminal and the KM-Tejas interconnect would affect two individual dry wells. Prior to construction, Calhoun Point Comfort would coordinate with the TRRC to confirm whether the wells would be located within the boundaries of the LNG terminal and KM-Tejas interconnect site and that the wells have been properly plugged and abandoned. Construction of the proposed pipeline would not affect the four wells within 150 feet of the construction right-of-way. Prior to construction, Calhoun Point Comfort would conduct a detailed survey of the pipeline route and the construction right-of-way would be adjusted in order to avoid any obstacles encountered, including existing oil and gas wells. With the implementation of these measures, we conclude that the Project would have minimal impact on existing oil or gas wells.

4.1.3 Paleontological Resources

Calhoun Point Comfort indicated that 39 fossil records have been recorded at Nobels Point in Port Lavaca, Texas, about 3.0 miles west of the project area. No sensitive paleontological resources have been identified in the project area; however, should such resources be encountered during construction of the Project, Calhoun Point Comfort would contact the Texas Memorial Museum, and other applicable agencies, to develop and implement appropriative mitigation measures.

4.1.4 Geologic Hazards

The following section provides a summary of the site conditions with respect to seismicity and faulting, soil liquefaction, subsidence, karst terrain, and flooding/storm damage.

4.1.4.1 Seismicity and Faulting

The proposed Project is located within the Gulf Coastal Plains geomorphic province, which is characterized by a low seismic hazard potential. According to the Seismic Risk Map for the Uniform Building Code, the Gulf Coast region, including the project area, is within Seismic Zone 0, the lowest risk zone.

Calhoun Point Comfort conducted a site-specific seismic evaluation to further assess seismic hazards at its proposed LNG terminal site. This evaluation included a probabilistic seismic hazard analysis to produce hazard curves based on peak ground acceleration and a site response analysis to determine the effects of the soil profile on the earthquake ground motion. The evaluation was conducted in accordance with the NFPA guidelines for stationary LNG storage containers. Results of this study indicate that potential seismic hazards at the LNG terminal site are low (PSI, 2005).

Although numerous faults exist in the Gulf Coast region, review of the physiographic and historical data for the project area indicates that movement along these faults in modern times is low. Therefore, based on this low risk of seismic activity and faulting we conclude that seismic activity and faulting would not be a significant hazard to the proposed Project.

4.1.4.2 Soil Liquefaction

Soil liquefaction occurs in saturated soils; that is, soils in which the space between individual particles is completely filled with water and the soils are subject to intense and prolonged ground shaking from seismic events. When liquefaction occurs, the strength of the soil decreases and the ability of a soil deposit to support structures is reduced. Soils that are composed of particles that are about the same size, such as water or wind-deposited sediments, are more susceptible to liquefaction than soils with a wide range of particle sizes.

Calhoun Point Comfort evaluated the liquefaction potential at the proposed LNG terminal site and determined that this potential would be low (PSI, 2005). While sediments and landforms present in the project area have soil liquefaction potential under seismic shaking events, the low risk of seismic activity in this area minimizes the potential hazard to the proposed Project from

soil liquefaction. Therefore, we conclude that soil liquefaction would not be a significant hazard to the proposed Project.

4.1.4.3 Subsidence

Subsidence is defined as sudden sinking or gradual downward settling of land with little or no horizontal motion, caused by surface faults, and intensified or accelerated by subsurface mining or the pumping of oil, natural gas, or groundwater. Although several oil and gas wells exist in the project area, there is no significant oil or gas extraction in the area. In addition, extraction of groundwater in the area is negligible. Various degrees of subsidence have been documented along the entire Texas coast, with the most significant subsidence in the Houston-Galveston area.

Subsidence is typically a concern when designing LNG storage tank foundations. Calhoun Point Comfort would construct each LNG storage tank on a foundation that consists of a 265-foot-wide, 4-foot-thick concrete pile cap supported by concrete piles driven on a 4-foot by 4-foot matrix. The concrete pile cap would be designed to act as a two-way slab to distribute vertical loads laterally. Subsidence would not likely affect the integrity of the proposed pipeline. Required periodic monitoring of the pipeline right-of-way during operation would help to identify subsidence-related situations that might require maintenance. Therefore, we conclude that subsidence would not be a significant hazard to the proposed LNG terminal or pipeline facilities.

4.1.4.4 Karst Terrain

Karst terrain develops in areas that are underlain by carbonate rocks and evaporites. Groundwater dissolution of near-surface carbonate rocks and evaporites, combined with surface weathering and erosion, produces karst topography. The potential for karst is greatest where surficial deposits are less than 30 feet thick and the underlying carbonate rocks occur at a depth at or just above the water table. These conditions do not exist in the project area; therefore, we conclude that impact related to karst terrain would not be a hazard for the proposed Project.

4.1.4.5 Flooding/Storm Damage

The Calhoun LNG Project would be located along the Gulf of Mexico shoreline and would be subject to coastal storms, hurricanes, flooding, and other coastal processes. According to the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM), a majority of the proposed LNG terminal site would lie within Coastal Flood Zone V20. The eastern portion of the site would be located within the Moderate Flood Hazard Zone (Zone B). The entire Point Comfort Pipeline would lie within Zone B. Table 4.1.4.5-1 includes definitions of FEMA flood hazard zone designations in the project area.

Under significant weather events, such as hurricanes and tropical storms, the LNG terminal facilities would be subjected to severe flooding, storm surge, high winds, erosion along the shoreline and docking facilities, and potential site access interruptions. Each of the LNG terminal components would be designed to withstand these forces so that factors such as wind shear, flooding and water damage, and erosion of land area would have minimal affects on the operation and safety of the facilities. Calhoun Point Comfort designed its LNG terminal to

mitigate the potential effects of flooding/storm damage. Calhoun Point Comfort indicated that the base flood elevation for the project area is about 15 feet. The shoreline facilities would be designed to withstand storm surge and flooding and the LNG terminal would be at an elevation of 29 feet above msl. Because the structural and mechanical elements have been designed into the LNG terminal facilities to withstand coastal flooding and storms, we conclude that flooding due to storm events is not likely to adversely affect the proposed Project.

Calhoun Point Comfort would avoid potential for erosional exposure of pipelines by directionally drilling large waterbodies and burying pipelines at least 5 feet below small waterbody channel bottoms. Flooding and storm damage are not expected to pose a hazard to the proposed pipeline facilities.

TABLE 4.1.4.5-1

Federal Emergency Management Agency Flood Hazard Zone Designations in the Calhoun LNG Project Area

Zone Designation	Description
Zones B	Zones B is the flood insurance rate zones that correspond to areas outside the 100-year floodplains, areas of 100-year sheet flow flooding where average depths are less than 1 foot, areas of 100-year stream flooding where the contributing drainage area is less than 1 square mile, or areas protected from the 100-year flood by levees. No Base Flood Elevations or depths are shown within this zone.
Zone V and V20	Zone V is the flood insurance rate zone that corresponds to the 100-year coastal floodplains that have additional hazards associated with storm waves. Base Flood Elevations derived from the detailed hydraulic analyses are shown at selected intervals within this zone. Mandatory flood insurance purchase requirements apply. Zone V20 is the area inundated by 100-year flooding with velocity hazard (wave action); no base flood elevations have been determined.

4.1.5 Waterway for LNG Marine Traffic

No significant impacts to geologic resources would be expected along the waterway for LNG marine traffic from the normal operations associated with the LNG terminal. Further, no significant impacts would be expected to occur to geologic resources from an accidental LNG release, with or without ignition, within the Zones of Concern along the waterway for LNG marine traffic.

4.2 SOILS AND SEDIMENTS

4.2.1 Soil Composition and Limitations

The proposed LNG terminal would be within the Ijam soil series while the proposed pipeline would cross the Dacosta, Edna, Lake Charles, Midland, Placedo, Telferner, Aransas, Chicolete, Fordtran, Ganado, Inez, Laewest, Marcado, Navidad, and Texana soil series. These soil series include clay, loam, clay loam, fine and very fine sandy loam, loamy fine sand, and sandy clay loam.

The LNG terminal site would be located on 73 acres of manmade, industrial land that was created by the placement of dredged material from Lavaca Bay and Cox Bay. Calhoun Point Comfort conducted a geotechnical investigation of the dredge material, or sediments, that currently make up the manmade, industrial land on which the proposed LNG terminal would be located. Calhoun Point Comfort drilled a total of six soil borings at the LNG dock, tank, and process areas (PSI, 2005b). The sampling and physical testing was done in accordance with standard methods published by the American Society of Testing Materials (ASTM).

The LNG tank and process area contains dredged spoils and fill soils that form the upper 26 feet of the soil profile. Dredged spoils and fill soils are mainly very soft to soft silty sands, fat clays, and sandy fat clays. Undrained shear strength of dredge spoils and fill soils is 150 pounds per square feet (psf). Below the fill soils, firm to hard lean clays and sandy lean clays exist within a depth of 44 feet to 47 feet. Undrained shear strength of these soils is in the range of 700 psf to 2,200 psf. A medium dense to very dense clayey sand layer with undrained shear strength of 1,800 psf to 2,200 psf extends at depths of 47 feet to 100 feet below ground surface. Groundwater level was measured at depths of 1 foot to about 4 feet below the existing ground surface at the process area. The moisture content of dredged spoils varied from 22 percent to 199 percent and the liquid limit of these soils ranged from 28 to 104 percent.

The dock area contains predominately fat clays and sandy lean clays, with very soft to very stiff clayey sand layers extending to a depth of 60 feet. This layer has an in-situ moisture content of 15 percent to 94 percent, liquid limit of 21 to 52, plasticity index of 26 to 48, and undrained shear strength of 800 psf to 1,000 psf. Clayey sands, medium dense to very dense with clayey layers and seams extends below 60 feet to about 120 feet with in-situ moisture content of 18 percent to 32 percent, liquid limit of 30 to 58, plasticity index of 14 to 37, and undrained shear strength of 2,000 psf to 2,500 psf. Several of the recovered cohesive samples were slicken sided with shell fragments, and calcareous and ferrous nodules which are the features of typical Beaumont clays.

Table 4.2.1-1 provides a summary of soil characteristics and limitations associated with the proposed LNG terminal, pipeline, and laterals. Major soil characteristics and limitations for the pipelines and laterals are discussed below.

TABLE 4.2.1-1

Soils Affected by the Calhoun LNG Project

Facility/Soil Series	Percent of Affected Area	Erosion Potential	Revegetation Potential	Compaction Potential	Drainage Characteristics	Hydric	Prime Farmland
LNG Terminal							
Ijam Clay	100	Low to Moderate	Poor	Low to Moderate	Very Poorly Drained	Yes	n/a
Point Comfort Pipeline and Laterals							
Dacosta	39.0	Slight	Poor to High	Moderate to High	Somewhat Poorly to Moderately Well Drained	No	Yes
Edna	3.0	Slight	Moderate to High	Low to Moderate	Poorly to Somewhat Poorly Drained	No/Yes a/	No
Lake Charles	4.0	Slight	High	High	Somewhat Poorly Drained	No	No
Midland	2.0	Slight	Moderate to High	Moderate	Poorly Drained	Yes	No
Placedo	2.0	Slight	Poor	High	Very Poorly Drained	Yes	No
Telferner	1.0	Slight	High	Low to Moderate	Somewhat Poorly Drained	No	No
Aransas	1.0	Slight	Moderate to High	High	Poorly Drained	Yes	No
Chicolete	3.0	Slight	High	High	Moderately Well Drained	No	No
Fordtran	2.0	Slight	High	Low to Moderate	Moderately Well Drained	No	No
Ganado	4.0	Slight	High	High	Somewhat Poorly Drained	Yes	No
Inez	1.0	Slight	High	Low to Moderate	Moderately Well Drained	Yes	No
Laewest	25.0	Low to High	High	High	Moderately Well Drained	No	Yes
Marcado	5.0	High	High	Moderate	Moderately Well Drained	No	No
Navidad	1.0	Slight	High	Low to Moderate	Well Drained	No	No
Texana	7.0	Slight	High	Moderate	Poorly Drained	Yes	Yes

a/ Not listed as a hydric soil in Calhoun County but listed as hydric soil in Jackson County.

Prime Farmland

Prime farmland is land that has the best combination of physical and chemical characteristics for producing food, feed, forage, fiber, oilseed, and other agricultural crops with minimum inputs of fuel, fertilizer, pesticides, and labor, and without intolerable soil erosion as determined by the U.S. Secretary of Agriculture. Prime farmland can include land that possesses the above characteristics but is being used currently to produce livestock and timber. Urbanized land and open water are excluded from prime farmland. Prime farmland typically contains few or no rocks, is permeable to water and air, is not excessively erodible or saturated with water for long periods, and is not subject to frequent, prolonged flooding during the growing season. Soils that do not meet the above criteria may be considered prime farmland if the limiting factor is mitigated (e.g., using artificial drainage or irrigation).

Construction of the proposed pipeline would temporarily impact about 221.7 acres of prime farmland soil. These impacts could include interference with agricultural drainage, loss of soil through erosion, mixing of topsoil and subsoil, and compaction. These impacts would result primarily from trench excavation and backfilling, and vehicular traffic along the construction right-of-way. Most impacts would be short-term and would not affect the potential use of prime farmland for agricultural purposes.

Five meter stations associated with the proposed pipeline would be located on prime farmland soil: the Channel/HPL meter station at MP 5.1, the KM-Tejas meter station at MP 12.0, the Valero meter station at MP 12.1, the Gulf South/KM Texas meter station at MP 21.4, and the Tennessee meter station at MP 27.1.

Operation of these aboveground facilities would result in the permanent removal of a total of about 1.7 acres of prime farmland soils. Because the majority of soils crossed by the pipeline are considered prime farmland, there is little opportunity to avoid placement of aboveground facilities on prime farmland. Since each of the meter stations would require only from 0.1 to 0.5 acre for operation, impact at each site would be minimal. We believe the conversion of 1.7 acres of prime farmland for operation of the proposed meter stations would not be a significant impact.

Calhoun Point Comfort would adhere to the measures contained in our Plan which are designed to minimize impact on agricultural soils. Construction measures include postponing soil disturbances when soils are excessively wet and separating subsoils from topsoils when grading and trenching (for residential, wetland, and agricultural soils). Calhoun Point Comfort would also develop specific procedures in coordination with the appropriate agencies to prevent the introduction or spread of noxious weeds and soil pests resulting from construction and restoration activities.

Hydric Soils

Hydric soils are defined as "soils that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part" (*Federal Register*, July 13, 1994). Soils that are artificially drained or protected from flooding (e.g., by levees) are still considered hydric if the soil in its undistributed state would meet the definition of a hydric soil. These soils are typically associated with wetlands.

Construction and operation of the proposed Project would affect hydric soils and eight soil series exhibiting hydric characteristics. These soils are generally poorly drained with a high clay content. Calhoun Point Comfort would construct the proposed Project in accordance with our Procedures, which include provisions for construction in areas containing saturated soils and postponing soil disturbances when soils are excessively wet. We believe that Calhoun Point Comfort's implementation of these measures during construction would minimize impacts on hydric soils.

Erosion Potential

Erosion is a natural process that can be accelerated by human disturbance. Factors that influence soil erosion include soil texture, structure, length and percent of slope, vegetative cover, and rainfall or wind intensity. Soils most susceptible to erosion by water are typified by bare or

sparse vegetative cover, noncohesive soil particles with low infiltration rates, and moderate to steep slopes. Wind erosion processes are less affected by slope angles.

Clearing, grading, and equipment movement could accelerate erosion processes, and without adequate protection could result in discharge of sediment to waterbodies and wetlands. Soil loss due to erosion could also reduce soil fertility and impair revegetation.

The proposed LNG terminal site is sparsely vegetated. The potential for erosion of soils and discharge of sediments off-site would be relatively moderate during construction. Since Calhoun Point Comfort has adopted our Plan and Procedures for erosion and sedimentation control during construction, these concerns would be minimal.

Along the Point Comfort Pipeline, the Laewest and Marcado soil series with a slope of 1 to 8 percent exhibit a relatively larger erosion potential when compared to other soil series. During pipeline construction, Calhoun Point Comfort would use erosion control structures, temporary seeding and revegetation, and erosion control fabric in accordance with our Plan and Procedures. For waterbody crossings, Calhoun Point Comfort would use the waterbody crossing methods contained in our Procedures and erosion and sedimentation control practices specified in our Plan. These erosion control measures include the installation of slope breakers and sediment barriers such as silt fence or hay bales, the use of mulch and erosion control fabrics, and restoration within 20 days of backfilling the trench, weather permitting. We conclude that implementation of these measures would minimize overall soil erosion that could result from construction of the Project. Shoreline erosion is discussed below in section 4.2.3.

Revegetation Potential

Successful restoration and revegetation in areas that are not permanently developed is important to maintain ecosystem productivity and to protect underlying soil from potential damage, such as erosion. Soils on the LNG terminal site are currently sparsely vegetated and two soil series along the pipeline route, Dacosta and Placedo, were identified as having a low potential for revegetation. Areas where aboveground facilities would be built would not be revegetated. This would encompass about 73 acres at the LNG terminal, including roads. The aboveground facilities along the pipeline would cover about 3.5 acres.

Calhoun Point Comfort would implement the requirements in our Plan for revegetation of disturbed areas. These measures include compensation or restoration of all turf, ornamental shrubs, and specialized landscaping at the landowners request and addition of fertilizers and soil pH modifiers and seedbed preparation or seeding at the local soil conservation authority, land management agency, or landowners request. Calhoun Point Comfort indicated it would revegetate and restore disturbed areas using mixtures recommended by appropriate state and federal agencies. Landscaping and surface treatments built at the LNG terminal site should prevent wind and water erosion from the site during operation. We conclude that if revegetation is conducted in accordance with these measures, areas disturbed by construction would be successfully revegetated. See section 4.4.3 of this EIS for further information on revegetation.

Compaction Potential

Soil compaction modifies the structure and reduces the porosity and moisture-holding capacity of the soil. The degree of compaction is dependent on moisture content and soil texture. Fine-

textured soils with poor internal drainage are the most susceptible to compaction. Construction equipment traveling over wet soils could disrupt soil structure, reduce pore space, increase runoff potential, and cause rutting. Compaction and rutting impacts would be more likely to occur when soils are moist or saturated.

Soils found at the proposed LNG terminal site could experience some level of compaction; however, potential impacts associated with soil compaction at the site would be minimal given that the site would be highly developed. Based on soil texture and drainage characteristics, essentially all of the soils that would be disturbed by pipeline construction activities have the potential to experience some level of compaction, with six of the affected soil series having high compaction potential.

Calhoun Point Comfort would mitigate for potential compaction in agricultural areas by following measures contained in our Plan. Mitigation for soil compaction would include segregating topsoil, postponing soil disturbances when soils are excessively wet, and using deep tillage operations during right-of-way restoration using a paraplow or similar implement. We conclude that use of these measures during construction would minimize soil compaction resulting from construction of the proposed Project.

4.2.2 Contaminated Soils

As part of Calhoun Point Comfort's determination of the likelihood to encounter contaminated soils at the proposed LNG terminal site or along the proposed pipeline route, Environmental Data Resources, Inc. (EDR) conducted a search of available environmental database records within 0.25 mile of the LNG terminal site and pipeline route. EDR found that eight potentially contaminated sites and facilities with historic releases of hazardous substances occur in the vicinity of the proposed Project (table 4.2.2-1).

TABLE 4.2.2-1

Potentially Contaminated Sites and Facilities within 0.25 mile of the LNG Terminal and Pipeline Route

Site/Facility Name and Location	MP Location/Approximate Distance and Direction from the Proposed Pipeline	Potential Contamination Issue
ES Joslin Power Station – 135 County Road 319	MP 0.0-0.2/1,320 feet to the southeast	One 500 gallon underground storage tank - removed in 1994.
Aluminum Company of America (Alcoa) – State Highway 35	MP 0.3-2.3/0 feet to the east and west	Alcoa (Point Comfort)/Lavaca Bay Superfund Site.
Enclean – State High 35 and Lamar	MP 2.3/350 feet to the west	Two 2,000 gallon and two 4,000-gallon underground storage tanks – removed in 1993.
Village Grocery – 104 Highway 35	MP 2.3/350 feet to the west	Two 8,000 gallon and one 6,000-gallon underground storage tanks – currently in use.
City Waterhouse – Julia Lane	MP 2.7/260 feet to the west	One 2,000 gallon underground storage tank - removed in 1997.
Formosa Plastic Corporation – 101 Formosa Drive	MP 3.4/260 feet to the east and 2,270 feet to the north	Hazardous materials released to the soil or surface waters and generator of hazardous wastes.
The Inteplast Group – 101 Inteplast Boulevard	MP 10.5/425 feet to the east	Generator of industrial wastes.
Edna Compressor Station – FM 1882	MP 27.1/650 feet to the north	Generator of industrial wastes.

Calhoun Point Comfort would implement its *Contaminated Soils Management Procedures* during construction within 0.25 mile of the sites/facilities identified in table 4.2.2-1, which include: visual and olfactory inspection all disturbed soils; segregation of any contaminated soils encountered and proper containerization, labeling, and storage; sampling and characterizing of contaminated soils; transportation and disposal at an approved disposal facility; or, if approved by the Texas Commission of Environmental Quality (TCEQ) and TRRC, treated *in situ*.

Although the proposed pipeline would cross through the Alcoa (Point Comfort)/Lavaca Bay Superfund Site from approximately MP 0.29 to MP 2.27, the releases of hazardous materials that caused the site to be classified as a Superfund site occurred about 0.5 mile west of the pipeline route. Calhoun Point Comfort indicated that no contaminated soils issues occur along this segment of the proposed pipeline.

NOAA has established a set of guidelines in conjunction with the EPA that evaluates sediments contaminated with toxic chemicals to determine its ecological risk. These guidelines are based on a number of evaluation methods and aid in decisions as to whether a certain amount of toxic chemicals is likely to harm the ecosystem. The Screening Quick Reference Tables present screening concentrations for inorganic and organic contaminants in various environmental media and include guidelines for preserving samples and analytical technique options (NOAA, 2005).

Calhoun Point Comfort sampled the soils at four locations within the LNG terminal site, one at each LNG tank site and two within the process area, including the firewater tank site. These samples were tested for polycyclic aromatic hydrocarbons (PAHs) and mercury.

The results of the analyses revealed that PAHs did not exceed the reportable limit; however, mercury did exceed the reportable limit in one sample, taken at a depth between 13 and 15 feet, from the process area. Calhoun Point Comfort indicated that the value detected in this sample, 147 parts per billion (ppb), is between the threshold effects level (TEL) and effects range low (ERL), 130 ppb to 150 ppb, respectively, of NOAA's Screening Quick Reference Tables. The ERL represents the value at which toxicity may begin to be observed in sensitive species. Because the value of 147 ppb detected at the LNG site is below the ERL of 150 ppb, it is unlikely that any toxic effects on terrestrial or marine organisms would occur from disturbance of soils at the LNG site.

Should contaminated soils be encountered within the LNG terminal site and along the Point Comfort Pipeline, Calhoun Point Comfort would implement its Contaminated Soils Management Procedures to minimize the spread of contaminated soils and to properly remove, dispose of or decontaminate such soils.

Contamination from spills or leaks of fuels, lubricants, and coolant from construction equipment could adversely affect soils. The effects of contamination would typically be minor because of the low frequency of spills and leaks. Calhoun Point Comfort has developed a SPCC Plan which describes spill prevention practices, spill handling and emergency notification procedures, and training requirements and would be implemented during construction of the LNG terminal and pipeline.

We believe that using the measures detailed in this Calhoun Point Comfort's Contaminated Soils Management Procedures and its SPCC Plan would minimize the potential for contamination and spread of contaminated soils.

4.2.3 Shoreline Erosion

The shoreline along the Gulf Coast exists in various states of erosion, accretion, or equilibrium. These processes are dynamic and vary with time as well as location. In the Port area, the shoreline is classified as deltaic headlands, peninsulas, and barrier islands. Deltaic headlands are primarily comprised of mud with relatively low percentages of sand, which would contribute to higher erosion rates. Bay shore erosion rates in the Port area vary based on wind, hurricanes, and other tropical storms that can alter the shoreline in a short period of time. Since the Port's peninsula and coastline is within a protected bay area, major shoreline erosion has not been noted. Between 1856 and 1957, Brown et al. found that the amount of land accretion on Cox Bay equaled the amount of eroded land. McGowen and Brewton noted that as promontories were eroded, sediment was deposited in small reentrants, or valleys, and that the dredging of turning and boat basins has created about 110 acres of new land.

A portion of the shoreline within the proposed LNG terminal site would be modified by dredging of the proposed LNG ship berth. The shoreline of the berth area would be protected from erosion by installing erosion controls such as rip-rap or articulated concrete mats or other slope stabilization materials.

Waterway for LNG Marine Traffic

LNG vessel traffic through the MSC and the Point Comfort Channel would not significantly affect soils resources. LNG vessels could result in increased shoreline erosion within the channels and at the proposed terminal site. However, based on the existing amount of shipping traffic in these channels, the operation of additional (LNG) vessels would not result in a significant increase of shoreline erosion.

For the Matagorda Ship Channel Improvement Project (MSCIP), the Calhoun County Navigation District engaged Moffatt & Nichol, a marine engineering and design firm, to perform a study of existing vessel traffic in the MSC and to assess the extent to which this traffic may be contributing to shoreline erosion in the bay. One conclusion of the study was:

- Existing wave climate and resulting erosion potential are dominated by wind waves (in Matagorda Bay). The relative wave energy from wind waves is estimated to comprise 97 to 99 percent of the total wave energy. Only approximately 1 to 3 percent of the total wave energy is from the existing vessel traffic.

The study also examined the potential impact of the widening and deepening of the channel and how this action along with the transit of larger vessels within the MSC might affect shoreline erosion in the bay. The study found that:

- Deepening and widening the navigation channel would result in a reduction in primary wave (drawdown) and secondary wave (wake) height for existing vessels.
- A proposed LNG vessel passing through the modified channel would result in greater drawdown than existing vessel passing through the existing channel at a comparable vessel speed.
- Increasing the depth of the channel is projected to result in a reduction of wave energy from passing vessel wakes. A proposed LNG vessel passing through the modified

channel would result in a smaller wake than an existing vessel passing through the existing channel.

An unignited marine spill of LNG that contacted soils along the waterway for LNG marine traffic would temporarily affect these soils. The extremely cold temperature of LNG would significantly lower the soil temperature, affecting its ability to support vegetation; however, these effects would be temporary as the LNG would vaporize quickly and disperse in the atmosphere. An unignited marine spill would not significantly affect shoreline erosion potential. Based on the low probability of an unignited marine spill and the temporary impacts associated with such an event, we conclude that an unignited marine spill would not result in significant effects to soil resources.

If a pool fire were to occur in association with a marine LNG spill, soil surfaces in Zones 1 and 2 could be impacted from radiant heat. The increased temperatures would briefly raise soil surface temperatures; damage or destroy vegetation exposing soils to increased erosion potential; and contribute to nutrient loss, a short-term suspension of biological activity, and evaporation of available water from the surface of the soil. No significant or long-term soil impacts would result. The impacts from an LNG marine spill and an associated pool fire within Zone 2 would be expected to be less than those in Zone 1. No impacts would be expected to occur on soils within Zone 3. However, the maximum flammable range for a vapor cloud could extend to the outer limits of Zone 3. If the vapor cloud were to come in contact with an ignition source, the resulting fire could burn back to the spill and temporarily impact any soils it came in contact with in the Zones of Concern. Because of the extensive operational experience of LNG shipping, the structural LNG vessel design, and the navigational safety and security controls further described in the section 4.12, the above marine LNG spill scenarios are not reasonably foreseeable events that would impact soil resources along the waterway for LNG marine traffic.

4.2.4 Sediments

The sediments that would be affected by the proposed Project are located within the CCND's new turning basin and Calhoun Point Comforts LNG ship berth. Both the turning basin and ship berth would be dredged to a depth of minus 40 feet MLLW, or 4 feet deeper than the existing channels. Construction of the turning basin and ship berth would require dredging about 2.7 mcy of material from Lavaca Bay. Of this amount, about 2.0 mcy would be for the CCND's turning basin and 0.7 mcy would be for Calhoun Point Comfort's ship berth.

Contaminated Sediments

On April 20, 1988, the Texas Department of Health (TDH) issued a fish closure of a 1 square mile area of Lavaca Bay to the taking of finfish and crabs. On January 13, 2000, the TDH reopened a portion of the closure area, Cox Bay, located due south of the LNG terminal site. The Cox Bay portion of the closed area was reopened based on the reduced contaminants in surface sediments and reduced burden of mercury in fish tissues (EPA ROD, 2001). During a treatment study, Alcoa dredged and disposed approximately 80,000 cubic yards of mercury-contaminated sediments which resulted in the removal of about 2,300 pounds of mercury from the Lavaca Bay system (EPA, 2004). An engineering evaluation, cost analysis and design that presents removal action alternatives to protect Dredge Island in the event of a severe storm has also been completed. As a result of this evaluation, about 10,700 linear feet of the levees or

dikes used to contain the contaminated material were refurbished to a height of 30 feet and the slopes were reinforced (EPA ROD, 2001).

Since the early 1990s, Lavaca Bay, Cox Bay, and the MSC have been investigated as part of the Alcoa (Point Comfort)/Lavaca Bay Superfund Site. The source of the contaminants within the Superfund Site is attributed to the release of PAHs and mercury due to the operations of Witco Chemical Corporation and Alcoa's chlor-alkali processing from the 1960s to 1980s. In 1994, investigative and remedial activities began under an Administrative Order on Consent for Alcoa signed by Alcoa and the EPA. The remedial investigation included major sampling of sediments and surface water in a "Closed Area" of Lavaca Bay immediately adjacent to the proposed terminal site. The remedial investigation concluded that the primary contaminants of concern in the bay system include mercury and PAHs (EPA, 2004).

During 2000, the COE's Galveston District conducted additional research in Lavaca Bay and in 2002 it published its findings in the report of *Environmental Assessment Assumption of Maintenance for Point Comfort Turning Basin*. The COE's research included analysis of water and sediment samples from the Point Comfort Turning Basin and solid phase bioassays and bioaccumulation tests. In this research, the concentrations of mercury in 23 sediment samples collected ranged from below detection level (<0.02 milligrams per kilogram [mg/kg]) to a high of 0.28 mg/kg. The higher values are above the EPA's TEL of 130 ppb and the ERL of 150 ppb; however, all values were below probable effects level (PEL) of 696 ppb and below the apparent effects threshold (AET) of 410 ppb. The PEL is the sediment benchmark concentration above which impacts on benthic communities are probable, whereas the AET is the calculated benchmark concentration where some degree of biological effects have been confirmed in benthic communities.

After reviewing the results of this study, consulting with the EPA, and performing a risk evaluation, the COE concluded that the increased potential for encountering excessive concentrations of hazardous materials during dredging within the Point Comfort Turning Basin would be remote. The EPA agreed with the COE's assessment regarding bioaccumulation studies and stated that it believes that toxic effects are not expected on benthic or water-column organisms exposed to the sediments. The EPA also stated that it believes that there is no potential for undesirable effects due to bioaccumulation as a result of the presence of contaminants in the sediments from the Turning Basin (COE, 2002).

In 2001, the EPA issued a ROD on the Alcoa (Point Comfort)/Lavaca Bay Superfund Site including a Selected Remedy which had the following major components for the Lavaca Bay system:

- Extraction and treatment of the chlor-alkali process area groundwater by a series of extraction wells. Treatment included aeration using air stripper and carbon adsorption for mercury removal.
- Installation of a Dense Non-Aqueous Phase Liquid (DNAPL) collection or treatment system at the Witco Area to intercept potential DNAPL migration to Lavaca Bay.
- Dredging of the Witco Channel to remove approximately 200,000 cubic yard of mercury contaminated sediments.

- Remediation of Witco Marsh by dredging or filling to address the concern of biological uptake of mercury.
- Accelerate the natural recovery of sediments north of Dredge Island by placing a thin cap of clean materials over the area.
- Institutional controls to manage exposure to finfish/shellfish.
- Long-term monitoring of sediments and fish to confirm natural recovery of sediment and fish tissue to an acceptable level.

Remedial activities in Lavaca Bay and Dredge Island are ongoing. Although the surface sediments of Lavaca Bay have not been restored to background levels, water quality monitoring results indicate that remediation efforts have had positive results (TCEQ, 2005).

The CCND's dredging activities would require a permit from the COE. The COE is required to follow specific protocols regarding the toxicity of sediments to be dredged and the possible contamination of surrounding waters. Dredged materials placed in proposed cap areas would comply with all sampling, testing, reporting, or other requirements articulated in the EPA's ROD for the Alcoa Site remedial action objectives. Pre-dredging soil sampling would be performed to ensure that mercury or PAH levels would not adversely affect the proposed placement areas. In addition, the dredging work would be performed in accordance with TCEQ water quality certification.

One of the major components of the Selected Remedy of the EPA ROD is enhanced natural recovery which would include capping contaminated sediments in-place with a covering of clean dredged material. The TPWD has expressed concern about using dredged material to cap mercury contaminated areas, and has commented that it believes further study should be conducted to evaluate the potential fate of the mercury in the enhanced recovery areas. It is our understanding that Calhoun Point Comfort's proposed DMMP would be consistent with the previously established Selected Remedy, and we do not believe it is within the scope of this EIS to further evaluate the potential effectiveness of the Selected Remedy. The issues regarding mercury in Lavaca Bay are well documented and the procedures to handle contaminated sediments have been established. Where sediments have a mercury concentration over 0.50 mg/kg (dry weight), silt fences would be installed to contain the sediment within an authorized disposal area. Decant water from the dredged material could only be discharged if the mercury concentration is less than 0.5 milligrams per liter (COE, 2002).

Dredged Material Disposal

Calhoun Point Comfort has proposed to use dredged material from the CCND's new turning basin and Calhoun Point Comfort's ship berth to aid in capping contaminated sediments and for creating coastal marsh habitat. As described in section 2.4.1.2 of this EIS, the placement of material is proposed at DMPAs located between 1 and 2 miles of the LNG terminal site. These DMPAs include Dredge Island Expansion North and the adjacent Dredge Island Marsh and Enhanced Recovery Projects B sites, and the Enhanced Recovery Projects A site (see figure 2.4-2). In total, the DMPAs have the capacity to accommodate the 2.7 mcy of material that would be dredged for the turning basin and the ship berth (table 2.4.1.2-1). The CCND proposes to remove the dredged material from its new turning basin and Calhoun Point Comfort's ship berth using a cutterhead suction dredging system. Typically for a dredging

project of this size, a 24- to 30-inch-diameter, high-density polyethylene pipeline would be used for the dredge. The slurry would be transported through a discharge pipeline to the disposal areas (see figure 2.4-2). Depending on the length of the discharge pipeline, a booster pump may be used.

The TPWD has also expressed concern over Calhoun Point Comfort's proposed placement of dredged material within the Enhanced Recovery Projects A, which would include placement of material in 50-foot-wide rows to be established as oyster reef enhancement areas, separated by 50-foot-wide undisturbed (and uncapped) areas left as access channels. The TPWD is concerned that this design could allow for accidental disturbance of the uncapped mercury contaminated sediments in the access channels during possible future oyster harvesting, which is typically done by dredge. It is our understanding that Calhoun Point Comfort's proposed DMMP would be consistent with the previously established Selected Remedy, and we do not believe it is within the scope of this EIS to further evaluate the potential effectiveness of the Selected Remedy.

Calhoun Point Comfort would conduct dredging operations according to its comprehensive DMMP to be developed as part of the Section 10/404 permit application process with the COE. The DMMP would contain specifications for dredging, placement of dredged material, and the testing for and handling of contaminated sediments. The DMMP would address dredging contamination issues including:

- monitoring of disposed dredged material for contaminants;
- steps to be taken for any hazardous material/contaminated sediments encountered during dredging;
- handling of clean versus contaminated dredge material;
- control of discharge water from dredge decanting;
- capacity of areas in Dredge Island to accept contaminated dredge material;
- impacts associated with sedimentation or contaminant movement from a dredging plume within Lavaca Bay; and
- description of what measures would be implemented to avoid, minimize, or mitigate dredging plume impacts.

Waterway for LNG Marine Traffic

The passage of large vessels would result in stirring of sediments in the ship channel by the turbulence created by the vessel's screws. These impacts should be limited to the 16 to 24 hours per week that the LNG vessels would traverse the area from the sea buoy to the LNG berth. The areas that would be affected by this turbulence would be limited to existing channels that experience this disturbance on a regular basis from existing ship traffic, and therefore, impacts on sediments from LNG marine traffic would not be significant. Turbulence from the vessel's screws would not be felt at the ocean bottom in depths of 60 feet and deeper beyond the sea buoy. The potential effects of an LNG spill, whether ignited or unignited, on sediments within the MSC is expected to be minimal. Because LNG is less dense than fresh or sea water, in the event of an LNG spill it would float to the surface and any LNG contact with bottom sediments would be minimal.

4.3 WATER RESOURCES

4.3.1 Groundwater

Waterway for LNG Marine Traffic

Normal LNG vessel operations in the MSC would not impact groundwater resources. Since LNG is less dense than fresh or sea water, in the event of an LNG release, LNG would float to the surface and vaporize, resulting in no impacts to groundwater. Therefore, based on the properties of LNG, no significant impacts to groundwater would occur from an accidental LNG release, with or without ignition, within the Zones of Concern along the waterway for LNG marine traffic.

LNG Terminal and Pipeline

The proposed Project would be underlain by the Gulf Coast Aquifer, which is characterized as an unconfined aquifer with unconsolidated sand, silt, and clay deposits that are vertically connected. Numerous retreats and advances of ancient shorelines have resulted in a complex, overlapping mixture of sand, silt, and clay (Ryder, 1996). The formations of the Gulf Coast Aquifer system are hydrologically connected to form a large, artesian aquifer system comprised of four major units: the Catahoula, Jasper, Evangeline and Chicot aquifer formations, with the Evangeline and Chicot being the shallowest, mostly sandy portions. In most areas, the Evangeline aquifer is separated from the overlying Chicot aquifer by clay beds. The Chicot aquifer consists of five alluvial deposits including the Lissie and Beaumont formations. The Beaumont formation underlies the project area and is about 200 to 300 feet deep. The majority of the groundwater used in Calhoun and Jackson Counties is obtained from wells completed in the Lissie formation, Beaumont clay, and recent alluvium.

The groundwater supply in Calhoun County is of shallow depth, lacks availability of fresh water, and is not a major water source. The groundwater supply in southwestern Jackson County is generally of poor quality. Fresh groundwater supplies are available in the remaining areas of Jackson County except along the Lavaca River from Lavaca Bay northward to the confluence of the Lavaca and Navidad Rivers. Cities such as Edna and Ganado, located about 3.0 and 12.0 miles northeast of the pipeline terminus, respectively receive water supply from public wells. The Lavaca-Navidad River Authority provides water to a number of cities and industrial facilities in both Calhoun and Jackson Counties from Lake Texana, located about 6.0 miles east of the project area. The EPA has not designated the Gulf Coast Aquifer as a sole source aquifer. The proposed Project would not cross any aquifer protection areas and no municipal or commercial water wells are located within 400 feet of proposed construction workspaces.

One unused, industrial water supply well is located within 150 feet of the proposed LNG terminal. This well is on CCND property and owned by the Delta Drilling South Texas Division. If necessary, Calhoun Point Comfort indicated that the CCND would plug and abandon the well pursuant to state requirements. No other public or private water supply wells are within 150 feet of the LNG terminal. Groundwater would not be used during construction or operation of the LNG terminal.

Four private water supply wells have been identified near the proposed Point Comfort Pipeline construction right-of-way. A 130-foot-deep, livestock well near MP 7.7 would be 80 feet from the right-of-way. An unregistered well near MP 11.2 would be inside the right-of-way, and Calhoun Point Comfort stated that this well is pumped by a windmill and appears to be used for livestock or irrigation, or it may be abandoned. A 125-foot-deep, household well near MP 19.0 would be within 218 feet of the construction right-of-way and a 475-foot-deep, irrigation well near MP 26.5 would be within 3 feet of the right-of-way.

Prior to construction, Calhoun Point Comfort would stake and flag the wells near MP 11.2 and MP 26.5, and they would be avoided during construction. Blasting is not anticipated by Calhoun Point Comfort. Refueling of equipment would be prohibited within 200 feet of all known wells and BMPs, to be identified in Calhoun Point Comfort's Storm Water Pollution Prevention Plan (SWPP Plan), would be implemented to direct surface water runoff from areas disturbed by construction away from existing wells. Calhoun Point Comfort would conduct pre- and post-construction testing of well yield and water quality for the wells near MP 7.7, MP 11.2, and MP 26.5, and for any other wells or springs found to be within 150 feet of the construction right-of-way for the pipeline. Should these wells be impacted during construction, Calhoun Point Comfort would employ interim measures and provide temporary sources of potable water. If significant impacts on these wells occur after construction, Calhoun Point Comfort would restore or replace the wells or, if necessary, provide an alternate source of water.

If shallow groundwater is encountered during construction of the proposed Project, it may be necessary to dewater during construction. Trench dewatering operations would be brief, typically lasting several days or less. Potential impacts on the groundwater would include minor fluctuations in groundwater levels and/or increased turbidity within the aquifer adjacent to the activity. Because of the relatively small amount of water removed, the short duration of the activity, and the local discharge of the water, groundwater levels would quickly recover after pumping stops. Calhoun Point Comfort would follow our Plan and Procedures that provide guidance on the location of dewatering structures so that there would be no deposition of sediments into wetlands and waterbodies, and no impacts on cultural resources or habitat for sensitive species. We believe that effects of dewatering on groundwater would be localized, temporary, and insignificant.

The greatest potential for impacts on groundwater would be an accidental release of a hazardous substance, such as fuels, lubricants, and coolants, during construction or operation. Spills or leaks of hazardous liquids could contaminate groundwater and affect users of the aquifer. To minimize potential impacts related to spills or leaks of hazardous liquids, Calhoun Point Comfort as part of its draft *Water Quality Management Plan*, developed an SPCC Plan that would be implemented during construction of the facilities. The SPCC Plan addresses potential spills of fuel, lubricants, and other hazardous materials and describes spill prevention practices, spill handling and emergency notification procedures, and training requirements. It also describes mitigation measures, including containment and cleanup, to minimize potential impacts should a spill occur. We believe that using the measures detailed in Calhoun Point Comfort's draft *Water Quality Management Plan* and SPCC Plan would minimize or eliminate the potential for adverse impacts on groundwater resources.

4.3.2 Surface Water

The proposed Project would be generally located within the upper Matagorda Bay system (Bronikowski, 2004). Matagorda Bay is the third largest estuarine system in Texas and contains a number of defined embayments and waterbodies including Lavaca and Cox Bays and the MSC. Matagorda Bay is separated from the Gulf of Mexico by the Matagorda Peninsula and water exchange occurs through five main tidal inlets, one of which includes the MSC. Freshwater input to the system comes from a large drainage basin entering the bay from the Colorado and Lavaca Rivers and a number of creeks and bayous. The entire Matagorda Bay system covers 270,085 acres and includes 85,992 acres of coastal wetlands and 6,918 acres of submerged aquatic vegetation with an average depth of about 7 feet (GulfBase, 2005).

Lavaca Bay covers 40,959 acres and is classified by the TCEQ as water quality limited with recreation, exceptional aquatic life, and oyster waters as designated uses. Cox Bay covers 5,119 acres and is TCEQ classified as effluent limited with contact recreation, exceptional aquatic life use, and oyster waters as designated uses. Both bays are shallow with an average depth of 4 feet (EPA ROD, 2001). Since the early 1990s, Lavaca Bay, Cox Bay, and the MSC have been investigated as part of the Alcoa (Point Comfort)/Lavaca Bay Superfund Site (see section 4.2.4 of this EIS for information on the impact of the Superfund Site on Lavaca and Cox Bays).

Salinity levels in the upper Matagorda Bay system vary with location and with season. Monthly mean salinities in Matagorda Bay range from 15 parts per thousand (ppt) to about 35 ppt (White et al., 1989). Monthly mean salinities in Lavaca Bay range from less than 5 ppt to about 18 ppt (White et al., 1989).

Matagorda Bay temperature variations result from the effects of inflow water temperatures, heat gained due to insulation, latent heat loss by evaporation, intermixing with marine waters, and heat loss by back radiation. Temperatures of monitored inflows (rivers) range from 35.5°C in the summer to 5°C in the winter. Vertical temperature stratification occurs to a lesser extent than vertical salinity stratification in the system. In general, temperature varies insignificantly with depth, even in the dredged MSC. Unlike salinity, horizontal temperature gradients are slight and usually no system-wide distinguishable patterns exist. Generally, temperature gradients vary spatially within 2°C throughout the bay system. Although the estuary is almost completely homogenous at any time, a seasonal temperature pattern does exist. Minimum temperatures occur in January and February (average 12°C) and with a gradual increase reaching maximum temperatures in July and August (29°C) with a cooling trend through December (EPA, 1995).

Two tidal measurement stations are maintained in Matagorda Bay – one near Port O'Connor and one at Port Lavaca. The average diurnal tidal fluctuation is only approximately 1 foot, but this tidal fluctuation may be increased to approximately 3 feet temporarily during the passing of winter cold fronts when northerly and northeasterly winds push water against the western shoreline and out of the bay. With the MLLW datum set for 0.0 feet for both Port O'Connor and Port Lavaca, the mean high high water (MHHW) is 0.79 feet for Port O'Connor and 0.93 feet at Port Lavaca.

Waterway for LNG Marine Traffic

As described previously, the LNG vessel transit route would extend from the Gulf of Mexico through the MSC. The MSC extends for about 22 miles through Matagorda and Lavaca Bays to the Port of Port Lavaca – Point Comfort. The existing authorized depth of the MSC is 36 feet and channel widths range between 200 and 300 feet. Water depth outside these maintained areas is much shallower, only 4 to 6 feet deep in some areas. Areas of Lavaca Bay are dredged periodically to allow for ship and barge passage to the Port as well as the approach channel and existing turning basin. Maintenance dredging of the MSC generally occurs approximately every other year in the bayside channel and once every 2.5 to 3 years in the entrance channel.

The passage of large vessels would result in increased turbidity due to the stirring of sediments in the ship channel by the turbulence created by the vessel's screws. These impacts would be limited to the 16 to 24 hours per week that the LNG vessels would traverse the area from the sea buoy to the LNG berth. The areas that would be affected by this turbulence would be limited to existing channels that experience this disturbance on a regular basis from existing ship traffic, and therefore, impact on water quality from turbidity caused by LNG marine traffic would not be significant. Turbulence from the vessel's screws would not be felt at the ocean bottom in depths of 60 feet and deeper beyond the sea buoy.

Accidental spills or releases of hazardous materials during LNG transit could also impact the waterway. No oil or mixtures containing more than 15 parts of oil per million may be discharged within 50 miles of the shore (MARPOL 73/78). No solid debris may be discharged from vessels (30 CFR 250.40 and MARPOL, Annex V, Public Law 100-220 [101 Statute 1458]). Therefore, although additional debris may enter the water column incidentally from the increased vessel traffic, the anticipated amount of any additional debris would be small and not significant.

LNG marine traffic would intake cooling water for ships boilers while transiting offshore into the MSC. Impacts to water quality from these intakes would include increased water temperature from engine cooling operations. However, the temperature change would not be significant given the total volume of water within these areas and the limited amount of impact to any one given area.

If an unignited marine LNG spill were to occur along the transit route, given that LNG is lighter than water, the LNG would float on the water until it had vaporized. No significant impacts to water quality would be expected from an unignited release of LNG because LNG is not soluble in water and the cryogenic liquid would vaporize rapidly upon contact with the warm air and water. Within Zone 1, the water's surface within the LNG pool may be temporarily impacted by sudden lowering of temperature until the LNG had vaporized. If an associated fire were to occur with the release of LNG, the water's surface temperature could increase within Zone 1 of the vicinity of the fire. Upon ignition, LNG will burn rapidly, intensely, and with no residual unburned product. Therefore, the fire would not result in any unburned residual product mixing with the water. If the radiant heat were to harm the shoreline vegetation, this could result in increased sedimentation within Zone 2. Impacts to Zone 2 would be expected to be considerably less than Zone 1. No surface water impacts would be expected within Zone 3 from a pool fire. The maximum flammable range for a vapor cloud could extend to the outer limits of Zone 3. If the vapor cloud were to come in contact with an ignition source, the resulting fire could burn back to the spill and impact any vegetation within its path, thus increasing the likelihood of

increased sedimentation. However, because of the marine transit safety and security measures, the probability of an LNG vessel spill from collisions, allisions, and terrorist attacks would be unlikely. The potential surface water impacts are considered not significant due to the low probability of a spill.

LNG Terminal

No natural fresh water ponds, lakes, or streams occur on or adjacent to the proposed LNG terminal site.

The primary impacts on Lavaca Bay from construction and operation of the Project would be from the dredging of the CCND's turning basin and Calhoun Point Comfort's ship berth and from stormwater runoff.

Dredging activities would temporarily stir up sediment and degrade the water quality in the area of the dredging. The hydraulic cutterhead dredge system that would be used to excavate the material generally creates less turbidity than other types of dredges, and the cutter speed can be adjusted to match the sediment properties, thus minimizing turbidity. The CCND and Calhoun Point Comfort expect that the pumps used to convey the material from the cutterheads, in a hydraulic dredging operation, would contain most of the suspended solids caused by the dredging and that they would be conveyed with the dredged material to the DMPAs within Lavaca Bay. Once on the DMPAs, the suspended solids would settle out prior to the excess water being discharged back to Lavaca Bay.

The suspended solids and turbidity levels eventually would decline to ambient levels following completion of dredging activities. Turbidity resulting from dredging could reduce light penetration and the corresponding primary production of aquatic plants, algae, and phytoplankton in the slip area. The suspension of organic materials and sediments could cause an increase in biological and chemical oxygen demand in the slip area. Lower dissolved oxygen concentrations could cause a temporary displacement of motile organisms and could stress or kill sessile benthic organisms within the affected area. Calhoun Point Comfort would work closely with the COE to identify and incorporate the appropriate specifications and guidelines governing dredging activities into the dredging contract. Turbidity impacts related to dredging are expected to be short-term and to have minimal adverse effects on water quality and aquatic life. Calhoun Point Comfort would monitor and manage suspended solids and turbidity at the dredge site and employ mitigation measures including the use of silt curtains and absorbent boom, shallower dredge cuts, containment structures, or stop dredging activates until turbidity levels have declined.

The CCND would be required to obtain several permits that would address dredging and dredged material management, including permits from the COE under Section 404 of the CWA and Section 10 of the Rivers and Harbor Act. Permits for water discharges into the bay from the LNG terminal would be obtained from the EPA and/or the TRRC under Section 401 of the CWA. A NPDES permit under Section 402 of the CWA issued by the TRRC would be necessary to regulate return water emanating from the DMPAs within Lavaca Bay. Dredge discharge and/or decant liquids would be collected and tested during dredge operations to ensure permit compliance. Typically, such permits would establish limits on the concentration and area of suspended solids during dredging, and would likely require monitoring during dredging and

establish criteria for maximum suspended sediment concentrations allowed in the return water. These specifications would be included in Calhoun Point Comfort's DMMP for the Project. The DMMP would address use of dredged material to cap areas of contaminated sediment within Lavaca Bay (see section 4.2.4 of this EIS), and also address mitigation for the loss of wetlands or other habitats of concern that would result from placement of dredged material (see sections 4.4.1 and 4.5.2.5 of this EIS). Calhoun Point Comfort would be required to finalize its DMMP with the appropriate agencies, including the COE and NOAA Fisheries, prior to the start of construction of the LNG terminal.

During site preparation and construction at the LNG terminal site, disturbed soils would be exposed to precipitation with the potential for erosion. To minimize erosion impacts on surface waters, Calhoun Point Comfort would comply with the NPDES Construction General Permit that would include preparation and implementation of a Stormwater Pollution Prevention Plan. Stormwater collected at the LNG terminal site would be discharged through two stormwater discharge points located at the southern corner of the terminal site and southeast shoreline from the process area. Stormwater removal from within the LNG storage tank dikes must conform to 49 CFR 193.2173, requiring water to be pumped out at 25 percent of the maximum predictable collection rate from a storm of 10-year frequency and 1-hour duration. Water removed would be discharged in the vicinity of the removal area via overland flow to reduce sedimentation. Calhoun Point Comfort would implement our Procedures in addition to its Stormwater Pollution Prevention Plan to reduce the potential impacts associated with stormwater runoff.

There is also the potential for impacts on the bay from accidental spills of hazardous materials during construction, or LNG spills during transport or terminal operation. In the event of an accidental spill of oil, gas, lubricants, or other hazardous materials during construction or operation, Calhoun Point Comfort would follow the measures outlined in its draft *Water Quality Management Plan* and SPCC Plan. In addition, LNG vessels calling at the LNG terminal would be required to have a vessel response plan that satisfies Coast Guard requirements and applicable international standards.

Calhoun Point Comfort has designed its LNG terminal to account for an accidental spill of LNG during operation of the facility, and prevent the LNG from entering Lavaca Bay. The LNG facilities would include safety and hazard detection systems, three LNG containment sumps and two LNG process sumps and associated LNG spill collection system. In the unlikely event that LNG is spilled into the water, the cryogenic liquid would vaporize rapidly upon contact with the warm air and water. Being less dense than water, LNG would float on the surface prior to vaporizing. Because LNG is not soluble in water and the LNG would completely vaporize shortly after being spilled, there would be no liquid left that could mix with and/or contaminate the water.

Pipeline

The proposed Point Comfort Pipeline would cross 65 surface waterbodies. No waterbody segments that would be crossed by the pipeline are included on the list of impaired waterbodies under Section 303(d) of the CWA or have concerns resulting from contaminated sediments. However, the crossing of the Lavaca River (MP 23.4) would be at the boundaries of two Texas water quality stream segments and one of the segments, upstream of the Point Comfort Pipeline crossing, has low dissolved oxygen levels and partially supports aquatic life. A list of the

waterbodies crossed by the proposed pipeline is included in table 4.3.2-1 and shows the location by waterbody name, MP, type, crossing width, water quality classification, and proposed crossing method. Only four natural, permanently flowing waterbodies would be crossed by the pipeline: a slough (MP 4.5), the Navidad River (MP 16.5), the Lavaca River (MP 23.4), and a tributary to Lavaca River (MP 23.5).

TABLE 4.3.2-1

Waterbodies Crossed by the Point Comfort Pipeline

Milepost	Waterbody	Type a/	Crossing Width (feet)	Crossing Method
Point Comfort Pipeline				
0.25	Ditch	CD/ Intermittent	<10	open cut
0.29	Ditch	CD/ Intermittent	<10	open cut
0.29	Ditch	CD/ Intermittent	<10	open cut
0.30	Ditch	CD/ Intermittent	<10	open cut
0.31	Ditch	CD/ Intermittent	<10	open cut
0.79	Industrial pond	CD/ Perennial	90	HDD
1.87	Ditch	CD/ Perennial	15	open cut
4.46	Lake tributary	ND/ Perennial	45	open cut
5.18	Ditch	CD/ Perennial	9	open cut
5.96	Ditch	CD/ Intermittent	31	open cut
6.58	Gully	CD/ Intermittent	46	open cut
7.63	Ditch	CD/ Perennial	7	open cut
9.86	Gully	ND/ Intermittent	156	open cut
9.94	Gully	ND/ Intermittent	46	open cut
11.15	Gully	ND/ Intermittent	13	open cut
12.12	Ditch	CD/ Intermittent	<10	bore
12.45	Ditch	CD/ Intermittent	<10	bore
12.63	Ditch	CD/ Intermittent	<10	open cut
12.77	Ditch	CD/ Intermittent	15	open cut
12.89	Channelized creek	CD/ Intermittent	25	open cut
13.28	Ditch	CD/ Intermittent	<10	bore
13.59	Ditch	CD/ Intermittent	<10	HDD
13.61	Ditch	CD/ Intermittent	<10	HDD
13.62	Ditch	CD/ Intermittent	<10	HDD
13.63	Ditch	CD/ Intermittent	<10	HDD
14.02	Ditch	CD/ Intermittent	50	open cut
14.81	Channelized creek	CD/ Intermittent	20	open cut
14.99	Drainage canal	CD/ Intermittent	30	open cut
15.92	Drainage	CD/ Intermittent	30	open cut
16.54	Navidad River	ND/ Perennial	140	HDD
16.94	Dry Creek	ND/ Intermittent	30	HDD
17.05	Dry Creek	ND/ Intermittent	20	open cut
17.50	Ditch	CD/ Intermittent	<10	open cut
17.54	Ditch	CD/ Intermittent	<10	open cut
19.13	Ditch	CD/ Intermittent	<10	open cut
19.45	Ditch	CD/ Intermittent	<10	open cut
19.49	Ditch	CD/ Intermittent	<10	open cut
19.64	Ditch	CD/ Intermittent	<10	bore
19.93	Ditch	CD/ Intermittent	<10	open cut
20.02	Ditch	CD/ Intermittent	<10	bore
20.03	Ditch	CD/ Intermittent	<10	bore
20.54	Ditch	CD/ Intermittent	<10	bore
20.68	Ditch	CD/ Intermittent	<10	open cut
20.93	Ditch	CD/ Intermittent	<10	open cut
20.94	Ditch	CD/ Intermittent	<10	open cut
21.27	Ditch	CD/ Intermittent	<10	open cut

TABLE 4.3.2-1

Waterbodies Crossed by the Point Comfort Pipeline

Milepost	Waterbody	Type a/	Crossing Width (feet)	Crossing Method
21.82	Creek	ND/ Intermittent	28	open cut
22.74	Creek	ND/ Intermittent	45	open cut
23.13	Borrow pit	Pond/ Perennial	600	HDD
23.42	Lavaca River	ND/ Perennial	77	HDD
23.46	Creek	ND/ Perennial	12	HDD
23.78	Creek	CD/ Intermittent	13	open cut
24.21	Ditch	CD/ Intermittent	25	open cut
24.79	Ditch	CD/ Intermittent	14	open cut
25.33	Channelized creek	CD/ Intermittent	40	HDD
25.74	Ditch	CD/ Intermittent	44	open cut
25.93	Ditch	CD/ Intermittent	58	open cut
26.17	Ditch	CD/ Intermittent	<10	bore
26.19	Ditch	CD/ Intermittent	<10	bore
26.47	Ditch	CD/ Intermittent	<10	open cut
26.67	Ditch	CD/ Intermittent	<10	bore
26.69	Ditch	CD/ Intermittent	<10	bore
26.72	Ditch	CD/ Intermittent	<10	bore
26.75	Ditch	CD/ Intermittent	20	bore
26.99	Ditch	CD/ Intermittent	030	bore

a/ Type: CD = channelized drainage; ND = natural drainage

Pipeline construction could impact surface waters in a variety of ways. Clearing and grading of stream banks, in-water trenching, trench dewatering, and backfilling could result in modifications to aquatic habitat, increased sedimentation and turbidity, decreased dissolved oxygen levels, increased stream warming, releases of chemical and nutrient pollutants from sediments, and accidental release of chemical contaminants such as fuels and lubricants. The greatest potential impacts for the waterbody crossings would result from suspension of sediments caused by in-stream trenching and backfilling. The extent of the impact would depend on sediment loads, stream velocity, and sediment particle size at the time of construction. These factors would determine the density, downstream extent, and persistence of the sediment plume. In general, impacts on the in-stream aquatic biota and the habitat value of the waterbody would be temporary and short-term during construction. Through the transport of sediment and recruitment of aquatic biota from upstream sources, these resources would be expected to return to preconstruction conditions soon after the completion of in-stream work, backfilling, and restoration.

In order to minimize impacts to water quality, Calhoun Point Comfort would cross 11 of the 65 waterbodies using the HDD crossing method. The HDD method involves boring a pilot hole beneath the waterbody to the opposite bank and then enlarging the hole with one or more passes of a reamer until the hole is the necessary diameter. A prefabricated pipe segment is then pulled through the hole to complete the crossing. A successful drill generally results in no impact on the waterbody being crossed. For this reason, directional drilling is considered to be a preferred crossing method for waterbodies, especially those that are sensitive. However, there are certain impacts that could occur as a result of the drilling, such as an inadvertent release of drilling mud. This could occur in the area of the mud pits or tanks, or along the path of the drill due to unfavorable ground conditions. Drilling mud is most often comprised of naturally occurring materials, such as bentonite, which in small quantities would not be detrimental to vegetation,

fish, or wildlife. However in larger quantities, the release of drilling mud into a waterbody could affect fisheries and vegetation; although impacts would be significantly less than those associated with an open-cut crossing. Calhoun Point Comfort submitted a draft project-specific HDD Frac-Out Monitoring and Response Plan that addresses how potential frac-outs would be minimized, procedures for detecting a frac-out, measures to be implemented should a frac-out occur, remediation of an affected area, how an abandoned drill hole would be sealed, and measures of notification of downstream users, and reporting and notification.

Calhoun Point Comfort has not yet conducted geotechnical investigations of all of the waterbodies that would be directionally drilled. These investigations must be conducted to determine the feasibility of completing directional drills at these waterbody crossings. Once the geotechnical investigations are completed, Calhoun Point Comfort would prepare final site-specific drilling plans. Calhoun Point Comfort would file its final *Water Quality Management Plan,* SPCC Plan, and HDD Frac-Out Monitoring and Response Plan approximately one year prior to commencement of construction of the pipeline.

In the event that an HDD of a waterbody is unsuccessful, Calhoun Point Comfort would install the crossings using the open-cut method. Calhoun Point Comfort would be required to file a plan for the crossing of each waterbody if the directional drill is unsuccessful. This would be a site-specific plan that includes scaled drawings identifying all areas that would be disturbed by construction. Calhoun Point Comfort would be required to file this plan concurrent with its application to the COE for a permit to construct using this plan. The Director of OEP must review and approve this plan in writing before construction of the crossing.

Fourteen waterbodies that would be affected by the proposed pipeline are channelized intermittent roadside ditches. These waterbodies would be crossed by the bore method. The remaining 40 waterbodies that would be affected are both channelized and natural intermittent drainages and would be crossed by the open-cut method. It is possible that no flow would be present during construction across these intermittent waterbodies, in which case crossing by the bore or open-cut method would have minimal impact on the waterbody. If flow were present in these waterbodies, Calhoun Point Comfort would complete most instream work within 24 hours (for streams less than 10 feet across) or within 48 hours (for streams greater than 10 feet across). Trench spoils would be stored at least 10 feet from the water's edge and would have erosion and sedimentation controls installed. Stream banks would be stabilized and temporary sedimentation barriers installed across the right-of-way within 24 hours of completing instream construction. Therefore, most impacts would be temporary and suspended sediment concentrations and turbidity levels would be expected to return to preconstruction levels soon after construction in each stream was completed.

Stormwater from areas disturbed during construction would be discharged under a General Construction Permit, which Calhoun Point Comfort would obtain from the EPA under the NPDES program. In addition, Calhoun Point Comfort would obtain a Section 10 permit from the COE for work in navigable waterways and a Section 404 permit for placement of dredged or fill material into all waters of the United States, including wetlands. Wastewater discharge permits would be obtained from the TRRC and EPA.

In response to past concerns raised by federal, state, and local agencies regarding the potential impact of construction of pipeline projects in general, we developed our Procedures to provide

guidelines for an acceptable level of protection for wetlands and waterbodies affected by pipeline projects. Our Procedures include requirements for pre-construction planning, environmental inspection, construction methods, sediment and erosion control, restoration, and post-construction maintenance. It includes provisions to handle stormwater and protection of waterbodies and wetlands from accidental spills of fuels or hazardous materials. Calhoun Point Comfort proposes to cross all waterbodies in accordance with our Procedures. We believe that using the measures detailed in our Procedures would minimize both short- and long-term impacts on water resources.

Lubricant, hydraulic fluid, and fuel spills from refueling construction equipment, fuel storage, or equipment failure in or near a waterbody could flow or migrate to the waterbody and immediately affect aquatic resources and contaminate the waterbody downstream of the release point. Calhoun Point Comfort would follow the measures outlined in its draft *Water Quality Management Plan* and SPCC Plan to minimize the potential impacts of spills of hazardous materials during construction in waterbodies.

4.3.2.1 Hydrostatic Testing

Prior to being placed into service, the proposed LNG storage tanks and pipeline would be hydrostatically tested to ensure structural integrity. Hydrostatic testing procedures for the LNG storage tanks and pipeline are discussed below.

LNG Storage Tanks

Once construction is completed, the LNG storage tanks would be hydrostatically tested, in accordance with API Standard 620, Appendix Q.8 (see section 2.4.1.4). Hydrostatic testing of each tank would involve filling the inner tank with approximately 28 million gallons of fresh water. Test water would be obtained from the CCND or purchased from Formosa Plastic Corporation or the City of Point Comfort. At the maximum level calculated, the water would be maintained for at least 48 hours for inspection. To minimize water usage, the two tanks would undergo hydrostatic testing using the same water by transferring the water at the conclusion of the test of the first tank to the second tank to be tested. After testing, the tanks would be cleaned with fresh water and dried. Pumps in each tank would control the discharge rate of the test water. Fresh water would be discharged into Lavaca Bay at a rate of approximately 10,000 gpm and be in compliance with hydrostatic test water permits issued by the TRRC or the EPA. No chemicals would be added to the hydrostatic test water before or after testing. Prior to discharge, all test water would be analyzed for chemical composition and dissolved oxygen would be restored. Calhoun Point Comfort stated that, if the construction sequence allows, it would use the test water from the LNG tanks to hydrostatically test the Point Comfort Pipeline.

Pipeline

Prior to being placed into service, the pipeline and laterals would also be hydrostatically tested to DOT standards, as listed in 49 CFR 192. In addition, Calhoun Point Comfort has prepared a Draft Hydrostatic Testing Plan to address the methods of water withdrawal and discharge. The pipeline would be tested in one segment, using approximately 8.1 million gallons of water for the entire pipeline. Of this amount, about 3,681 gallons and 13,165 gallons would be used to test the Formosa and Transco Laterals, respectively. The sections of pipe that would be installed using

the HDD method would be tested separately to ensure the integrity of the HDD segment. Of the 8.1 million gallons, about 346,500 gallons would be used to test each HDD segment.

Temporary manifolds and pumping systems would be used to withdraw water. Calhoun Point Comfort estimates that about 4.5 million gallons of water would be withdrawn from the Navidad River near MP 16.5 pending the ability to obtain permission for water rights and withdrawal from TCEQ and the Lavaca-Navidad River Authority. The remaining 3.6 million gallons would be purchased from Formosa Plastic Corporation or the CCND under existing water allocations and permits. Formosa Plastic Corporation has informed Calhoun Point Comfort that it could supply all of the water needed for hydrostatic testing from its industrial waste water system. As a result, Calhoun Point Comfort and Formosa Plastic Corporation are currently in negotiations and expect to have an agreement fully executed prior to the start of construction. In its comments on the draft EIS, Calhoun Point Comfort stated that it would obtain necessary authorizations and permits prior to using any water directly from the Navidad River and file copies with the FERC prior to hydrostatic testing, as well as file with the FERC any water purchase agreements it reaches with Formosa Plastic Corporation or the CCND.

Water intake hoses would be screened to prevent the entrainment of aquatic species. Calhoun Point Comfort indicated that water may also be obtained from a retention basin at the LNG terminal site or, if the construction sequence allows, test water from the LNG tanks could be used to hydrostatically test the pipeline. Water would be pushed from one segment to another by connecting piping at the manifold sites as each test segment is filled sequentially. The pipeline segments would be pressurized to the design test pressure and the pressure would be maintained for a minimum of eight hours. If during the test period any leaks are detected, the leaks would be repaired and the test section re-pressurized until the DOT specifications are met. After testing is completed, the water would be discharged into a retention basin at the LNG terminal site via a temporary water line. Discharge of hydrostatic test water would be in accordance with our Procedures and NPDES permit requirements.

Discharge of hydrostatic test water used to test the integrity of oil and gas facilities requires permitting from the TRRC, as regulated by the Texas Administrative Code (TAC) Title 16, Part 1, Chapter 3, Rule 3.30 Memorandum of Understanding Between the TRRC and the TCEQ under Section (e)(6)(A). In addition, hydrostatic test waters that fall under the jurisdiction of the TRRC and that would be discharged into waters of the state would require a permit from the EPA under the NPDES, as regulated by the CWA. The appropriate Section 401 Water Quality Certification and Section 404 permit must also be obtained prior to discharge of hydrostatic test water into surface waterbodies. Compliance with requirements of our Plan and Procedures, and with permitting requirements from EPA and state and local agencies would minimize impacts resulting from the discharge of hydrostatic test water.

4.3.2.2 Operational Impacts

Waterway for LNG Marine Traffic

Operational impacts during use of the waterway for LNG marine traffic are discussed above under section 4.3.2.

LNG Terminal

Operational impacts of the LNG terminal on marine waters would include periodic maintenance dredging of the CCND's turning basin and Calhoun Point Comfort's ship berth, as well as incidental propeller wash from the LNG vessel traffic in the Port. Based on the operating history of the Port, the CCND and Calhoun Point Comfort expect maintenance dredging to be required about every two years. Both maintenance dredging and incidental propeller wash could result in temporary increases in turbidity in Lavaca Bay from the resuspension of bottom sediments.

The ship berth would include erosion protection (i.e., articulated concrete blocks) placed on slopes to stabilize the shoreline and prevent erosion from wave action and wheel wash and bow thrusters from the LNG vessel wash. We believe that turbidity caused by maintenance dredging using a hydraulic cutterhead dredge would be short-term, localized, and not significant. Maintenance dredging should not add appreciably to ongoing maintenance dredging activities in the Port and the MSC. The CCND and Calhoun Point Comfort anticipate that materials generated during maintenance dredging would be pumped to the Dredge Island Expansion North DMPA within Lavaca Bay. Maintenance dredging and dredge disposal would require an additional approval from the COE.

In the event of an accidental spill of oil, gas, lubricants, or other hazardous materials during construction or operation, Calhoun Point Comfort would follow the measures outlined in its draft *Water Quality Management Plan* and SPCC Plan. In addition, LNG vessels calling at the LNG terminal would be required to have a vessel response plan that satisfies Coast Guard requirements and applicable international standards. Stormwater discharges from defined contributing drainage areas would be directed to EPA NPDES and TRRC-permitted outfalls with Individual Permit coverage. A Stormwater Pollution Prevention Plan would also be prepared to comply with NPDES requirements for stormwater runoff from areas of the LNG facility that are not covered by Individual NPDES or Texas Permit authorization.

Calhoun Point Comfort has designed its LNG terminal to account for an accidental spill of LNG during operation of the facility, and prevent the LNG from entering Lavaca Bay. The LNG facilities would include safety and hazard detection systems, three LNG containment sumps, and two LNG process sumps and associated LNG spill collection system. In the unlikely event that LNG is spilled into the water, the cryogenic liquid would vaporize rapidly upon contact with the warm air and water. Being less dense than water, LNG would float on the surface prior to vaporizing. Because LNG is not soluble in water and the LNG would completely vaporize shortly after being spilled, there would be no liquid left that could mix with and/or contaminate the water.

The SCV technology that would be used to process the LNG produces excess water at an estimated rate of 200 gpm. During the vaporization process, this excess water would become acidic. Calhoun Point Comfort would neutralize the excess water with a caustic solution before it is discharged into Cox Bay. The temperature of the produced water is expected to range from 60 to 70°F. Discharges of excess water from the SCV process area would comply with state and federal water quality standards and the requirements of the National and Texas Pollutant Discharge Elimination System.

As with other large cargo ships, LNG vessels would take on some ballast water to maintain stability and trim as they offload their cargo, but they would not be fully loaded when departing the Calhoun LNG Terminal. The amount of ballast water required by each LNG vessel would vary according to its size and the weather conditions. A typical 138,000 m^3 LNG vessel would require about 13.7 millions gallons of water, which would be obtained in Lavaca Bay and transported out of the waterway. The larger 200,000 m^3 vessels would withdraw about 19.8 million gallons of water. This would constitute a minor but long-term impact to water resources of Lavaca Bay.

Although ballast water intake by the LNG vessel would occur during offloading of the LNG, no release of ballast water would occur within Lavaca Bay. Any limited discharge of ballast water that should occur would be conducted in accordance with the Coast Guard's mandatory ballast water management program (33 CFR 151).

Pipeline

Operation of aboveground facilities associated with the proposed pipeline, such as pig launchers and receivers, would not affect water resources. Impacts to surface waters are not expected during operation of the proposed pipeline because no further in-stream activities would be expected. Since the pipeline would be installed at a sufficient depth below the beds of waterbodies, exposure of the pipeline is not expected. In the event that a pipeline anomaly (i.e., corrosion, dent, or rupture) is detected during routine inspections that could require pipeline excavation or replacement within a waterbody, impacts would be expected to be similar to those described for construction. Therefore, operation of the project would not have a significant impact on water resources.

4.4 VEGETATION

4.4.1 Wetlands

The COE defines wetlands as areas that are inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Estuarine emergent wetlands and palustrine emergent, scrub-shrub, and forested wetlands occur within the Lavaca Bay watershed. Estuarine emergent wetlands are transitional vegetated areas along the shoreline bay shoreline margins. Estuarine emergent wetlands include both intertidal wetlands that are regularly flooded by the tide and supratidal wetlands (mid and high marsh) that are less frequently flooded by the tide. Palustrine wetlands are nontidally influenced freshwater wetlands that are generally dominated by persistent emergents, emergent mosses, or lichens, scrub-shrubs, or trees. They are found in all water regimes, except subtidal and irregularly exposed systems. Emergent wetlands consist of erect, rooted, herbaceous wetland plants that generally persist for most of the growing season. Scrub-shrub wetlands include areas dominated by woody vegetation less than 20 feet tall and are vegetated with true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions. Forested wetlands contain woody vegetation that is 20 feet or taller. Calhoun Point Comfort identified wetlands within the project area by field delineation conducted in December 2004 and April 2005. The delineation of wetlands followed the 1987 COE Wetland Delineation

Manual (COE, 1987). Wetland types were classified using the FWS classification system (Cowardin et al., 1979).

Waterway for LNG Marine Traffic

Perimeter salt marshes and freshwater marshes are found in upper Lavaca and Cox Bays and along Matagorda Bay. Smooth cordgrass (*Spartina alterniflora*) is common in mixed marsh grass stands in upper Lavaca Bay near the mouth of the Lavaca River and portions of Cox Bay, and at various locations along Matagorda Bay. Marsh plants including shoregrass (*Monanthochloe littoralis*), saltgrass (*Distichlis spicata*), black rush (*Juncus roemerianus*), saltwort (*Batis maritima*), and glassworts (*Salicornia* spp.) are found along the shores and inland reaches of these bays (TGLO, 2001).

Figure 4.4-1 sheets 1 through 4 show environmental resources along the waterway for LNG marine traffic. Wetland areas are found along the fringes of the bay throughout Matagorda Bay. The wetlands that would be more susceptible to normal LNG vessel transit and to LNG releases are found in the following areas as the LNG vessels would travel up the MSC to the Port:

- the fringe wetlands on the bay side of Matagorda Peninsula;
- the wetlands on the fringes of Sundown (or Bird) Island;
- the wetland on the west shoreline of Matagorda Bay from just north of Port O'Connor to just north of Indian Point (or up to Magnolia Beach); and
- the wetlands on the fringes of Snake Island, which is the southern-most dredged material island in a string of islands south of the LNG site. This island is approximately 1.0 mile northwest of Gallinipper Point and 2 miles south of the proposed LNG site.

Traveling from offshore to port, LNG vessels would encounter the following wetlands: The bay side of Matagorda Peninsula (on both sides of the inlet) has mudflats, vegetated wetlands, and some submerged aquatic vegetation (SAV) (see figure 4.4-1 sheet 1). The wetlands, including shallow channels within the coastal marshes and the SAV serve as habitat for shrimp and crab juveniles. The mud flats to the west and east of the ship channel inlet are listed as critical habitat for wintering piping plover. These wetlands are found in Zone of Concern 1 (Zones of Concern are summarized in section 2.1.2). Sundown (or Bird) Island, on which wetland habitat is found, is an important feature and sensitive area within the bay (see figure 4.4-1 sheets 1 and 2). Sundown Island extends beyond the bounds of Zone 1 into Zone 2. The MSC passes very close to Snake Island at the locations where the MSC turns from a northwest axis to a due north orientation (see figure 4.4-1 sheets 3 and 4). This island has fringe mud flats and wetlands. The marshes at Indian Point are the first shoreline feature that is intersected by Zone 2. The shoreline from Port O'Connor to Alamo Beach (or Gallinipper Point) has many natural resources that fall within Zone 3, including marshes and shallow embayments with SAV (see figure 4.4-1 sheets 2 and 3).

Non-Internet Public

FINAL ENVIRONMENTAL IMPACT STATEMENT
FOR THE PROPOSED
CALHOUN LNG TERMINAL AND PIPELINE PROJECT
Docket Nos. CP05-91-000 and CP05-380-000

Pages 4-31 through 4-34
Figure 4.4-1 Sheets 1 through 4

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through the Public Reference Room, or by e-mail at
public.referenceroom@ferc.gov

Of these wetlands the most sensitive areas are Sundown Island and Snake Island because of their use by colonial nesting waterbirds (see section 4.5.1.1 of this EIS). Normal LNG vessel operations would not impact wetlands resources.

If an unignited release of LNG were to occur along the LNG marine traffic route, given that LNG is lighter than water, the LNG would float on the water until it had vaporized. If the LNG were to contact any wetland plants along the shoreline areas, those species above the water line could be impacted by the extremely low temperatures. While impacts within Zone 1 could be significant, no wetland impacts would be expected outside of Zone 1 from the resulting pool of LNG.

If an associated fire were to occur with a marine LNG spill, wetland vegetation within Zone 1 could be impacted by the high radiant heat. Impacts on wetland vegetation within Zone 1 would be significant. In Zone 2, wetland vegetation could be impacted from radiant heat. Those species could dry out due to the extreme heat. Impacts on wetland vegetation within Zone 2 would likely be less severe than those in Zone 1. In addition, given the resilience of wetland species in wet warm climates and that root systems would remain intact, these species would be expected to reestablish rapidly in the affected areas. Zone 3 would not be expected to experience any significant impacts from a pool fire. The maximum flammable range for a vapor cloud could extend to the outer limits of Zone 3. If the vapor cloud were to come in contact with an ignition source, the resulting fire could burn back to the spill and impact any wetlands within its path. However, because of the marine transit safety and security measures, the probability of an LNG vessel spill from collisions, allisions, and terrorist attacks would be unlikely. Therefore, although there is a potential that significant impacts could occur to wetlands along the waterway for LNG marine traffic, the likelihood is extremely remote.

LNG Terminal

No tidal wetlands or vegetated tidal flats would be impacted by construction and operation of the proposed LNG terminal. An estuarine marsh and tidal flat occurs along the southern boundary of the terminal site outside of the construction area, and would not be affected. However, approximately 11 acres of intertidal wetland, including 1.6 acres of fringe marsh and 9.4 acres of high marsh, would be permanently filled as a result of proposed dredged material placement within the Dredge Island Expansion North and Dredge Island Marsh DMPAs. To mitigate for this permanent impact, Calhoun Point Comfort proposes to create about 33 acres of fringe marsh and 18.8 acres of high marsh within these same DMPAs (see appendix E).

Pipeline

The pipeline would affect palustrine (freshwater) emergent marsh, scrub-shrub, and forested wetlands. Representative palustrine emergent and scrub-shrub wetland plant species found along the pipeline right-of-way include Eastern baccharis (*Baccharis halimifolia*), longs sedge (*Carex longii*), green flatsedge (*Cyperus virens*), spikerush (*Eleocharis* spp.), spider lily (*Hymenocallis carolinia*), whiteroot rush (*Juncus brachyocarpus*), soft-stem rush (*Juncus effuses*), water primrose (*Ludwigia peploides*), pepperwort (*Marsilea vestita*), pink smartweed (*Polygonum pensylvanicum*), water pepper (*Polygonum hydropiperoides*), foxglove (*Physostegia intermedia*), white-topped sedge (*Rhynochospora colorata*), horned beakrush (*Rhynchospora corniculata*), curly leaf dock (*Rumex crispus*), grassy arrowhead (*Sagittaria graminea*), dwarf palmetto (*Sabal*

minor), soft-stem bulrush (*Scirpus validus*), rattlebox (*Sesbania drummondii*), wiregrass (*Spartina patens*), gulf cordgrass (*Spartina spartinae*), duckweed (*Spirodela polyrhiza*), and cattail (*Typha* spp.).

Representative forested wetland plant species found along the pipeline right-of-way include American elm (*Ulmus americana*), water oak (*Quercus nigra*), green ash (*Fraxinus carolinia*), Chinese tallow (*Triadica sebifera formerly Sapium sebiferum*), live oak (*Quercus virginiana*), and cedar elm (*Ulmus crassifolia*) with a herbaceous and scrub-shrub understory that contains many of the species described above.

Calhoun Point Comfort submitted its Section 404 permit application to the COE during June and July 2005, and has conducted a jurisdictional determination site walk with the COE. As a result of the site walk, Calhoun Point Comfort filed minor changes to the wetland impacts, and the final EIS includes these changes. The COE completed its verification of the wetland delineation for the pipeline route on November 28, 2006 and for the LNG terminal site and DMPAs on December 5, 2006.

Approximately 2.8 miles of palustrine wetlands would be crossed by the Point Comfort Pipeline. No wetlands would be crossed by the Formosa or Transco Laterals and no wetlands would be affected by aboveground facilities. Construction of the Point Comfort Pipeline would affect about 20.6 acres of wetlands, while operation of the Project would result in the permanent conversion of 0.7 acre of forested wetlands to emergent wetlands for the life of the Project. Of the total amount, about 17.5 acres would be emergent, 0.4 acre would be scrub-shrub, 0.8 acre would be forested, and 2.0 acres would be emergent/forested mix (see table 4.4.1-1).

Calhoun Point Comfort identified two locations where additional temporary workspaces would be located partially or completely within wetlands. Between MP 1.2 and 1.4 about 1.8 acres of forested wetland would be affected by the temporary workspace needed for pull back stringing and pipe bending near the bore site for a railroad spur crossing. At MP 1.9, about 1.4 acres of emergent wetland would be affected by the temporary workspace needed for a truck turnaround and an HDD entry hole for the crossing of State Route 35.

We have reviewed these temporary workspace locations and believe that there is no other reasonable or practical location for them except in the wetlands and that these workspaces are necessary for the installation of the pipeline. Calhoun Point Comfort has made efforts to locate additional temporary workspaces, to the extent practical, to minimize wetland impacts and would continue this effort during its design of the Project. Although forested wetlands would take longer to revegetate, all 3.2 acres (1.8 acres forested, 1.4 acres non-forested) of temporary workspace located in wetlands along the pipeline routes would be allowed to return to pre-existing conditions following restoration. However, NOAA Fisheries considers this type of impact to forested wetlands to be permanent due to the length of time required for the forest canopy regeneration. Using the NOAA Fisheries' definition, a total of about 2.63 acres of forested wetlands would be permanently impacted along the pipeline right-of-way and temporary workspaces and would be included in calculations for determining mitigation.

TABLE 4.4.1-1

Wetlands Crossed by the Point Comfort Pipeline

County / Milepost	NWI Classification a/	Length of Wetland Crossed Within Construction Right-of-Way	Wetlands Affected During Construction b/	Wetlands Affected During Operation c/	Area Avoided by HDD d/
		Miles	Acres	Acres	Acres
Calhoun					
0.3	PSS	0.01	0.05	0.01	
1.2	PEM/PFO	0.25	1.95 e/, f/	0.54 f/	
1.7	PEM	0.02	0.08	0.00	
1.9	PEM	0.41	5.39 e/	0.00	0.62
4.5	PEM	0.01	0.02	0.00	
6.6	PEM	0.01	0.02	0.00	
Subtotal		**0.71**	**7.51**	**0.55**	**0.62**
Jackson					
9.2	PEM	0.06	0.52	0.00	
9.3	PEM	0.03	0.07	0.00	
9.4	PEM	0.06	0.53	0.00	
12.3	PSS	0.05	0.30	0.08	
12.4	PEM	0.02	0.03	0.00	
12.5	PEM	0.24	1.47	0.00	
12.8	PEM	0.08	0.56	0.00	
16.4	PEM/PFO	0.16	0.00	0.00	1.04
16.9	PEM	0.01	0.00	0.00	0.13
17.0	PEM	0.01	0.12	0.00	
17.1	PEM	0.18	2.12	0.00	
17.8	PEM	0.04	0.28	0.00	
18.0	PFO	0.04	0.25	0.02	
18.2	PEM	0.10	0.77	0.00	
18.4	PEM	0.18	1.33	0.00	
19.5	PEM	0.04	0.35	0.00	
19.9	PEM	0.08	0.55	0.00	
20.1	PEM	0.09	0.95	0.00	
21.9	PEM	0.01	0.04	0.00	
22.5	PEM	0.04	0.02	0.00	
22.7	PFO	0.02	0.10	0.03	
22.8	PFO	0.06	0.00	0.00	0.29
23.6	PFO	0.07	0.49	0.10	
23.7	PEM	0.02	0.05	0.00	
23.8	PEM	0.05	0.47	0.00	
24.9	PEM	0.17	1.75	0.00	
25.1	PEM	0.01	0.00	0.00	0.02
25.3	PEM	0.05	0.00	0.00	0.44
25.4	PFO	0.05	0.00	0.00	0.39
25.5	PEM	0.02	0.00	0.00	0.07
25.5	PEM	0.01	0.00	0.00	0.10
25.5	PEM	0.03	0.00	0.00	0.12
25.5	PFO	0.02	0.00	0.00	0.08
Subtotal		**2.10**	**13.12**	**0.15**	**2.73**
Total g/		**2.81**	**20.63**	**0.70**	**3.35**

a/ Compiled using NWI Maps. Palustrine Emergent (PEM), Palustrine Forested (PFO), Palustrine Scrub/Shrub (PSS)
b/ Based on 75-foot-wide construction right-of-way for crossing distance ≤ 100 feet, otherwise a 100-foot construction right-of-way.
c/ Permanent acreage is based on a width of 30 feet that would be cleared of trees and shrubs.
d/ Pipeline segment would be installed by Horizontal Directional Drill. Acreage mitigated is the wetland amount avoided.
e/ Wetland within additional temporary workspace.
f/ Of the 1.95 acres affected during construction, 1.79 would be forested and 0.16 would be emergent. Of the 0.54 acres affected during operation, 0.42 would be forested and 0.12 would be emergent.
g/ Due the effects of rounding the totals may not sum correctly.

For those terrestrial wetlands that would be temporarily affected during construction of the pipeline, potential impacts would include the temporary disturbance of wetland vegetation, soils, and hydrology. Soil disturbance and removal of wetland vegetation could temporarily affect wetland capacities to facilitate surface water flow, buffer flood flows and/or control erosion. Failure to properly segregate topsoil over the pipeline trench line could result in the mixing of the topsoil with the subsoil, which could affect the success of post-construction reestablishment and natural recruitment of native wetland vegetation. Rutting of wetland soils from construction equipment could result in soil mixing, which could also affect success of post-construction restoration. Trenching during pipeline installation could penetrate impervious soil layers, which could alter perched water tables. Altering perched water tables could result in drier soil conditions that could inhibit the reestablishment of wetland vegetation. Uncontrolled surface runoff from adjacent disturbed upland areas could transfer silt and sediment into off right-of-way wetlands.

A majority of the impacts to wetland resulting from construction and operation of the proposed pipelines would be temporary. Calhoun Point Comfort would re-establish all pre-existing wetland elevations in temporarily impacted wetland areas immediately after pipeline installation is complete and would monitor restored wetland areas in accordance with an approved restoration and monitoring plan.

To minimize construction-related impacts on wetlands, Calhoun Point Comfort would implement our Procedures. The Procedures would include the following measures, among others, to minimize impact on wetlands:

- Hazardous materials, chemicals, fuels, and lubricating oils would not be stored within a wetland or within 100 feet of a wetland boundary.
- Construction equipment operating within the right-of-way would be limited to that equipment necessary for clearing, excavation, pipe installation, backfilling, and restoration activities. All nonessential equipment would use upland access roads to the maximum extent practicable.
- Equipment operating within saturated wetlands would be low-ground-weight equipment or would operate from prefabricated construction mats.
- Temporary erosion and sediment control measures would be installed immediately after the initial disturbance of wetland soils and would be inspected and maintained regularly until final stabilization.
- Sediment controls would be installed across the construction right-of-way, as needed, within wetlands to contain trench spoil.
- Vegetation would be cut at ground level, leaving existing root systems in place to promote regrowth. Stumps would be removed from the trench line; stumps may be removed from the working side of the right-of-way if removal is required for safety concerns.
- The uppermost foot of wetland topsoil would be segregated from the underlying subsoil in areas disturbed by trenching, except in areas with standing water or saturated soils, or where no topsoil layer is evident.

- Vegetation maintenance would not be conducted over the full width of the permanent right-of-way in wetlands. Shrubs and trees may be selectively removed within 15 feet of the pipeline that are greater than 15 feet in height.
- Monitoring the success of wetland revegetation annually for the first three years after construction or until wetland vegetation is successful.

In addition to the measures required by our Procedures, Calhoun Point Comfort would be required to comply with the permit conditions contained in the COE's Section 404 permit and the state Section 401 permit. As part of its review of the Project, the COE will evaluate whether practicable alternatives have been taken to avoid wetland impacts to the maximum extent possible. Calhoun Point Comfort must also demonstrate that it has taken appropriate and practicable steps to minimize wetland impacts in compliance with the COE's Section 404(b)1 guidelines that restrict discharges of dredge or fill material where a less environmentally damaging alternative exists.

All permanently impacted wetlands would require compensatory mitigation according to an approved wetland mitigation plan. In general, the loss of wetlands would require compensatory mitigation. The specific type and amount of compensatory mitigation would be determined by the COE as part of the Section 404 permit process. Calhoun Point Comfort has initiated consultation with the COE, FWS, and TPWD regarding the development of a mitigation plan that would compensate for impacts to wetlands.

On September 7, 2005, Calhoun Point Comfort met with the FWS, COE, NOAA Fisheries, and TGLO and discussed wetland mitigation options associated with the Point Comfort Pipeline. Based on feedback received at this meeting, Calhoun Point Comfort developed a *draft Wetland and Waters of the U.S. Mitigation Plan* that was filed with the Commission on November 1, 2005 (see appendix E). Where feasible, Calhoun Point Comfort selected a pipeline route or proposes to utilize construction methods (i.e., HDD) to avoid or minimize impacts on wetlands and waterways. In its draft plan, Calhoun Point Comfort considered three wetland mitigation options to compensate for unavoidable wetland losses: (1) on-site mitigation/ restoration; (2) off-site restoration; and (3) mitigation banking.

On-Site Mitigation/Restoration

Initially, Calhoun Point Comfort considered in-kind, on-site mitigation/restoration. Since surface elevations would be restored to pre-construction conditions, wetland vegetation would be allowed to revegetate along the construction right-of-way. As a result, herbaceous wetlands would not be permanently impacted by construction or operation of the pipeline. About 2.63 acres of forested wetlands would be permanently impacted along the pipeline right-of-way. On-site mitigation/restoration for forested wetland impacts would involve the purchase, enhancement and/or restoration, and stewardship of land immediately adjacent to the right-of-way and on-site restoration or construction of wetlands. Calhoun Point Comfort determined that this option would be impractical and unfeasible since a suitable location for such a purchase along the pipeline route is not available.

Off-site Restoration

Calhoun Point Comfort consulted with the FWS and TPWD to determine if any ongoing or planned wetland restoration projects occur in the project area. If an off-site restoration project were identified, Calhoun Point Comfort could fulfill its mitigation requirements by providing funding for all or part of the off-site restoration project. Calhoun Point Comfort, in consultation with the FWS, identified a potential off-site mitigation project that would involve the purchase and preservation of forested wetlands in Victoria County, located adjacent to Calhoun and Jackson Counties. Calhoun Point Comfort is currently investigating the specifics and feasibility of this mitigation option.

Mitigation Banking

Based on Calhoun Point Comfort's September 7, 2005 meeting with the FWS, COE, and TGLO, Calhoun Point Comfort determined to pursue the purchase of wetland credits from a COE approved wetland mitigation bank as the preferred mitigation option to compensate for forested wetlands impacts. Although the forested wetland impacts along the pipeline route would occur in Calhoun and Jackson Counties, there is no approved COE wetland mitigation bank that services these counties.

Currently there are two wetland mitigation banks that could provide wetland credits to mitigate the forested wetland impacts along the Point Comfort Pipeline: (1) the Katy-Cypress Wetlands Mitigation Bank; and (2) the Palacios Wetland Mitigation Bank. The Katy-Cypress Wetlands Mitigation Bank is located about 80 miles from the project area and is in a different watershed. It is permitted to service Calhoun County, but not Jackson County.

The Palacios Wetland Mitigation Bank is currently pending COE approval due to reconstruction of the bank. It would service Calhoun and Jackson Counties. Currently, this wetland bank cannot sell wetland credits; however, Calhoun Point Comfort's consultations with the mitigation bank operator indicate that it would gain COE approval in the near future. Since credits have not yet been sold by the bank the conservation easement has not been activated. Once activated, the land at the bank could only be used for wetland mitigation banking. The Palacios Wetland Mitigation Bank includes about 150 acres of herbaceous freshwater wetlands, no forested wetlands exist. As a result, the use of this wetland mitigation bank would be considered out-of-kind to mitigate for the forested wetland impacts along the pipeline route.

The TPWD has stated that it does not agree with the mitigation currently included in Calhoun Point Comfort's draft mitigation plan, and that the draft mitigation plan does not adequately compensate for wetland impacts from the proposed pipeline. Should the FWS, COE, and TPWD agree to out-of-kind mitigation (i.e., purchasing herbaceous wetland credits to mitigate for forested wetland impacts) then the Palacios Wetland Mitigation Bank would be a viable mitigation option. Calhoun Point Comfort stated that the COE could request a higher mitigation ratio (e.g., 3:1 or 4:1 ratio of herbaceous to forested wetland). Because consultation with the appropriate agencies has not yet been completed to establish a mitigation ratio, **we recommend that:**

- **Calhoun Point Comfort should continue its consultation with the COE, FWS, EPA, TPWD, and TGLO to further develop its Wetlands and Waters of the U.S. Mitigation Plan. <u>Prior to construction</u>, Calhoun Point Comfort should file its final plan with the Secretary.**

4.4.2 Seagrasses

Seagrasses or submerged aquatic vegetation found in subtidal areas are regulated by the COE as Special Aquatic Sites. Typically, seagrasses are considered near-shore habitats that occur in some estuarine systems. Submerged aquatic vegetation is generally absent from Lavaca Bay.

Waterway for LNG Marine Traffic

Seagrasses or submerged aquatic vegetation potentially affected within the waterway for LNG marine traffic is discussed above under section 4.4.1.

LNG Terminal

No near-shore marine habitat such as seagrass or submerged aquatic vegetation would be affected by the proposed LNG terminal.

4.4.3 Upland Vegetation

Waterway for LNG Marine Traffic

Upland vegetation communities within the potential Zones of Concern for the waterway for LNG marine traffic include coastal grasslands, scrub-shrub, woodlands, and agricultural lands. Normal operation of LNG vessels would not affect upland vegetation along the waterway for LNG marine traffic.

If an unignited release of LNG were to occur along the LNG marine traffic route, given that LNG is lighter than water, the LNG would float on the water until it had vaporized. If the LNG were to contact any upland plants along the shoreline, the vegetation could be impacted by the extremely low temperatures. While impacts within Zone 1 could be significant, no upland vegetation impacts would be expected outside of Zone 1 from a pool of LNG resulting from a spill. No upland vegetation occurs within Zone 1 with the exception of the MSC entrance and the area surrounding the LNG terminal site.

If an associated fire were to occur with a marine LNG spill, upland vegetation within Zone 1 could be impacted by the high radiant heat. Impacts on upland vegetation within Zone 1 would be significant. In Zone 2, upland vegetation could be impacted from radiant heat. Those species could dry out due to the extreme heat. Impacts on upland vegetation within Zone 2 would likely be less severe than those in Zone 1. Because root systems would remain intact, plant species able to resprout from root systems would be expected to reestablish rapidly in the affected areas. Upland vegetation within Zone 3 could also be affected by a pool fire, as the maximum flammable range for a vapor cloud could extend to the outer limits of Zone 3. If the vapor cloud were to come in contact with an ignition source, the resulting fire could burn back to the spill and impact any vegetation within its path.

Because of the marine transit safety and security measures, the probability of an LNG vessel spill from collisions, allisions, and terrorist attacks would be unlikely. Although there is a potential that significant impacts could occur to upland vegetation within the Zones of Concern along the waterway for LNG marine traffic in the event of an LNG spill and associated fire, the likelihood is extremely remote.

LNG Terminal and Pipeline

The upland vegetation communities that would be affected by construction and operation of the proposed Project include coastal grasslands, scrub-shrub, woodlands, and agricultural lands. The proposed 73-acre LNG terminal site consists of disturbed, undeveloped, manmade industrial land that is sparsely vegetated with Bermuda grass (*Cynodon dactylon*), southern carpet grass (*Axonopus affinis*), white clover (*Trifolium repens*), and crow poison (*Nothoscordum bivalve*). This area would be cleared during construction of the LNG terminal and all vegetation would be replaced with industrial facilities and landscaped vegetation.

Construction of the proposed pipeline would require the use of about 416.6 acres of land, of which 338.6 acres would be open land (agricultural/range land), 27.4 acres would be woodland, and 50.6 acres would be developed land. The open land is covered by grasslands and scrub-shrub vegetation. Shrub species include huisache (*Acacia farnesiana*), Eastern baccharis, hackberry (*Celtis laevigata*), yaupon (*Ilex vomitoria*), honey mesquite (*Prosopis glandulosa*), dewberry (*Rubus* spp.), McCartney rose (*Rosa bracteata*), greenbrier (*Smilax bona-nox*), and cedar elm, while herbaceous species include grasses such as southern carpet grass (*Axonopus affinis*), Bermuda grass (*Cynodon dactylon*), longtom (*Paspalum lividum*), knotroot bristlegrass (*Setaria geniculata*), vasey grass (*Paspalum urvillei*), Johnson grass (*Sorghum halepense*), and smutgrass (*Sporobolus indicus*). Hackberry, honey mesquite, cedar elm, and live oak are common species found in woodlands crossed by the pipeline. Typical crops grown on the agricultural land include corn, sorghum, and cotton. After installation of the pipeline, crops could still be grown over the right-of-way. The permanent pipeline easement in open land would be kept in an herbaceous state.

The proposed aboveground facilities would be on industrial land and herbaceous, shrub, and brush range lands.

Calhoun Point Comfort would follow our Plan and apply our mitigation measures for minimizing erosion and enhancing revegetation before, during and after the construction of the Project. Impacts on vegetation within the LNG terminal site would be minimal since this area is currently in industrial use. To minimize impacts on vegetation along the pipeline right-of-way, about 93.0 percent (25.2 miles) of the route for the 36-inch-diameter pipeline would be immediately adjacent to existing rights-of-way.

Upon completion of construction activities, all temporarily disturbed areas would be restored to pre-construction contours. The effects of clearing (e.g., removal of protective vegetative cover, increase in sun, wind, and precipitation exposure, and alteration of the vegetation structure) would be of longer duration in forested areas than in other areas (e.g., agricultural and open lands) and, in the case of permanent right-of-way, would be for the life of the Project. In accordance with our Plan, Calhoun Point Comfort would not seed actively cultivated farm land, unless requested to do so by the landowner. Calhoun Point Comfort would plant and maintain Bermuda grass at the LNG terminal site and allow the pipeline right-of-way to revegetate per our Plan. Calhoun Point Comfort would also consult with the appropriate state and federal agencies to develop a revegetation and restoration plan that includes seed mixes.

Routine vegetation maintenance clearing could occur within the existing permanent right-of-way no more than once every three years. However, to facilitate leak and corrosions surveys, a corridor no more than 10 feet wide centered on the pipeline could be maintained by mowing or a similar means on an annual basis, in accordance with our Plan and Procedures. We believe that with the implementation of our Plan and Procedures, the Project would not significantly impact upland vegetation.

4.4.4 Noxious Weeds and Invasive Species

Calhoun Point Comfort indicated that a noxious weed, the Chinese tallow tree (*Triadica sebifera* formerly *Sapium sebifera*), was found in wetlands along the pipeline right-of-way. Our review of Calhoun Point Comfort's wetland delineation report reveals that the tallow tree was observed in a scrub-shrub wetland at MP 12.3, an emergent wetland at MP 12.4, and a forested wetland at MP 25.5 (Hill Country, 2005). Tallow trees were introduced into the United States in the late 1700s. It was originally cultivated as an ornamental shrub and possibly touted as a food source for poultry. Tallow tree is capable of invading areas and rapidly replacing the natural communities with nearly monospecific stands. Characteristic of woody invaders, it grows rapidly, begins reproduction when young (only three years old), produces abundant viable seed, and can reproduce from cuttings. Seeds are spread by birds and also may float for great distances. Although popular with landscaping, tallow tree degrades the surrounding ecosystem by producing tannins and increasing the rate of eutrophication (the aging process and conversion of water habitats to marsh and dry land). It persists in all environments except in permanently saturated areas.

Because of its occurrence in the project area and in the absence of any known management program for this species, it is likely that the Chinese tallow tree could be reestablished in the construction areas within one to two years. To control the spread of this species within maintained areas, Calhoun Point Comfort consulted with the Jackson County Texas Cooperative Extension Center about a management approach to control the spread of Chinese tallow tree along the permanent pipeline right-of-way, especially near MP 12.3, MP 12.4, and MP 25.5. Two herbicidal (Brush Buster) methods could be employed to control Chinese tallowtree: (1) the leaf spray method which works best on tallowtrees that have multiple stems at the ground level and are less than 8 feet tall and (2) the stem spray method which works best for young trees or older trees with few basal stems in sparse stands. Application of herbicides to control Chinese tallowtree would be conducted in accordance with herbicide label directions and additional suggestions provided by the Texas Cooperative Extension's *Brush Busters How to Take Out Tallowtree* guidelines.

Our Plan addresses vegetation maintenance for uplands including guidelines for follow up inspections and guidelines for determining successful revegetation. We believe that by following our Plan, consulting with the appropriate state and federal agencies about recommended seed mixes, and the Texas Cooperative Extension about the management of Chinese tallow tree, construction and operation of the Calhoun LNG Project would not significantly impact upland vegetation.

4.5 WILDLIFE AND AQUATIC RESOURCES

4.5.1 Wildlife

Several habitat types would be affected by the proposed Project including manmade and industrial, open water, shoreline, coastal grasslands, scrub-shrub, woodlands, agricultural, pasture, and palustrine wetland habitats.

Manmade and Industrial Habitat

The manmade and industrial habitat type consists of deposited dredge material, disturbed, undeveloped, and industrial lands that are sparsely vegetated with grasses. The proposed 73-acre LNG terminal site consists of unmanaged dredge material that is primarily utilized by common birds including sparrows and pipits, which may occur on the higher and drier portions of the terminal site, and terns, black skimmers (*Rynchops niger*), killdeer (*Charadrius vociferus*), and common night hawk (*Chordeiles minor*), which may nest on the bare, sand and gravel patches found at the terminal site. Previously disturbed, industrialized and developed lands that occur along the pipeline route include lands managed by Formosa Hydrocarbons Company and Formosa Plastics Corporation, road shoulders, roadside ditches, and existing rights-of-way. These areas are utilized for forage grounds by wading birds and support a variety of small mammals, invertebrate and amphibian species, but are not considered valuable wildlife habitat.

There are two colonial waterbird nesting areas in the vicinity of the proposed LNG terminal site. Texas Waterbird Colony No. 609-120 is located on Dredge Island between 0.4 mile and 1.4 miles west and northwest of the terminal site and the Texas Waterbird Colony No. 609-121 is located on a dredged material disposal area known as Snake Island about 1.5 miles south of the terminal site. Nesting activities at both of these sites are monitored by the TPWD. The least tern (*Sterna antillarum*), little blue heron (*Egretta caerulea*), roseate spoonbill (*Ajaia ajaja*), snowy egret (*Egretta thula*), tricolored heron (*Egretta tricolor*), white ibis (*Eudocimus albus*), white-faced ibis (*Plegadis chihi*), glossy ibis (*Plegadis falcinellus*), laughing gull (*Larus atricilla*), gull-billed tern (*Sterna nilotica*), great egret (*Ardea alba*), great blue heron (*Ardea herodias*), Forster's tern (*Sterna forsteri*), cattle egret (*Bubulcus ibis*), Caspian tern (*Sterna caspia*), black skimmer (*Rhynchops niger*), and black-crowned night-heron (*Nycticorax nycticorax*) have all been recorded at both Colonies No. 609-120 and No. 609-121. The reddish egret (*Egretta rufescens*), royal tern (*Sterna maxima*), sandwich tern (*Sterna sandvicensis*), brown pelican (*Pelecanus occidentalis*), and American oystercatcher (*Haematopus palliatus*) have only been recorded at Colony No. 609-121 (QuickBase, 2005). Calhoun Point Comfort consulted with the FWS about these waterbird colonies and reported that Colony 609-120 has been inactive for about 10 years and Colony 609-121 remains active.

Open Water

The open water habitat type is generally considered to be any aquatic habitat that lacks emergent, hydrophytic vegetation and is at least 6 feet deep. This habitat type is maintained by rainfall, river and runoff inflow, and Gulf of Mexico tidal influences. The American alligator (*Alligator mississippiensis*) could be present in the Lavaca and Cox Bays as it forages for fish, snakes, turtles, frogs, muskrats, nutria, and other small animals that may be present near the proposed terminal site.

Shoreline Habitat

Estuarine shoreline habitats include shallow estuarine open water (less than 6 feet deep), intertidal and supratidal unvegetated mud and sandflats, and emergent wetlands. Open water and shorelines provide habitat for a variety of birds including pelicans, cormorants, ducks, grebes, shorebirds, sparrows, wintering Common Loon (*Gavia immer*), and Osprey (*Pandion haliaetus*). Along the southern boundary of the terminal site, outside of the construction area, these birds tend to concentrate in the estuarine marsh and tidal flat area.

Coastal Grassland, Scrub-Shrub, and Woodland Habitats

The coastal grassland habitat type consists of pockets of short- to mid-grasslands that are interspersed with herbaceous and woody plants. The majority of the coastal grassland habitat has been heavily grazed or is currently maintained. The scrub-shrub habitat consists of large shrubs, small trees, and a sparse understory. The woodland habitat includes large forested areas interspersed with grassy clearings. Wildlife using these habitat types include mammals such as white-tailed deer (*Odocoileus virginianus*), bobcat (*Felis rufus*), collared peccary-javelina (*Tayassu tajacu*), common raccoon (*Procyon lotor*), Virginia opossum (*Didelphis virginiana*), Eastern cottontail (*Sylvilagus floridanus*), black-tailed jackrabbit (*Lepus californicus*), striped skunk (*Mephitis mephitis*), and nine-banded armadillo (*Dasypus novemcinctus*). Birds such as vermilion flycatcher (*Pyrocephalus rubinus*), Couch's kingbird (*Tyrannus couchi*), northern bobwhite (*Colinus virginianus*), mourning dove (*Zenaidura macroura*), sandhill crane (*Grus canadensis*), cattle egret, and numerous other bird species including hawks, owls, woodpeckers, swallows, thrashers, wrens, blackbirds, and sparrows also utilize these habitat types.

Agricultural Land and Pasture/Range Land Habitats

The majority of the pipeline would cross agricultural land and pasture/range land. These habitats have generally been altered from their original vegetation community structure and diversity as a result of crop production and livestock grazing. Agricultural and pasture lands provide cover and serve as an important food source for a variety of small mammals, songbirds, waterfowl, and game birds. This habitat type also provides foraging grounds for larger predatory mammals and birds. Wintering species such as sandhill crane, geese, sparrows, and raptors utilize this habitat to forage.

Palustrine Wetland Habitat

The palustrine wetland habitat type includes emergent wetlands that are associated with perennial and intermittent streams and isolated, depressional wetlands. Wetlands are described and discussed in detail in section 4.4.1 of this EIS. Common mammals associated with the palustrine wetland habitat type include the swamp rabbit (*Sylvilagus aquaticus*) and rice rat (*Oryzomys palustris*). Some of the bird species commonly found in this habitat type include kites, crows, gulls, vultures, wrens, starlings, orioles, warblers, sparrows, owls, cuckoos, hawks, plovers, terns, swallows, sandpipers, osprey, ibis, and numerous species of ducks. Reptiles and amphibians commonly associated with this habitat type include American alligator, bullfrog (*Rana catesbiana*), western cottonmouth (*Agkistrodon piscivorus*), eastern mud turtle (*Kinosternon subrubrum*), yellow mud turtle (*Kinosternon flavescens*), cricket frog (*Acris* spp.), plainbelly water snake (*Nerodia erythrogaster*), snapping turtle (*Chelydra serpentina*), and green frog (*Rana clamitans*).

4.5.1.1 Potential Project Impacts on Wildlife

Waterway for LNG Marine Traffic

There are several important bird breeding areas within the bay. Although many of the small dredged material islands shown on figure 4.4-1 sheets 2, 3, and 4 may support small colonies of breeding shorebirds or wading birds, the two biggest and most consistently productive bird rookeries are at Sundown Island (figure 4.4-1 sheet 2) and Snake Island (figure 4.4-1 sheet 4).

Potential impacts to these bird rookery islands from normal LNG vessel traffic would include general disturbances from vessel operation noise and an increase in erosion potential from LNG vessel wakes. At each island, the bird colonies have been exposed to noise from passing deep draft ships for many years. The operational aspects of the LNG vessel traffic in the MSC should not change from past practices. Potential noise impact on bird rookeries from LNG vessel traffic would be greatest at Snake Island, since this is closest to the MSC (approximately 650 feet away vs. approximately 1,000 feet for Sundown Island). If large tugs for LNG vessels are measured at 87 dB at 50 feet, the noise levels would decrease 6 dB to 81 dB at 100 feet, decrease an additional 6 dB to 75 dB at 200 feet, and decrease to 69 dB at 400 feet, etc.

Since Snake Island is about 650 feet from the channel, the noise level at Snake Island from passing LNG vessels and tugs would be about 70 dB. This noise level would only be reached at the island for the 15 to 20 minutes (or less) that the LNG vessels would make the bend in the MSC as they head north to the terminal, and would occur 4 to 6 times per week (2 or 3 vessels per week, inbound and outbound). This area currently experiences similar noise from ongoing deep draft vessels calling at Port of Port Lavaca–Point Comfort and Alcoa multiple times per week. Calhoun states that it expects that LNG vessels would only require tug assistance at Snake Island (or at Gallinipper Point) on days when the wind velocity is high and that on other days, the LNG vessels would pick up the tug assistance north of Snake Island.

The noise generated near Sundown Island should be lower than at Snake Island, because there would not be tug assistance for the LNG vessels at that point and because Sundown Island is further from the channel (about 1,000 feet), abating the noise level further before the sound of the LNG vessel reaches the island. Therefore, we do not believe that the noise levels generated by the LNG vessels, with or without tugs, would significantly change the noise levels at the two bird rookery islands.

Regarding the erosion potential at each island, Moffatt & Nichol have performed a study of the wave energy from current ship traffic in the MSC as well as predicted wave energy from future LNG vessels and with a new ship channel depth and width. The study indicated that erosion potential for vessel wakes should not change significantly at the two rookery islands (see also section 4.2.3 of this EIS)**.**

In the case of an LNG release without ignition in proximity to either Snake Island or Sundown Island, impacts would probably be restricted to Zone 1. For Snake Island, an incident close to the island could result in a vapor cloud that could force the adult birds to flee. If the vapor cloud is thick enough to exclude oxygen, and if it hugs the ground, young birds that could not yet fly would suffocate. Therefore in a severe case, the breeding production could be reduced or lost for that year.

For Sundown Island, the impact would be less severe since most of the island is in Zone 2. In the case of an LNG loss without ignition, the vapor cloud, if it drifted to the west, would have more chance to disperse. The adult birds would have more response time and the nestlings would have a greater chance of survival.

Prevailing winds are from the south or southeast in this area of Matagorda Bay; therefore, a large percentage of the time a vapor cloud originating at the MSC would be blown to the north or northwest. For Snake Island, this would carry a vapor cloud away from the island a high percentage of the time. For Sundown Island, the wind direction would reduce the potential for an LNG accident near the island to have significant impact, except if the incident were to occur directly south or southeast of the island.

An LNG release accompanied by a fire in the vicinity of Snake Island during the bird nesting season (March to August) could have moderate to severe consequences. Snake Island is entirely within Zone 1; therefore, a pool fire in the vicinity of the island could be fatal to some or many of the birds on the island at that time. If an event that leads to a fire is accompanied by an explosion or loud noise, many of the adult birds would probably flee the nest sites. If the reaction time between the noise and the fire is too short, some of the birds may not be able to flee in time, resulting in mortality to the birds. Given enough response time, the adult birds would probably abandon the nest sites if responding to a mortal threat such as fire. Therefore, the circumstances surrounding the release and fire would dictate the severity of the impact on the breeding population. In a moderate event, the impact might be a partial reduction in breeding success for the colony for that year. In a severe event, some of the breeding adults as well as one year's nesting production could be lost, or reduced, and the colony may take years to recover.

The potential impacts from an LNG release and ignition at Sundown Island would be similar, but less severe than Snake Island. Sundown Island extends slightly into Zone 1 (see figure 4.4-1 sheet 2), but is primarily in Zone 2. Therefore, all the circumstances stated above would be similar, but presumably with higher survivorship at Sundown Island.

Because of the marine transit safety and security measures, the probability of an LNG vessel spill from collisions, allisions, and terrorist attacks would be unlikely. Therefore, although there is a potential that significant impacts could occur to nesting shorebirds within the Zones of Concern along the waterway for LNG marine traffic, the likelihood is extremely remote.

In addition to colonial nesting islands discussed above, there are bird feeding areas throughout the bay. Birds at these locations are not fixed at a given location (such as when breeding). Thus, any incident in proximity to feeding birds on the water, or in the shallows close to the shoreline, or along the dredged material spoil banks would probably result in the birds temporarily leaving the area. The concentration of feeding migratory birds is likely to be more dispersed than breeding colony populations. For more densely populated habitats, such as the mud flats and the shoreline along the west of the bay (see figure 4.4-1 sheets 2, 3, and 4), these areas are largely in Zones 2 or 3. The effects of an LNG release, either with or without a fire would be less severe in these zones and would probably result in the birds temporarily leaving the area with little or no mortality. Because of the marine transit safety and security measures, the probability of an LNG vessel spill from collisions, allisions, and terrorist attacks would be unlikely. Therefore, although there is a potential that impacts could occur to feeding shorebirds as a result of an incident along the waterway for LNG marine traffic, the likelihood is extremely remote.

LNG Terminal and Pipeline

The impact of construction resulting from the proposed Project on wildlife and wildlife habitats would vary depending upon the location, timing, and type of construction. The specific requirements of each species present within the project area would also contribute to expected project impacts. In general, impacts to terrestrial wildlife resulting from the construction of the proposed Project would be short-term and minimal because most terrestrial species are reasonably mobile and would be expected to temporarily relocate to similar adjacent habitats during construction activities. Some smaller, less mobile wildlife, such as small mammals, amphibians and reptiles, would likely experience direct mortality during clearing and grading activities. Impacts to wildlife resources would be minimized through required restoration of the pipeline construction right-of-way. Much of the area affected by construction would be allowed to revert to pre-construction conditions following construction.

Operation of the Project would result in the permanent conversion of about 76.5 acres of upland habitat to industrial use, of which 73 acres would be within the proposed LNG terminal site and the remaining 3.5 acres would be within the aboveground facilities associated with the proposed pipeline. This conversion to industrial use would represent a loss of wildlife habitat; however, impacts resulting from this loss would be minimal since the majority of the loss would be from the proposed LNG terminal site where the existing habitat consists of unmanaged dredge material.

Calhoun Point Comfort would survey the proposed LNG terminal site during the spring prior to construction to determine if the site is being used for nesting by terns, black skimmers, killdeer, or common night hawk. Results of the survey would be filed with the Secretary, FWS, and TPWD. Should nesting areas be discovered at the proposed LNG terminal site during this survey, Calhoun Point Comfort would consult with the FWS and TPWD to determine appropriate mitigation. Given the distances of active Texas Waterbird Colony 609-121 to the proposed project, we believe that construction and operation of the project would not disrupt birds nesting at this colony. Should nesting birds be found at this location, Calhoun Point Comfort would restrict construction activities within 1,000 feet of the rookery island during the nesting season (February through September).

Construction of the proposed LNG terminal could cause potential injury or mortality of migrating birds that may strike the LNG terminal facilities. Communication towers that can exceed 300 feet in height are known to be the source of large numbers of bird strikes and an estimated 4 to 5 million birds collide with them each year (Manville, 1999). By comparison, building window collisions are estimated to take from 97 to 970 million birds per year, or from 1 to 10 birds per building annually in North America (Klem, 1989, 1990; O'Connell; 1998). In addition to radio towers and large structures, electric utility power lines also have been documented as a cause of avian mortality due to wire strikes.

Studies on building strikes by birds generally focus not so much on the structures themselves, but the veneer of reflective or clear glass construction materials, the use of guy wires to support tall structures, or substantial lighting from either inside or outside sources (Klem, 1990). Lighting is a particular concern, since it appears that migrating birds, which often fly at night, are drawn to artificial lights. Absent from the extensive literature available on bird strikes is any mention of

storage tanks or other solid non-reflective/transparent man-made structures or natural solid objects (trees, hills, etc.).

The historical lack of favorable habitat would likely cause migratory species to be unattracted to the LNG terminal site, further reducing the likelihood of interaction with the LNG storage tanks (the tallest structures at the terminal). The LNG storage tanks would not be illuminated with high intensity lighting. The intensity and number of lights would be limited to what is required for security and operations. Due to the limited amount of suitable habitat historically present on the LNG terminal site, the lack of scientific literature reporting on bird striking storage tanks, and the low intensity lighting to be used, we believe the likelihood of adverse effects on migratory birds from collisions with the LNG storage tanks is minimal.

The proposed facility would obtain electrical power from an outside power source and would need 0.7-mile-long power line that would be within an existing utility right-of-way and along an existing access road (see section 2.2.2 of this EIS). The LNG tanks would be left in their light concrete non-reflective state. This design further reduces the likelihood of bird strikes since no reflective materials would be used and there would be no extensive lighting of the tanks, thus avoiding the two major sources of bird strikes on man-made structures. It is unlikely that the construction, placement, and/or operation of the 27.1-mile-long pipeline would have long-term impacts on migratory birds.

Project construction, specifically the clearing of vegetation, could potentially impact about 338.6 acres of habitat suitable for use by migratory birds protected under the Migratory Bird Treaty Act of 1918. The Migratory Bird Treaty Act implements various treaties and conventions for the protection of migratory birds. Under this act, taking, killing, or possessing migratory birds is unlawful. During operation of the pipeline, relatively little vegetation maintenance would be required due to the large percentage of agricultural land crossed. Calhoun Point Comfort would avoid vegetation maintenance during the peak nesting period between April 15 and August 1 of any year. If vegetation clearing must be conducted during this time, Calhoun Point Comfort would survey for all migratory bird nests prior to commencing work. To further protect nesting migratory birds, Calhoun Point Comfort would conduct surveys of areas that could be used by migratory birds before construction. If an active migratory bird nest is found along the construction right-of-way, Calhoun Point Comfort would establish a 25-foot buffer around the nest until young have fledged or the nest is abandoned or consult with the FWS and TPWD to identify the most appropriate measure that should be taken to avoid or minimize impacts.

4.5.2 Aquatic Resources - Estuarine

The Matagorda Bay system, which includes the open waters of Lavaca and Cox Bays, forms an extensive estuarine system comprised of perimeter salt marshes, oyster beds, and freshwater marshes. These aquatic habitats are highly productive systems that provide an abundant food base for those species that can tolerate the dynamic and stressful estuarine environment.

Estuarine habitats serve as active nursery grounds and adult feeding areas for numerous fish and invertebrate species. The Matagorda Bay estuary is comprised of open shallow and deepwater habitats, saline, brackish, and fresh water marshes, oyster reefs, and seagrasses. Reef systems throughout Matagorda Bay support a significant oyster fishery. Marine mammals are also

known to inhabit the area. Representative fish, invertebrate, and marine mammal species of the greater Matagorda Bay system are listed in table 4.5.2-1.

TABLE 4.5.2-1

Representative Fish, Invertebrate, and Marine Species of the Greater Matagorda Bay System

Common Name	Scientific Name
Atlantic bottlenose dolphin	*Scomberomorus maculates*
Atlantic croaker	*Micropogonias undulates*
Bay anchovy	*Anchoa mitchilli*
Black drum	*Pogonias cromis*
Blue crab	*Callinectes sapidus*
Brown shrimp	*Farfantepenaeus aztecus*
Eastern oyster	*Crassostrea virginica*
Florida pompano	*Trachinotus carolinus*
Gulf kingfish	*Menticirrhus littoralis*
Gulf menhaden	*Brevoortia patronus*
Gafftopsail catfish	*Bagre marinus*
Pinfish	*Lagodon rhomboids*
Pigfish	*Orthopristis chrysoptera*
Red drum	*Sciaenops occellatus*
Sand seatrout	*Cynocion arenarius*
Sheepshead	*Archosargus probatocephalus*
Silver perch	*Bairdiella chrysura*
Southern flounder	*Paralichthys lethostigma*
Southern kingfish	*Menticirrhus americanus*
Spot	*Leiostomus xanthurus*
Spotted seatrout	*Cynoscion nebulosus*
Sea catfish	*Arius felis*
Striped mullet	*Mugil cephalus*
White shrimp	*Litopenaeus setiferus*

4.5.2.1 Fish Species

Fish communities within the vicinity of the project area consist of species found in both estuarine and offshore marine habitats, and are classified as marine warmwater species. Distribution and abundance of these species vary depending on factors such as temperature, salinity, and reproduction cycles. While some species spend their lives within the estuary, many are migratory, using the estuaries as nurseries for rapidly growing juveniles, or opportunistically as adults when conditions are favorable. The species most common to Lavaca and Cox Bays include Atlantic croaker, spot, bay anchovy, sand seatrout, spotted seatrout, red drum, black drum, southern flounder, gafftopsail catfish, and sheepshead.

4.5.2.2 Invertebrates

Open bay communities support a variety of benthic invertebrates, which are typically subdivided into three size classes listed in order of increasing size: microbenthos, meiobenthos, and macrobenthos. Microbenthos, including bacteria, yeasts, fungi, microalgae (diatoms and flagellates) and protozoa are largely decomposers and are one of the most important components

of the open bay community; they form a major link between primary producers and higher trophic level consumers. The meiobenthic community typically consists of permanent residents, such as nematodes, harpacticoid copepods, gastrotrichs, and kinorhynchs, and temporary residents, including juvenile stages of clams, snails, polychaete worms and amphipods. Macrobenthos includes adult stages of bivalve mollusks (e.g., clams and oysters), polychaete worms, snails, and crabs. The macrobenthic assemblage known to occur in the vicinity of the project area in upper Lavaca Bay and Cox Bay is the Eastern oyster.

Whereas benthic infaunal invertebrates live in the bottom sediments, epibenthic invertebrates live on or near the surface of bottom sediments. Epibenthos typically prefer protected areas such as seagrass beds and salt marshes, but they also occur in open bay communities. Shrimp (e.g., brown, pink, and white) and blue crabs are the most abundant epifauna in the vicinity of the project area.

4.5.2.3 Commercial and Recreational Fisheries

Commercial and recreational fisheries are important industries in the greater Matagorda Bay system. Table 4.5.2.3-1 provides a list of representative saltwater commercial and recreational fish and shellfish species known to occur in the vicinity of the project area in Lavaca and Cox Bays.

TABLE 4.5.2.3-1

Representative Recreational and Commercial Fish and Shellfish Species Known to Occur in Lavaca Bay and Cox Bay

Common Name	Scientific Name	Fishery Classification
Atlantic croaker	*Micropogonias undulatus*	Warmwater marine/estuarine
Black drum	*Pogonias cromis*	Warmwater marine/estuarine
Gafftopsail catfish	*Bagre marinus*	Warmwater marine/estuarine
Sand seatrout	*Cynocion arenarius*	Warmwater estuarine
Sheepshead	*Archosargus probatocephalus*	Warmwater marine/estuarine
Southern flounder	*Paralichthys lethostigma*	Warmwater marine/estuarine
Spotted seatrout	*Cynoscion nebulosus*	Warmwater estuarine
Red drum	*Sciaenops ocellatus*	Warmwater marine/estuarine
Spanish mackerel	*Scomberomorus maculatus*	Warmwater estuarine
Pink shrimp	*Farfantepenaeus duorarum*	Warmwater estuarine
White shrimp	*Litopenaeus setiferus*	Warmwater estuarine
Brown shrimp	*Farfantepenaeus aztecus*	Warmwater estuarine
Blue crab	*Callinectes sapidus*	Warmwater estuarine
Eastern oyster	*Crassostrea virginica*	Warmwater estuarine

Calhoun Point Comfort reported that the dominant commercial fisheries in Matagorda Bay are brown, pink, and white shrimp; blue crab; and Eastern oyster. TPWD estimates indicate that the top three recreational fish species for Matagorda Bay are the spotted seatrout, red drum, and southern flounder.

As discussed in section 4.2.4 of this EIS, on April 20, 1998, the TDH issued a fish closure of a 1 square mile area of Lavaca Bay around the Port of Port Lavaca – Point Comfort and the Alcoa Industrial Channel and around Dredge Island to the taking of finfish and crabs. However, on January 13, 2000, the TDH reopened a portion of the closure area, Cox Bay, located due south of

the LNG terminal site. The closure for Cox Bay was reopened based on the reduced contaminants in surface sediments and reduced burden of mercury in fish tissues (EPA ROD, 2001).

Activities proposed at the Enhanced Recovery Projects DMPA may affect the local shrimping industry by restricting boat access through specific areas under certain low low water level conditions.

4.5.2.4 Fisheries of Special Concern

Fish species of special concern that occur in the vicinity of the proposed Project include state- and federally listed threatened and endangered species, federally managed species in Matagorda Bay and the Lavaca Bay estuary, and those of commercial and recreational value. Commercial and recreational fish species are discussed above in section 4.5.2.3. Threatened and endangered fish species are discussed in section 4.6 of this EIS. Species with EFH designations in Matagorda Bay and Lavaca Bay include red drum, Spanish mackerel, and pink, white and brown shrimp. EFH is further discussed below and in appendix B of this EIS.

4.5.2.5 Project Impacts on Estuarine Species

Waterway for LNG Marine Traffic

The entire bay from Matagorda Peninsula through all of Lavaca Bay is EFH for brown shrimp, white shrimp, Spanish mackerel, and red drum, both for the adults and the juveniles of each species. Zone 1 encompasses this EFH throughout the bay. See figures 4.5-1 through 4.5-8 for seasonal distribution and relative abundance for each of these four species.

The waterway for LNG marine traffic crosses through EFH through Matagorda and Lavaca Bays for the entire transit for four species: White shrimp (see figures 4.5-1 and 4.5-2); brown shrimp (see figures 4.5-3 and 4.5-4); red drum (see figures 4.5-5 and 4.5-6); and Spanish mackerel (see figures 4.5-7 and 4.5-8). Except for red drum, which are common throughout the bay in all seasons, these species have distributions and abundances that differ from season to season. However, the juveniles and adults could be encountered by LNG marine traffic throughout the year.

Figures 4.5-1 and 4.5-3 show that the juvenile shrimp are more abundant in the lower salinity, upper bays -- Keller, Cox, and Lavaca Bays -- and the embayed areas such as Powderhorn Lake, particularly during November to June. The highest quality habitat for the protection and growth of post-larval shrimp and crabs would be the submerged aquatic vegetation of some of the embayments, the emergent marsh, or wetlands, along the shorelines, and the shallow water bayous, embayments (e.g., Powderhorn Lake) and channels along the western shoreline from Port O'Connor to Alamo Beach. These shoreline features are primarily in Zone 3, except for some shoreline at Indian Point, which is in Zone 2.

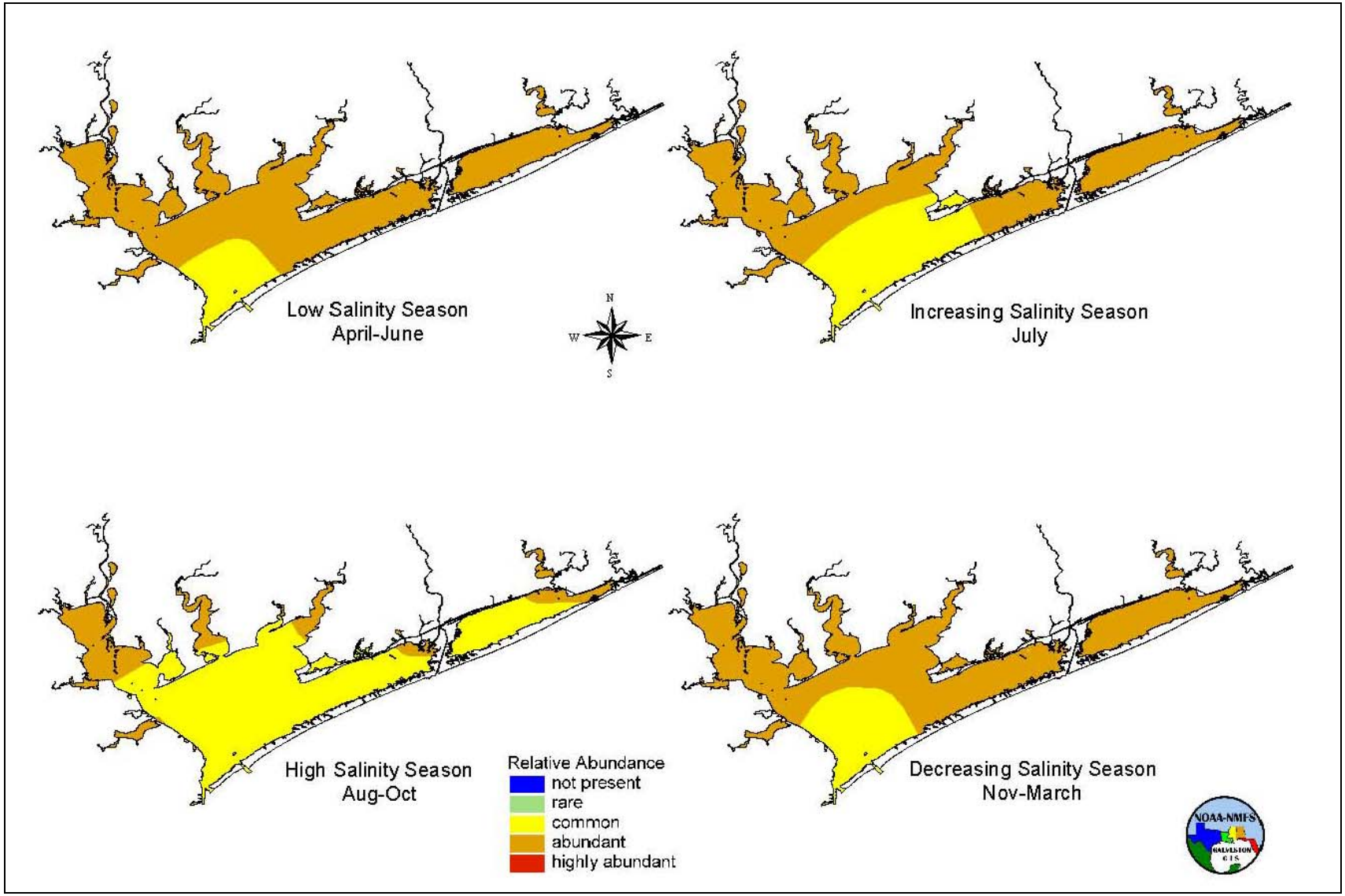

Figure 4.5-1
Calhoun LNG Project
EFH White Shrimp – Juveniles

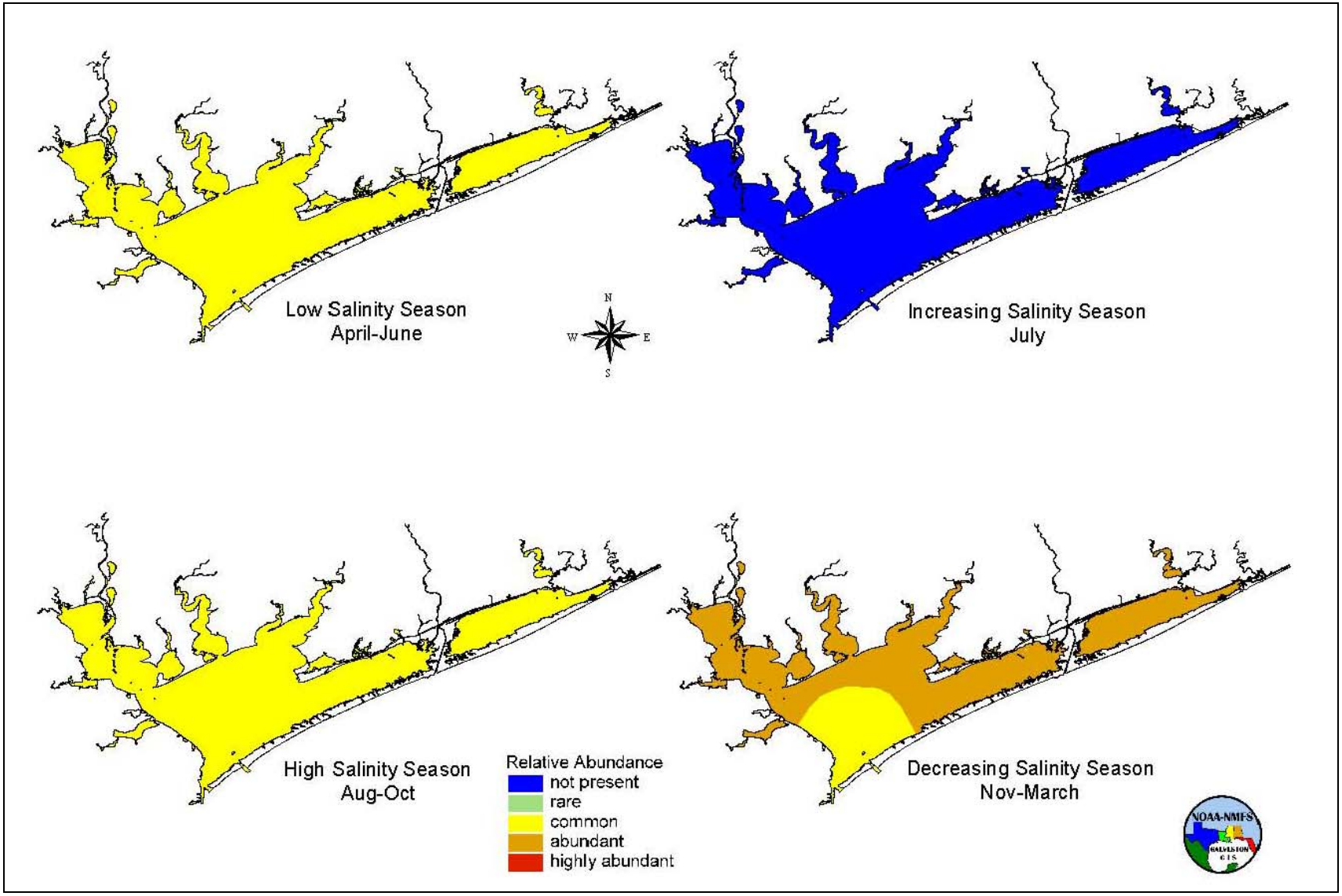

Figure 4.5-2
Calhoun LNG Project
EFH White Shrimp – Adults

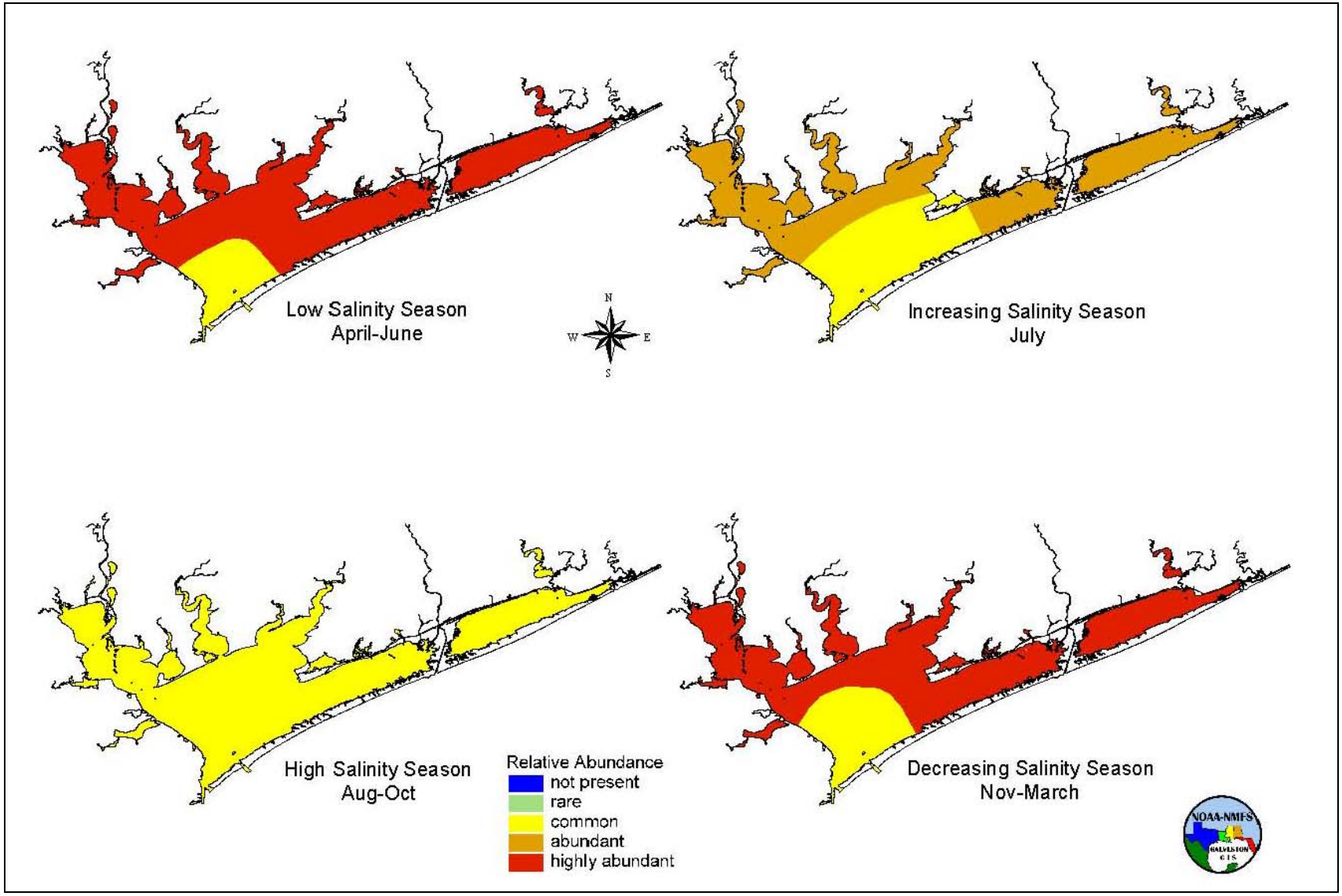

Figure 4.5-3
Calhoun LNG Project
EFH Brown Shrimp – Juveniles

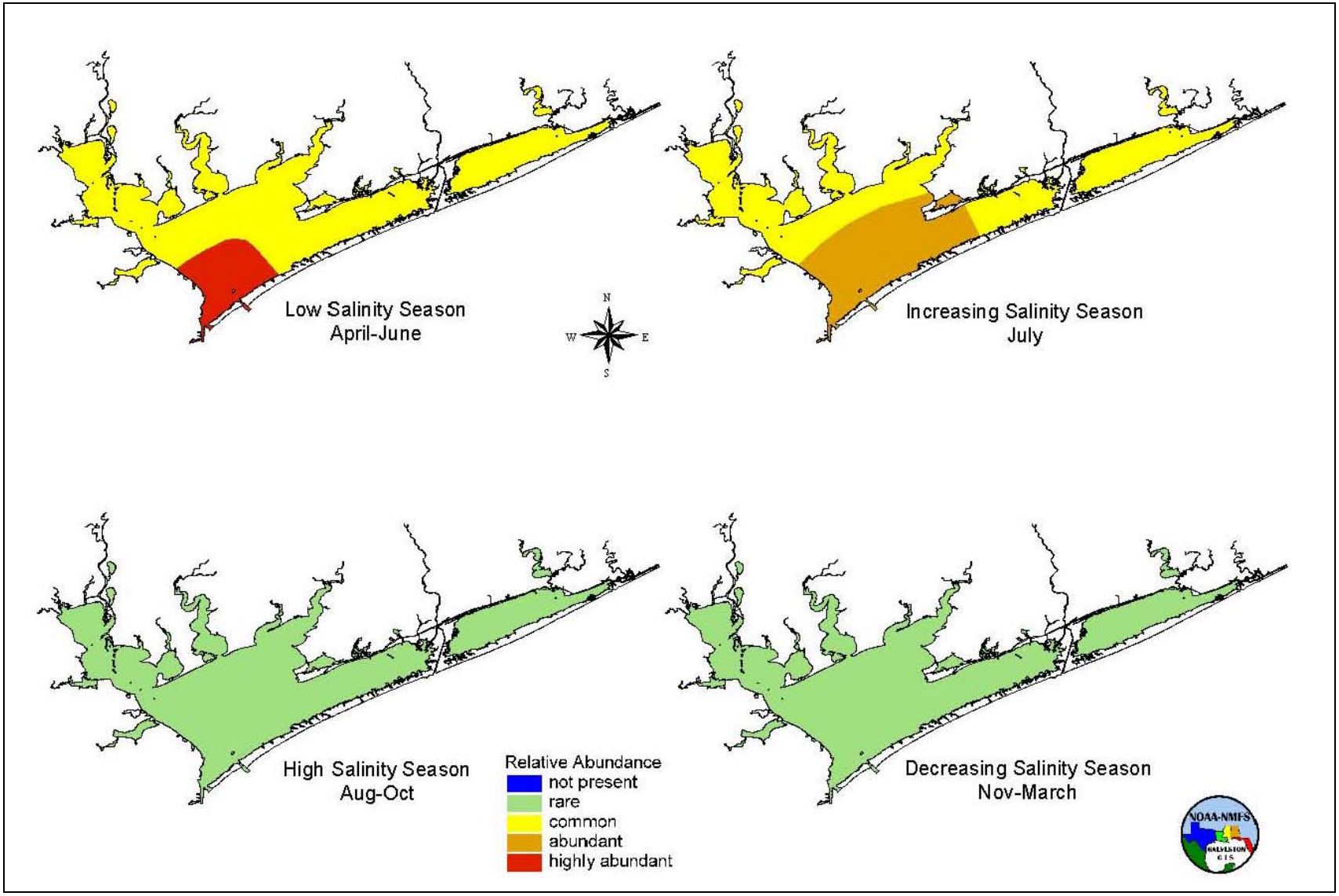

Figure 4.5-4
Calhoun LNG Project
EFH Brown Shrimp – Adults

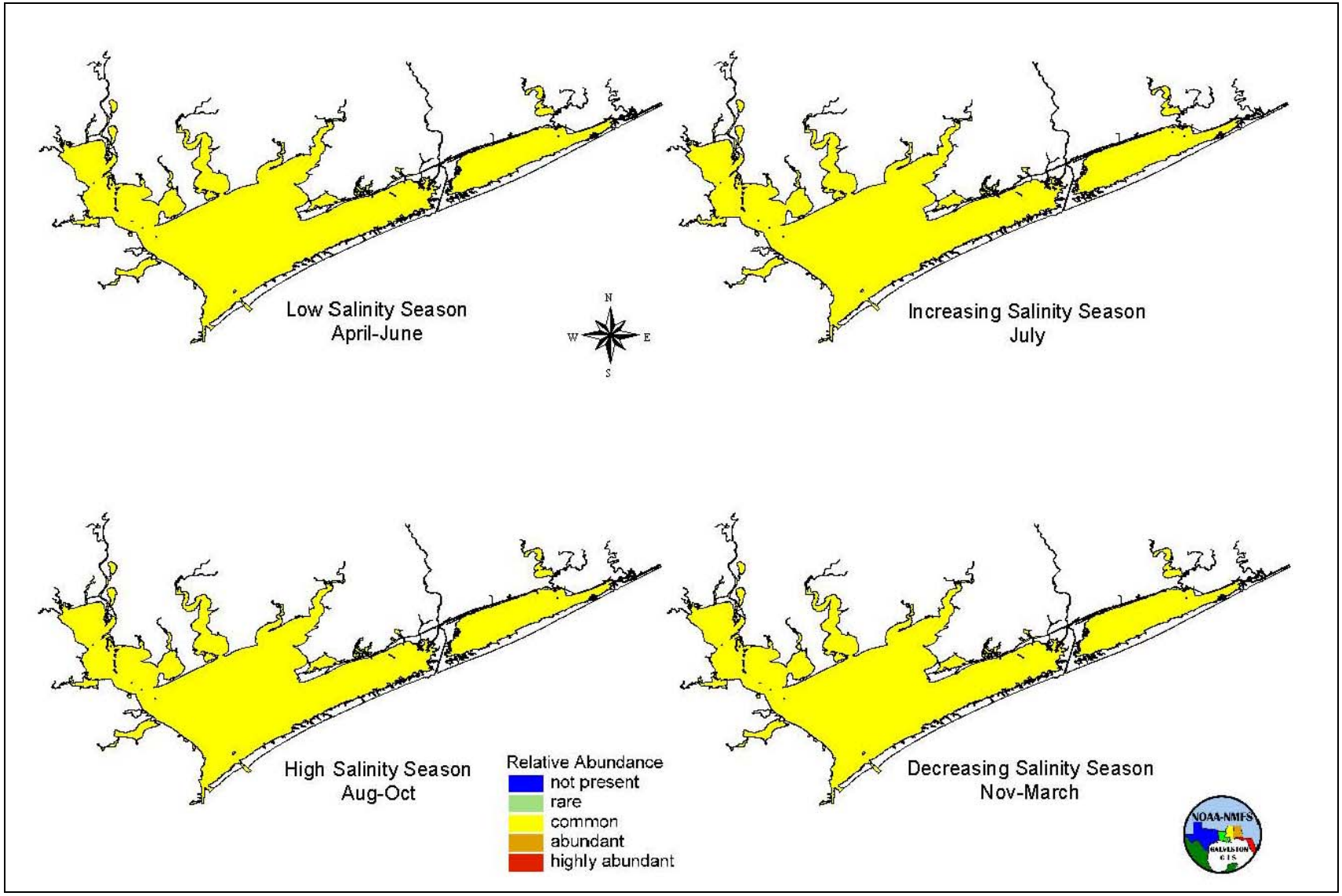

Figure 4.5-5
Calhoun LNG Project
EFH Red Drum – Juveniles

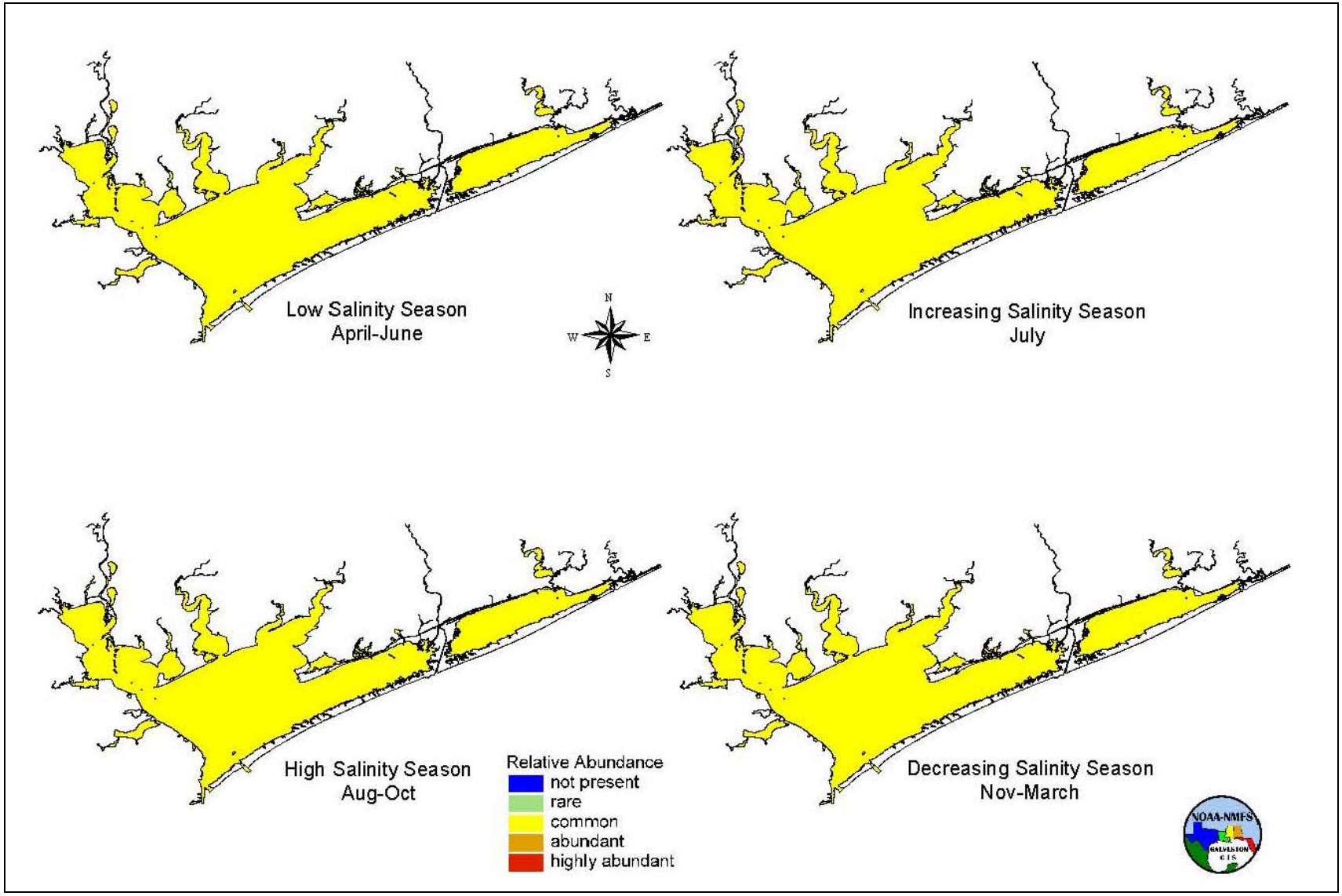

Figure 4.5-6
Calhoun LNG Project
EFH Red Drum – Adults

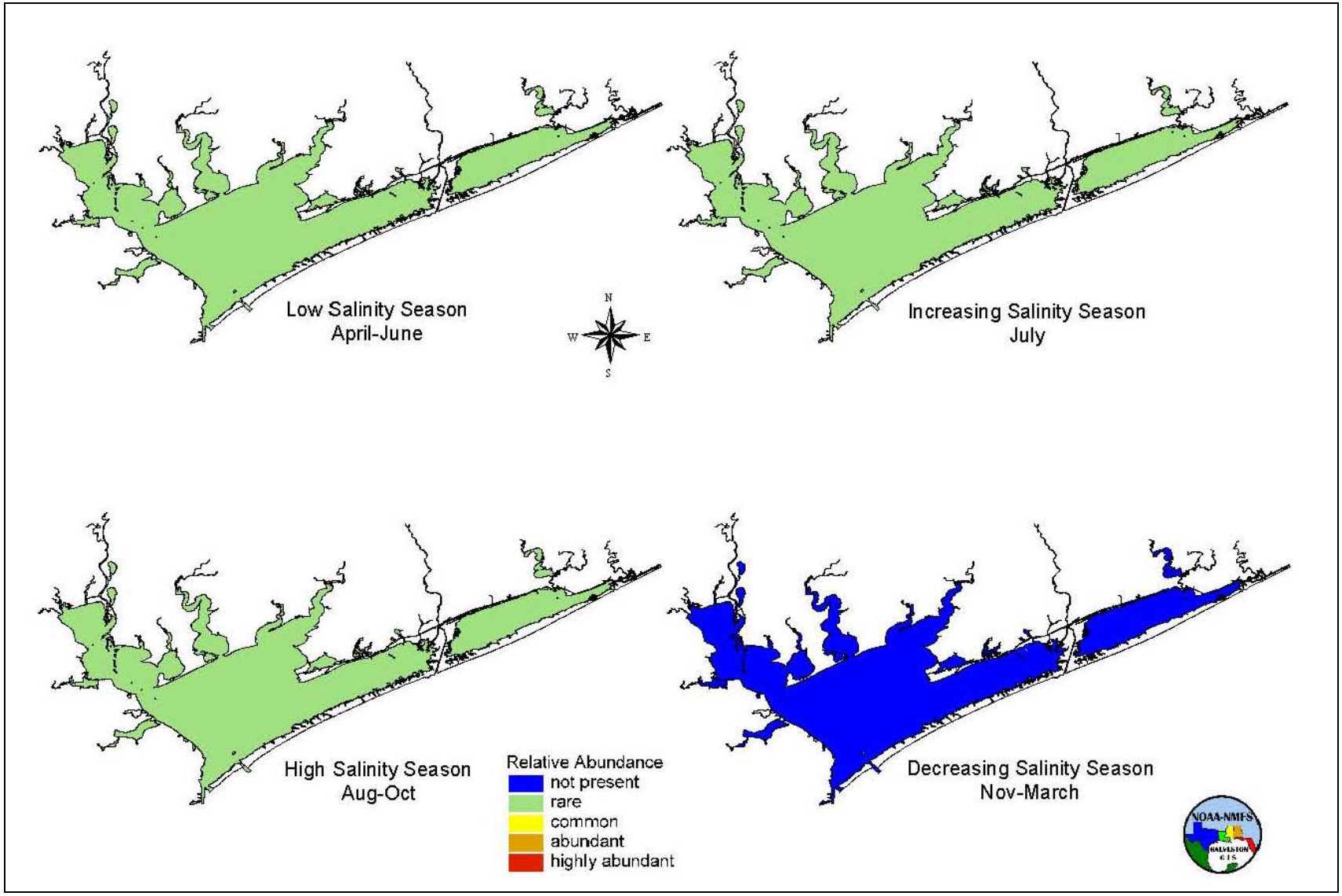

Figure 4.5-7
Calhoun LNG Project
EFH Spanish Mackerel – Juveniles

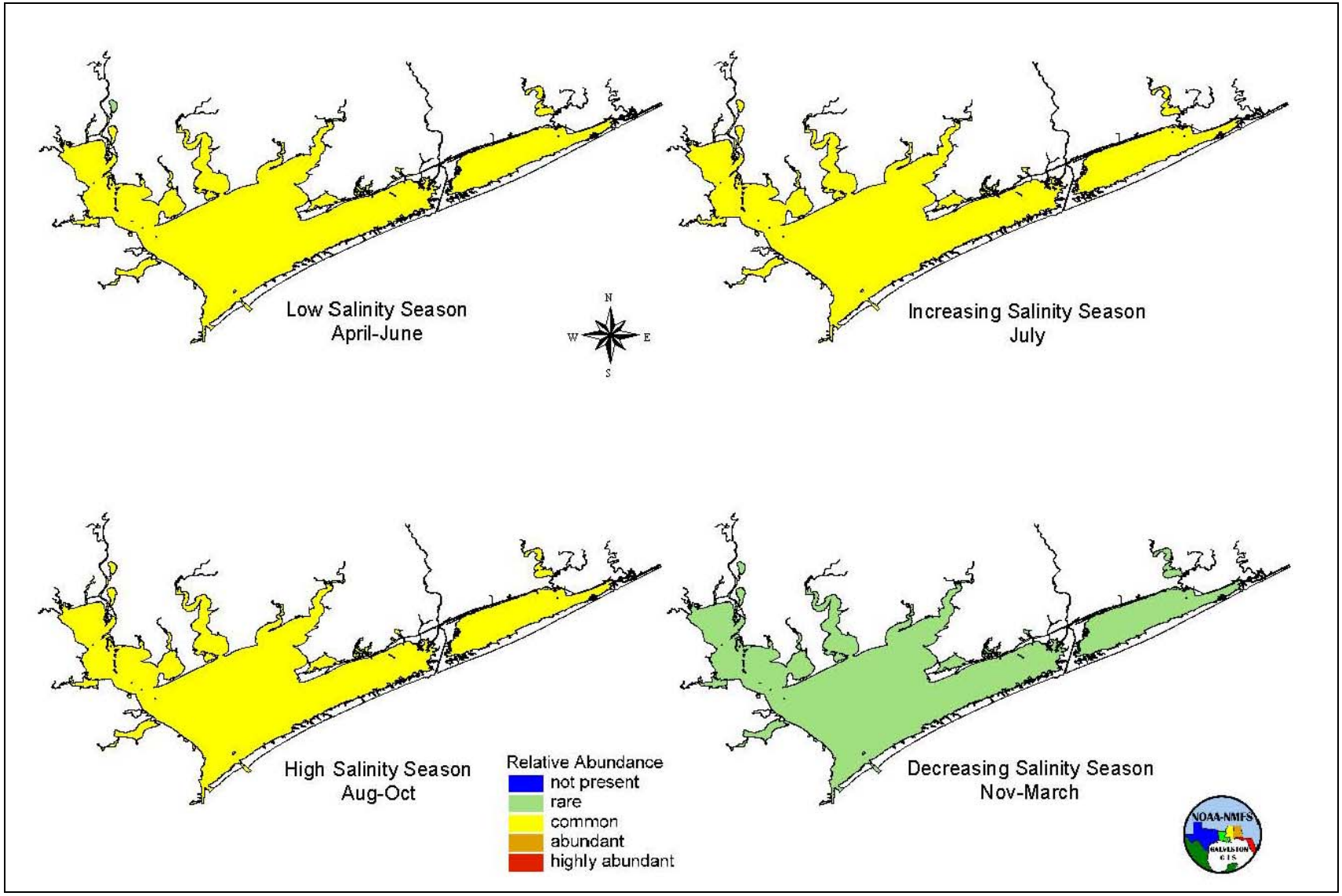

Figure 4.5-8
Calhoun LNG Project
EFH Spanish Mackerel – Adults

Normal vessel operations would be expected to have little impact on the adults of any of these species. The passage of vessels would result in stirring of sediments in the ship channel by the turbulence created by the vessel's screws. The areas that would be affected by this turbulence would be limited to existing channels that experience this disturbance on a regular basis from existing ship traffic, and therefore, impact on sediments from LNG marine traffic would not be significant. Larval and postlarval and juvenile forms of species with EFH could also be impacted to some extent by vessel ballasting activities. These ballasting activities would not differ greatly from the ballasting of other large draft vessels that call at Alcoa or the Port.

In the event of an LNG release, with or without ignition, the impacts to EFH should be limited to the immediate area of the incident (Zone 1). If an unignited LNG spill were to occur along the transit route, given that LNG is lighter than water, the LNG would float on the water until it had vaporized, possibly reaching shore. The primary impact on EFH species would be LNG rapidly boiling upon contact with water, resulting in the rapid cooling of the water within the LNG pool. If the LNG were to contact any aquatic species within Zone 1, the species could be injured or expired. Further, because the colder water would be more dense than the ambient water, it would sink to the bottom and could affect bottom species or live phases in the area of the incident. Mobile species would be expected to move from the area until water temperatures return to normal. However, non-mobile species, such as oysters, could be subjected to the cold (the further from the spill, the less water temperatures would be affected).

If an associated fire were to occur with the release of LNG, impacts to species within Zone 1 would be limited to species on or near the water's surface in the vicinity of the fire. Radiant heat within Zone 2 may impact some species on the water's surface. No impacts would be expected on species within Zone 3 from a pool fire. The maximum flammable range for a vapor cloud could extend to the outer limits of Zone 3. If the vapor cloud were to come in contact with an ignition source, the resulting fire could burn back to the spill and impact any species on the surface within its path. However, because of the marine transit safety and security measures, the probability of an LNG vessel spill from collisions, allisions, and terrorist attacks would be unlikely. Therefore, although there is a potential that significant impacts could occur to some EFH species and life stages as a result of an LNG release along the waterway for LNG marine traffic, the likelihood is extremely remote.

LNG Facilities and Proposed Dredging Impacts

Marine habitats associated with the proposed Project occur in the vicinity of the CCND's new turning basin, Calhoun Point Comfort's ship berth, the MSC, and the proposed DMPAs within Lavaca Bay. Impacts on aquatic organisms would arise primarily from dredging, dock construction, and ballast water intake by LNG vessels, which could result in habitat removal and conversion; loss of organisms by direct removal, entrainment, or burial; and loss related to turbidity or noise impacts.

Construction activities along the boundaries of the LNG terminal site would include grading and leveling to create the footprint of the LNG terminal. This activity could result in siltation at the water's edge and temporary increases in turbidity and/or the suspension of solids within the water column. Bulkhead activities (driving of sheet piles) would occur on the north side of the terminal site and at the ship berth location. Impacts associated with these activities are described below and would be short-term and localized. Fish and larger motile invertebrates such as

shrimp and crabs are expected to avoid the affected areas. In general, impacts would be minimized through the implementation of Calhoun Point Comfort's BMPs to be identified in Calhoun Point Comfort's SWPP Plan.

The creation of the CCND's new turning basin and Calhoun Point Comfort's ship berth would permanently remove the benthic organisms that occupy the sediments that would be dredged. However, benthic organisms may recolonize the bottom sediments after each dredge cycle. Very slight changes in the hydrography and water and sediment quality parameters (i.e., tidal amplitude, dissolved oxygen, salinity, toxic chemical accumulation, etc.) resulting from the creation of the turning basin and ship berth would not cause detectable adverse effects on aquatic species. All permanent impacts to existing shallow water habitats (less than 6 feet deep) that would be converted to deep water habitats would require compensatory mitigation according to a resource agency approved mitigation plan. However, the areas proposed to be dredged are between 15 and 40 feet deep and are not existing shallow water habitat; therefore, the proposed dredging would not result in conversion of shallow water habitat to deep water habitat.

In addition to the loss or alteration of aquatic habitats, the primary impacts to fish associated with dredging include entrainment of organisms by dredging machinery, and increased turbidity and sedimentation due to the resuspension of bottom sediments. The loss of benthic organisms due to entrainment would potentially occur during dredging, but should not be extensive enough to have a significant impact on the fishery resources of Lavaca Bay. To determine potential impacts on Eastern oyster habitat in Lavaca Bay, Calhoun Point Comfort conducted an oyster survey during December 2005 in the proposed dredge area for the CCND's turning basin and Calhoun Point Comfort's ship berth and at each of the DMPAs. Twenty-three oyster reefs were delineated in these areas resulting in about 35 acres of potential impact (see table 4.5.2.5-1).

TABLE 4.5.2.5-1

Oyster Reefs Delineated in the Project Area and Potential Project Impacts

Project Area	Number of Delineated Oyster Reefs	Area of Potential Impact (acres)
Dredge Area		
CCND's Turning Basin and Calhoun Point Comfort's Ship Berth	2	18
DMPAs		
Dredge Island Expansion North	6	5
Dredge Island Marsh	15	12
Enhanced Recovery Projects A	0	0
Enhanced Recovery Projects B	0	0
Total	**23**	**35**

Source: Calhoun Point Comfort's Oyster Reef Delineation Study Lavaca Bay System (January 2006) and estimates of oyster reef coverage within the expanded boundaries of DIEN DMPA.

Potential impacts on oyster reef habitat would result from dredging activities associated with the turning basin and ship berth and disposal and permanent storage of dredged material at the Dredge Island Expansion North and Dredge Island Marsh DMPAs. Calhoun Point Comfort reported that 3,743 acres of oyster reef habitat occur in the Lavaca Bay system. The amount of oyster reef habitat that would be affected by the project represents 0.8 percent of available

habitat within this system. To mitigate for loss of the approximately 35 acres of oyster reef habitat, Calhoun Point Comfort's revised draft DMMP includes creation of 63 acres of oyster reef within the Enhanced Recovery Projects A DMPA. We believe that with this mitigation there would be no significant impacts on oysters or oyster reef habitats within Lavaca Bay as a result of dredging activities and disposal and permanent storage of dredged material.

Demersal and pelagic fish of various life stages would also be at some risk of being entrained. However, much of the available evidence suggests that entrainment is not a significant problem for many species of fish and shellfish in bodies of water that require periodic dredging. In most instances, dredging related impacts appear to be most serious in narrow constricted river channels (Reine and Clarke, 1998).

Increases in turbidity can affect fish physiology and/or behavior. Potential physiological effects include mechanical abrasion of surface membranes, delayed larval and embryonic development, reduced bivalve pumping rates, and interference with respiratory functions. Possible behavioral effects from increased turbidity include interference with feeding for sight-foraging fish and area avoidance. Alternately, the reduced visibility of predatory fish could lower vulnerability to predation for prey species. Turbidity tends to interfere with light penetration and thus reduces photosynthetic activity by phytoplankton. Such reductions in primary production would be localized around the immediate area of dredge operations in Lavaca Bay and would be limited to the duration of the sedimentation plume at the turning basin and ship berth.

Excessive nutrient loading from sediment resuspension can also have an adverse impact upon the harbor because it can cause dramatic increase in the productivity of planktonic algal populations. The particles that would be resuspended as a result of dredging are fine silt and clays that would wash out of the channel before settling. If particles are suspended higher in the water column, or in deeper water, the settling time and distance would be greater. Calhoun Point Comfort would comply with any project-specific recommendations or requirements to minimize suspension of sediments that are attached to dredging permits. In general, impacts of dredging on marine water turbidity are expected to be localized, short-term, and minor, as discussed in section 4.3.2 of this EIS.

Siltation from dredging for the marine basin is expected to have minor effects on the shallow shoreline areas in the vicinity of the Project. Submerged aquatic vegetation is generally absent from Lavaca Bay; however, shoalgrass and wigeongrass have been found along the southern shoreline of Keller Bay, located southeast of the Project. Perimeter salt marshes, oyster beds, and freshwater marshes are found in upper Lavaca Bay and Cox Bay as well as Chocolate Bay, located south of the Project. It is expected that any turbidity or sedimentation impacts would be limited to within several hundred feet of dredging operations. Since turbidity and sedimentation impacts are expected to be minor and limited to within several hundred feet of dredging operations, no wetlands, seagrasses, or oyster reefs (beyond those directly affected by dredging and dredged material disposal as discussed above) are expected to be impacted by turbidity and sedimentation caused by the proposed dredging operations. If any of these sensitive habitats are determined to be located in close proximity to the proposed dredging operations and at risk of being impacted, appropriate measures (i.e., use of silt curtains and absorbent boom, shallower dredge cuts, containment structures, or stop dredging activates until turbidity levels have declined) would be implemented to protect these habitats. Therefore, no siltation or turbidity impacts to wetlands, seagrasses, or oyster reefs are anticipated.

Pile driving activities, in some cases, can generate intense underwater sound pressure waves that can adversely affect nearby marine organisms including marine mammals, sea turtles, and fish. The Atlantic bottlenose dolphin is common in Matagorda and Lavaca Bays. Although the effects of pile driving are poorly studied and there appears to be substantial variation in a species' response to sound, intense sound pressure waves can change fish behavior or injure/kill fish through rupturing swim bladders or causing internal hemorrhaging. The degree to which an individual fish exposed to sound waves would be affected is dependent upon variables such as the peak sound pressure level and frequency as well as the species, size, and condition of a fish (e.g., small fish are more prone to injury by intense sound waves than are larger fish of the same species). In some cases, sound pressure levels greater than 155 decibels (re: 1 micro Pascal [μPa]) can elicit avoidance behaviors or stun small fish (NOAA Fisheries, 2003). Sounds greater than 190 decibels (re: 1 μPa) are thought to physically injure some fish (Hastings, 2002). The presence of predators can also influence how a fish might be affected by pile driving (e.g., fish stunned by pile driving activities may be more susceptible to predators).

The intensity of the sound pressure levels produced during pile driving depends on a variety of factors including, but not limited to, the type and size of the pile, the firmness of the substrate into which the pile is being driven, the depth of water, and the type and size of the pile driving hammer. For example, driving hollow steel piles with impact hammers produce intense, sharp spikes of sound that can injure fish. In some cases, fish may be startled by the first few strikes of an impact hammer. However, this response can wane and the fish may remain in the area (NOAA Fisheries, 2001). As such, the potential effect on fish from impact hammers could be magnified since fish would not only be exposed to intense sound waves but may not avoid pile driving activities, which would prolong their exposure to the potentially harmful sounds and increase their risk of injury or death. In a review of studies documenting fish kills associated with pile driving, NOAA Fisheries (2003) reported that all have occurred during use of an impact hammer on hollow steel piles. On the other hand, the rapid repetitions of vibratory hammers produce relatively low intensity sound waves. Evidence also suggests that fish consistently display an avoidance response to sound from a vibratory hammer, even after repeated exposure (Dolat, 1997; Knudsen et al., 1997).

Calhoun Point Comfort has not yet identified the type of hammer that would be used to drive piles during construction of the ship berth. Driving steel pipe piles with an impact hammer in similar settings has been shown to generate sound levels from 192 to 194 decibels (re: 1 μPa), above the level that is thought to injure some fish. Depending on the specific conditions at the site, these sounds can have a transmission loss rate of 0.021 to 0.046 decibels (re: 1 μPa) per foot (Nedwell and Edwards, 2002; Nedwell et al., 2003). Based on these values, the use of an impact hammer could generate underwater sound levels great enough to affect some fish as far as 190 feet (i.e., 190 decibels (re: 1 μPa)) and 1,860 feet (i.e., 155 decibels (re: 1 μPa)) from a steel pile. Although the sound waves of the greatest intensity would be limited to the immediate vicinity of the piles within the unloading slip, sound levels of 155 decibels (re: 1 μPa) could extend to the far shore of Lavaca Bay while piles are being driven. Because the piles would be located in an active Port area, it seems likely that construction noise and activities would cause many marine species to avoid the area where the most intense sound levels would be generated.

Ship and boat traffic associated with construction and operation of the Project would also generate underwater sounds. Although vessel noise would not generally be of the intensity

produced from driving steel piles, project-related vessels (LNG vessels, tugs, and construction barges) operating in the MSC could generate sounds that elicit responses in fish. Most research suggests that fish exhibit avoidance behavior in response to engine noise (ICES, 1995). At the same time, research conclusions tend to suggest that since the effects are transient (i.e., once the ship passes, behavior returns to normal), then the long-term effects on populations are negligible (Stocker, 2001).

Hydrostatic test water discharges into Lavaca Bay would be in accordance with permit requirements issued by the TRRC. Hydrostatic testing is further discussed in section 4.3.2.1. Prior to discharge, all test water would be analyzed for chemical composition and treated if necessary. Therefore, we believe there would be no significant impacts on aquatic species or habitats as a result of discharging hydrostatic test water.

Operation of the LNG terminal should not have a significant effect on area fisheries. Operation would involve additional vessel traffic of up to about 120 LNG vessels per year. This would include berthing of an average of two to three LNG vessels per week, or two to three additional vessel movements both inward and outward through the MSC per week. Increased vessel traffic is not expected to result in increased impacts to marine mammals or sea turtles. To help minimize impacts to marine mammals and turtles, Calhoun Point Comfort would include NOAA Fisheries' *Vessel Strike Avoidance and Injured/Dead Protected Species Reporting* policy as part of its Terminal Use Agreement with LNG Ship operators (see section 4.6 of this EIS).

The Coast Guard has indicated that it may require Calhoun Point Comfort to use a floating, movable boat barrier around LNG vessels while at dock as an additional security measure. This barrier would essentially be a floating fence, stored along the shoreline while not in use, and towed into place by a small boat when an LNG vessel arrives at dock. The barrier would be attached to a mooring buoy at two corners, but would otherwise not extend below the water's surface, and would not pose a potential barrier to movement of aquatic organisms, or otherwise impact aquatic resources.

LNG vessels calling from international ports could potentially introduce aquatic invasive species into U.S. waters. However, no release of ballast water would occur within Lavaca Bay. Therefore, there would be no impact on aquatic species or habitats as a result of discharge of LNG vessel ballast water. It is expected that any LNG vessels calling at the Calhoun Point Comfort LNG terminal would be in full compliance with the domestic requirements for ballast water management as specified in the National Invasive Species Act of 1996 (NISA) and international standards that were adopted on February 13, 2004. In addition, the Coast Guard has developed responses to exotic/invasive species associated with foreign vessels and its Office of Operating and Environmental Standards developed *Mandatory Practices for All Vessels with Ballast Tanks on All Waters of the United States*. The mandatory practices include requirements to rinse anchors and anchor chains during retrieval to remove organisms and sediments at their place of origin and to remove fouling organisms that may be affixed to ship hulls, piping, and tanks. The removal of organisms would be conducted on a regular basis and the disposal of any removed substances would be in accordance with local, state, and federal regulations. Therefore, we conclude that the introduction of non-indigenous attached species via ship hulls is not likely to significantly alter the local biotic community.

There are potential impacts on marine organisms resulting from the intake of ballast water while in port. While the vessel is discharging its LNG, it would be taking on seawater ballast to maintain a constant draft at the berth. Depending on their size, the LNG vessels would require from up to approximately 13.7 million gallons of seawater ballast (138,000 m^3 vessel) to up to 26.2 million gallons of seawater ballast (220,000 m^3 vessel) per vessel. Ballast water would be drawn in through intake openings on the side of the LNG vessel. These openings would be covered with a strainer plate with slots about 1-inch-wide by 8- to 12-inches long. Aquatic species in the immediate vicinity of the LNG ship berth could therefore be impacted by entrainment during ballast water intake. Ballast water intakes on LNG vessels are near the bottom of the vessels; therefore, entrainment would be limited to organisms in the deeper water column (24 to 30 feet below the surface) near the bottom of the ship berth. Ballast water intake at Calhoun Point Comfort's proposed LNG terminal would be similar to ongoing ballast water intake by numerous vessels currently calling on the Port of Port Lavaca–Point Comfort, and impacts from entrainment during ballast water intake by LNG vessels would not add appreciably to current impacts.

In addition to ballast water intake, the SCV technology that would be used to process the LNG produces excess water at a rate of 200 gpm. During the vaporization process, the excess water would become acidic. Calhoun Point Comfort would neutralize the excess water with a caustic solution before it is discharged into the terminal drainage system and into Cox Bay. The temperature of the produced water would range from 60 to 70°F and would rise to ambient temperature before it is discharged into the bay. Discharges of excess water from the SCV process area would comply with the Texas Pollutant Discharge Elimination System and would be of ambient temperature. Discharges of freshwater would create a dilution zone outside of the outfall area and would result in an area of slightly lower salinity than the adjacent waters of Cox Bay. Calhoun Point Comfort would conduct an evaluation using site specific ambient condition data and the CORMIX Mixing Zone Expert System water model to confirm that fresh water discharges at design temperature and salinity conditions would maintain water quality standards within the mixing zone. The results of this evaluation would be submitted with Calhoun Point Comfort's permit applications to the TCEQ.

Dredged Material Management

As part of its DMMP, Calhoun Point Comfort proposes to use DMPAs within Lavaca Bay. These DMPAs would be between 1 and 2 miles from the LNG terminal site. Placement of dredged material at the Dredge Island Expansion North DMPA would fill about 163 acres of previously disturbed and unvegetated open bay habitat, about 33 acres of uplands, 10 acres of wetlands, and 5 acres of oyster reefs resulting in the creation of about 191 acres of upland confined placement area and 20 acres of bordering fringe wetland. Placement of dredged material within Dredge Island Marsh would impact about 7 acres of upland, 28 acres of open water, 12 acres of oyster reef, and 1 acre of tidal wetland, and would result in about 11 acres of upland, 5.2 acres of open water, and 31.8 acres of tidal wetland. Placement of dredged material at the Enhanced Recovery Projects A DMPA would raise the elevation of about 63 acres of shallow bottom habitat from about minus 6 feet MLLW to about minus 4 feet MLLW but retain the shallow unvegetated bay bottom habitat that currently exists. The entire 63 acres would be enhanced to encourage the establishment of oyster reef. Placement of dredged material within

the Enhanced Recovery Projects B DMPA would raise the bottom elevation of about 32 acres of shallow water habitat by about 2 feet, and the area would remain as open water habitat.

Dredged material placement could result in a large conversion of habitats, particularly converting about 249 acres of open bay to uplands, oyster reef, or wetland. About 11 acres of wetlands and 17 acres of oyster reef would also be converted to uplands. The loss of open water habitat could adversely impact estuarine species that utilize shallow muddy bottoms. To mitigate for the permanent impact on wetlands and oyster reef, Calhoun Point Comfort proposes to create about 33 acres of fringe marsh and 18.8 acres of high marsh within the Dredge Island Expansion North and Dredge Island Marsh DMPAs, and about 63 acres of oyster reef habitat within the Enhanced Recovery Projects A DMPA (see appendix E). Approval of this proposed mitigation would occur during permit review by the COE and NOAA Fisheries. Additional discussions on Calhoun Point Comfort's draft DMMP are in section 2.4.1.2 of this EIS, and impacts and mitigation to federally managed species are further presented in the EFH Assessment (appendix B).

4.5.3 Aquatic Resources - Freshwater

No natural freshwater ponds, lakes, or streams occur on or adjacent to the LNG terminal site. The proposed Point Comfort Pipeline would cross 65 surface waterbodies as listed in table 4.3.2-1 of this EIS. Only four of these waterbodies (a slough [MP 4.5], Navidad River [MP 16.5], Lavaca River [MP 23.4], and tributary to Lavaca River [MP 23.5]) are natural, perennial waterbodies. The remaining waterbodies are intermittent-flowing drainages or ditches. The waterbodies capable of supporting fish populations have been classified as warmwater and sport fisheries and include gamefish such as largemouth bass (*Micropterus salmoides salmoides*), sunfish (*Lepomis* spp.), crappies (*Pomoxis* spp.), and catfish (*Pylodictis* spp.).

Impacts on fisheries resources resulting from pipeline construction activities at waterbody crossings can include sedimentation and turbidity, alteration or removal of instream and stream bank fish cover, introduction of water pollutants, or entrainment of small organisms during hydrostatic testing. Studies generally have indicated that pipeline construction through waterbodies results in temporary impacts on streams and rivers, and that there are no long-term effects on water temperature, pH, dissolved oxygen, benthic invertebrate populations, or fish populations (Vinkour and Shubert, 1987; Blais and Simpson, 1997).

In order to minimize impacts, Calhoun Point Comfort would cross 11 of the 65 waterbodies using the HDD crossing method. Fourteen waterbodies are channelized intermittent roadside ditches that would be crossed by the bore method. Crossing by HDD or bore would avoid direct impact on the waterbodies and associated fisheries. The remaining 40 waterbodies crossed by the pipeline are both channelized and natural intermittent drainages that would be crossed by the open-cut method.

An open-cut crossing would result in short-term increases in turbidity and siltation downstream of the pipeline crossing sites. The concentration of suspended solids would decrease rapidly following the completion of in-stream work. The increased siltation may cause decreased flow of oxygenated water to benthic organisms and fish eggs, resulting in degradation of benthic and spawning habitat. Direct loss of spawning habitat, benthic invertebrates, and protective cover may occur at the pipeline crossing location due to trenching and backfilling. However, any

sedimentation and turbidity resulting from construction would be short-term. Where feasible, waterbody crossings would occur during periods of low or no-flow. Calhoun Point Comfort would construct all waterbody crossings in accordance with the construction and mitigation measures in our Procedures. Our Procedures require completion of most instream work within 24 hours for waterbodies 10 feet wide or less, and within 48 hours for streams 10 to 100 feet in width.

Use of our Procedures would reduce impacts on fisheries from construction-induced sedimentation and turbidity. Trench spoil would be stored within the approved right-of-way on or above the stream banks at least 10 feet from the water's edge. Temporary sediment control devices would be installed around spoil piles to minimize the potential for sediment-laden water to enter the stream. Additionally, all staging and temporary workspace areas would be located at least 50 feet back from the water's edge where topographic conditions permit (unless otherwise permitted), thus minimizing the potential for erosion and sedimentation along the stream banks.

Impacts on water quality from the open-cut crossing would be short-term and suspended sediment concentrations would be expected to return to pre-construction levels soon after construction across the waterbody is completed. Because of Calhoun Point Comfort's proposed use of our Procedures, and the use of the HDD and bore method for many waterbody crossings, impact on fish and other freshwater aquatic organisms is expected to be very localized and short-term.

Hydrostatic testing of the integrity of the completed pipelines would occur following construction, which would require water to be withdrawn from either the Navidad River or Formosa Plastic Corporation. Water withdrawal could potentially entrain fish eggs and juvenile fish. To minimize the potential for this impact, Calhoun Point Comfort would implement FERC's Procedures, which include covering the intake hose with an adequately sized mesh screen to reduce the potential for fish and fish egg entrainment, and adding no chemicals to the water for the hydrostatic testing of the pipelines. Thus, impacts to the fisheries resources from hydrostatic testing would be minimal with the use of these preventative measures.

4.6 THREATENED, ENDANGERED, AND OTHER SPECIAL STATUS SPECIES

In order to comply with Section 7 of the ESA, Calhoun Point Comfort, acting as the FERC's non-federal representative for purposes of complying with the ESA, consulted with the FWS and NOAA Fisheries regarding the presence of federally listed threatened and endangered species and their critical habitats within the project area. Calhoun Point Comfort also consulted with the TPWD regarding the presence of state-listed threatened and endangered species within the project area.

4.6.1 Federally Listed Threatened and Endangered Species

The FWS and NOAA Fisheries identified 22 federally listed threatened and endangered species that may be affected by the proposed Project including species that may be affected by LNG vessels in transit to and from the proposed terminal. However, based on our review of these species, we have determined that construction and operation of the proposed Project would have no effect on six of these species because proposed project facilities would not be located within

the known range of these species (see table 4.6.1-1). Therefore these species are not addressed further in this EIS. The remaining 16 species are listed in table 4.6.1-2 and described below.

TABLE 4.6.1-1

Federally Listed Threatened and Endangered Species Eliminated From Further Consideration for the Calhoun LNG Project

Species	Status a/	Reason for Elimination from Further Consideration b/	Determination
Birds			
Eskimo Curlew (*Numenius borealis)*	F- E TX – E	Considered to be extinct.	No effect
Interior Least Tern (*Sterna antillarum athalossos*)	F- E TX – E	Protection under the ESA and state regulation is restricted to "interior" populations. Project is outside of the protected range.	No effect
Mammals			
Louisiana Black Bear (*Ursus americanu luteolus*)	F - T TX - T	Suitable habitat not present in project area.	No effect
Ocelot (*Leopardus pardalis*)	F- E TX - E	Inhabits dense, thorny brush, mesquite-oak and oak forests, and partially cleared land. No ocelots or suitable habitat encountered during surveys.	No effect
Jaguarundi (*Herpailurus yagouaroundi*)	F- E TX - E	Inhabits areas that are similar to the ocelot, dense, thorny brush, and chaparral. No jaguarundi or suitable habitat encountered during surveys.	No effect
Red Wolf (*Canis rufus*)	F- E TX - E	Thought to be extirpated from Texas.	No effect

a/ Status: F = Federal, TX = Texas, E = Endangered, T = Threatened.
b/ Calhoun Point Comfort conducted habitat surveys during December 2004 and February, March, and April 2005.

TABLE 4.6.1-2

Federally Listed Threatened and Endangered Species Potentially Occurring in the Calhoun LNG Project Area

Species	Status a/	Preferred Habitat	Determination
Birds			
Brown Pelican (*Pelecanus occidentalis*)	F - E TX - E	Shallow coastal waters within 20 miles or less of the shoreline and in depths up to 80 feet.	Not likely to adversely affect
Bald Eagle (*Haliaeetus leucocephalus*)	F – T b/ TX - NL	Coastal areas, rivers, and large bodies of water.	Not likely to adversely affect
Whooping Crane (*Grus americana*)	F - E TX - E	Winter habitat in Texas consists of brackish bays, marshes, and salt flats and upland areas with oak mottles, grassland swales, and ponds.	Not likely to adversely affect
Piping Plover (*Charadrius melodus*)	F - T TX - T	Ocean, river, and inland lake shorelines, sandy beaches, sandbars, dunes, and silty flats.	Not likely to adversely affect
Mammals			
Sperm Whale (*Physeter macrocephalus*)	F- E TX – E	Deep waters off the continental shelf.	Not likely to adversely affect
Sei Whale (*Balaenoptera borealis*)	F - E	Deep waters off the continental shelf.	Not likely to adversely affect
Fin Whale (*Balaenoptera physalus*)	F- E TX – E	Deep waters off the continental shelf.	Not likely to adversely affect
Blue Whale (*Balaenoptera musculus*)	F- E TX – E	Deep waters off the continental shelf.	Not likely to adversely affect
Humpback Whale (*Megapetra novaeangliae*)	F - E	Deep waters off the continental shelf.	Not likely to adversely affect
North Atlantic right Whale (*Eubalaena glacialis*)	F- E TX – E	Deep waters off the continental shelf.	Not likely to adversely affect

TABLE 4.6.1-2

Federally Listed Threatened and Endangered Species Potentially Occurring in the Calhoun LNG Project Area

Species	Status a/	Preferred Habitat	Determination
West Indian Manatee (*Trichechus manatus*)	F- E TX – E	Warm, shallow coastal waters, estuaries, bays, rivers, and lakes with water depths between 3 and 6 feet deep. Along the coast they may be found in water nine to 15 feet deep.	Not likely to adversely affect
Reptiles			
Loggerhead Sea Turtle (*Caretta caretta*)	F - T TX - T	Open seas over the continental shelf, bays, estuaries, lagoons, creeks, and mouths of rivers.	Not likely to adversely affect
Green Sea Turtle (*Chelonia mydas*)	F - T TX - T	Lagoons, bays, inlets, shoals, and estuaries, as well as coral reefs, rocky outcrops, and high-energy beaches.	Not likely to adversely affect
Leatherback Sea Turtle (*Dermochelys coriacea*)	F - E TX - E	Open sea, coastal waters, and sandy beaches with a deepwater approach.	Not likely to adversely affect
Hawksbill Sea Turtle (*Eretmochelys imbricate*)	F - E TX - E	Coastal reefs, bays, rocky areas, estuaries, lagoons at depths of 70 feet or less, and open sea.	Not likely to adversely affect
Kemp's Ridley Sea Turtle (*Lepidochelys kempii*)	F - E TX - E	Shallow coastal and estuarine waters over sand or mud bottoms.	Not likely to adversely affect

a/ Status: F = Federal, TX = Texas, E = Endangered, T = Threatened, NL = No Listing.
b/ A final rule to delist the bald eagle was issued on July 9, 2007; however that rule does not become effective until 30 days later on August 8, 2007.

Based on our review of the identified federally listed threatened and endangered species as described in the following section, our recommendations to protect these species, and as illustrated in table 4.6.1-2, we have determined that construction and operation of the proposed Project is not likely to adversely affect the 16 listed species potentially found within the project area.

With the issuance of the draft EIS, we requested that the NOAA Fisheries and the FWS accept this EIS as our biological assessment for the proposed Project consistent with informal consultation as outlined in Section 7 of the ESA. In a letter to the Commission dated August 10, 2006, the NOAA Fisheries provided its comments on the draft EIS and concluded that federally listed species under its purview (whales and sea turtles) are not likely to be adversely affected by the proposed Project and that the FERC has completed its consultation responsibilities with the NOAA Fisheries under Section 7 of the ESA. In a letter to the Commission dated August 21, 2006, the FWS provided its comments on the draft EIS and concurred with our determination that the proposed Project is not likely to adversely affect the endangered brown pelican, whooping crane, threatened piping plover, and all federally listed sea turtles.

Since concurrence from the FWS regarding our determination that the proposed Project is not likely to adversely affect the bald eagle and the West Indian manatee is pending, **we recommend that:**

- **Calhoun Point Comfort should not begin construction of the proposed LNG terminal or pipeline <u>until</u>:**

  a. the Staff completes consultation with FWS; and

b. Calhoun Point Comfort has received written notification from the Director of OEP that construction and/or implementation of conservation measures may begin.

If construction has not begun within 1 year from the date of issuance of the FERC approval of the project, Calhoun Point Comfort should consult with the appropriate offices of the NOAA Fisheries and the FWS to update the species list and to verify that previous consultations and determinations of effect are still current. Documentation of these consultations, and the need for additional surveys and survey reports (if required), and the NOAA Fisheries and the FWS comments on the surveys and survey reports and their conclusions, should be filed with the Secretary and the Captain of the Port prior to construction.

Additional information regarding the bald eagle and the West Indian manatee including protection, impact minimization and mitigation measures, and our recommendations concerning these species is described in the respective species-specific discussions below.

4.6.1.1 Birds

Brown Pelican *(Pelecanus occidentalis)*

The brown pelican is federally and state-listed as endangered. Brown pelicans inhabit shallow coastal waters with depths up to 80 feet. They are rarely found inland and do not venture more than 20 miles out to sea except to take advantage of exceptional foraging conditions. They are colonial nesters with a preference to nest in small bushes and trees on undisturbed offshore islands that are free from human disturbance, flooding, and terrestrial predators. Brown pelicans will loaf and roost on beaches, sandbars, sandpits, mudflats, and man-made structures such as piers, wharves, pilings, oil/gas platforms, and docks.

Brown pelicans are a common resident along the Texas Gulf Coast and have been sparsely recorded at Texas Waterbird Colony No. 609-121, a dredged material disposal area about 0.3 mile south of the terminal site, during 1996, 2000, and 2001 (QuickBase, 2005). Brown pelicans were observed feeding and loafing in Cox Bay south of the project area during habitat surveys, and they would be expected to also utilize areas in the immediate vicinity of the proposed LNG terminal and the waterway for LNG marine traffic for feeding and loafing.

The nearest known brown pelican nesting site to the Project is Sundown Island, approximately 20 miles south of the LNG terminal site, and approximately 1,000 feet from the MSC. Sundown Island extends slightly into Zone of Concern 1 (see section 2.1.2 and figure 4.4-1 sheet 2), but is primarily in Zone of Concern 2. According to the FWS, the nesting population of brown pelicans at Sundown Island is the most prolific and important breeding site for the species on the central coast of Texas. In 2005, the island had more than 1,700 breeding pairs of brown pelicans (FWS, 2005).

Construction and operation of the proposed pipeline would not affect brown pelicans. Construction and operation of the proposed terminal including the turning basin and ship berth may affect brown pelicans. Dredging and terminal-related construction activities could disturb brown pelican habitat and behaviors including loafing and feeding. However, these impacts

would be temporary and since brown pelicans have become accustomed to shipping and port-related activities we believe impacts to them related to the construction and operation of the proposed Project would not be significant. LNG vessels in transit to and from the proposed Project may affect brown pelicans including nesting brown pelicans on Sundown Island. Specifically, brown pelicans found along the waterway could be impacted by LNG vessel noise and the resulting increase in shoreline erosion potential associated with wakes created by LNG ships. However, nesting birds on the island are accustomed to noise from passing deep draft vessels, and noise from LNG vessel traffic in the MSC would be consistent with noise from ongoing vessel traffic and LNG vessels passing through the MSC would not significantly affect shoreline erosion at Sundown Island (see also section 4.2.3 of this EIS). We believe that during normal shipping operations, LNG vessels passing Sundown Island at a distance of about 1,000 feet are not likely to adversely affect brown pelicans.

Additionally, an incident involving an LNG release from a vessel while in the vicinity of the island could affect brown pelicans. In the case of an LNG release without ignition, impacts would probably be restricted to Zone 1. An incident close to the island could result in a vapor cloud that could force the adult birds to flee. If the vapor cloud is thick enough to exclude oxygen, and if it hugs the ground, young birds that could not yet fly would suffocate. However, since most of Sundown Island is in Zone 2, any vapor cloud would likely disperse prior to reaching the island, reducing the chance of mortality to nestlings.

An LNG release accompanied by a fire in the vicinity of Sundown Island during the nesting season (March to August) could have moderate to severe affects on brown pelicans. A pool fire in the vicinity of the island could be fatal to some of the adults or nestlings. If an event that leads to a fire is accompanied by an explosion or loud noise, many of the adult birds would probably flee the nest sites. If the reaction time between the noise and the fire is too short, some of the birds may not be able to flee in time, resulting in mortality. Given enough response time, the adult birds would probably abandon the nest sites if responding to a mortal threat such as fire. Therefore, the circumstances surrounding the release and fire would dictate the severity of the impact on the breeding population. In a moderate event, the impact might be a partial reduction in breeding success for the colony for that year. In a severe event, some of the breeding adults as well as one year's nesting production could be lost, or reduced, and the colony may take years to recover.

Because of the marine transit safety and security measures, the probability of an LNG vessel spill from collisions, allisions and terrorist attacks would be unlikely. Therefore, the probability of an LNG release, either with or without ignition, is extremely low. The probability that such an event would occur in close proximity to Sundown Island during the brown pelican breeding season is even lower.

Although there is a potential that significant impacts could occur to nesting brown pelicans if an LNG release were to occur along the waterway for LNG marine traffic in the vicinity of Sundown Island, the likelihood is extremely remote.

Based on the characteristics of the brown pelican, Calhoun Point Comfort's proposed construction and operations procedures including mitigation, the potential affects to this species occurring from construction and operations-related activities and the potential affects of LNG vessels to brown pelicans found along the transit waterway, we have determined that

construction and operation of the proposed Project, including the passage of LNG vessels through the MSC, is not likely to adversely affect this species.

Bald Eagle *(Haliaeetus leucocephalus)*

At the time of printing of this EIS the bald eagle is classified as a federally-threatened species. A final rule to delist the species was issued on July 9, 2007; however that rule does not become effective until 30 days later on August 8, 2007. The bald eagle ranges over the United States and Canada. In Texas, bald eagles are present year-round as spring and fall migrants, breeders, or winter residents. Preferred nesting habitat is in undisturbed coastal regions, or along river systems or lake shores with large, tall trees for nesting and roosting. Nesting typically occurs from October to June or July. Bald eagles are vulnerable to disturbance throughout the nesting period.

The area adjacent to the Navidad River crossing at the northern end of the Project meets habitat requirements for bald eagle nesting and foraging. During an April 15, 2005 field survey of the proposed Point Comfort Pipeline route, Calhoun Point Comfort observed an adult bald eagle near MP 17.5. Based on information obtained by Calhoun Point Comfort during its consultation with the TPWD, it was discovered that two bald eagle nests are known to be located within about 1.0 mile of the proposed pipeline right-of-way, in the vicinity of the proposed crossing of the Navidad River (MP 16.5). The pipeline would be adjacent to existing right-of-way at this location. At this location, one bald eagle nest site is located about 0.9 mile south of the pipeline right-of-way, within full-canopied woodlands. The pipeline right-of-way and construction activities would not likely be visible from the nest site and Calhoun Point Comfort indicated that it would not locate any temporary access roads between this nest site and the right-of-way. The second bald eagle nest site at this location is between 0.8 and 1.0 mile north of the pipeline right-of-way. Visibility of the proposed right-of-way and pipeline construction activities from this nest site would be limited because of area woodlands.

The proposed Project would not directly affect the known bald eagle nest sites. Construction activities may affect foraging habits and could potentially affect nesting bald eagles if construction occurred during the nesting season, between October and July. However, the potential for construction to affect these nesting bald eagles is believed to be minimal because (1) of the distance between the nests and proposed construction right-of-way, (2) only a short section of the right-of-way, about 0.5 mile, would be within 1.0 mile of the nests, and (3) direct visibility and noise from construction activities would be limited by woodland vegetation between the nests and proposed right-of-way.

The FWS indicated that, for all projects occurring from October 1 to July 1 that are within 3 miles of a river or other large body of water, such as lakes or reservoirs, an eagle nest survey should be conducted within a 1-mile radius of the entire project. If nests are located, the project should be conducted during the summer months between July 1 and October 1 (FWS, 2005b). Calhoun Point Comfort has agreed to conduct bald eagle nest surveys before construction and would coordinate with the FWS and TPWD to determine the optimum survey dates, methodology, and area to be surveyed. In addition, Calhoun Point Comfort indicated that it would construct the pipeline through sensitive bald eagle habitat during the non-nesting period from July 1 to October 1, and it would coordinate with the FWS and TPWD to determine the exact area where such a timing restriction would apply (Amec-Paragon, 2005c).

With Calhoun Point Comfort's indication that it would consult with the FWS and TPWD concerning this species and that it would construct nearby pipeline during the non-nesting period, we believe that construction and operation of the Calhoun LNG Project is not likely to adversely affect bald eagles. To ensure that bald eagles are protected during construction of the pipeline, Calhoun Point Comfort prepared a draft bald eagle management plan that provides guidance on the protection of bald eagles, and their habitat, during construction. The draft bald eagle management plan was prepared in accordance with the FWS and TPWD's *Habitat Management Guidelines for Bald Eagles in Texas* and identifies measures to minimize impacts and protect bald eagle nest sites near construction activities. The draft plan identifies a 25-foot buffer that would be maintained around an active nest, which does not correspond with the primary and secondary management zones for nest sites as developed by the FWS and TPWD. In its comments on the draft EIS, Calhoun Point Comfort confirmed that its construction activities would comply with the FWS advisory guidelines of primary and secondary management zones should a bald eagle nest site be identified along the Point Comfort Pipeline. Calhoun Point Comfort stated that it would modify its final bald eagle management plan accordingly. **We recommend that:**

- **Calhoun Point Comfort should revise its bald eagle management plan to be consistent with the FWS guidelines regarding primary and secondary management zones that would be used should a bald eagle nest site be identified along the Point Comfort Pipeline construction right-of-way. Calhoun Point Comfort should file the revised plan with the Secretary <u>prior to construction</u>.**

Whooping Crane (*Grus americana*)

The whooping crane is federally and state-listed as endangered. The whooping crane winters in coastal Texas. Designated critical habitat for this species is located within the Aransas National Wildlife Refuge (NWR) in Aransas, Calhoun, and Refugio Counties, approximately 30 miles southwest of the project area. Some whooping cranes also winter on Matagorda Island, which at its closest point is about 20 miles south of the proposed LNG terminal site, but would be passed by LNG vessels as they enter Matagorda Bay through the entrance channel. Winter habitat consists of brackish bays, marshes, and salt flats that provide a variety of plant and animal foods such as blue crabs, clams, and berries. Whooping cranes may also occasionally use upland areas with oak mottles, grassland swales, and ponds that provide foods such as snails, crayfish, and insects. The central and eastern Panhandle also provides a major stopover area for birds migrating between summer and winter habitats.

Based on the habitat requirements of the whooping crane, known habitat locations, the location of the proposed Project, and the characteristics of this species including its relative mobility, we have determined that construction and operation of the proposed Project, including the passage of LNG vessels through the MSC, is not likely to adversely affect this species.

Piping Plover *(Charadrius melodus)*

The piping plover is federally and state-listed as threatened. Piping plovers inhabit shorelines of oceans, rivers, and inland lakes and nest on a variety of sites including sandy beaches, sandbars, dunes, and silty flats. During the winter, they utilize beaches, mud and sand flats, and offshore spoil islands. The piping plover breeds on the northern Great Plains, in the Great Lakes, and

along the Mid- to North-Atlantic coast, and winters on the Atlantic and Gulf of Mexico coasts from North Carolina to Mexico. They arrive at their Texas wintering grounds during mid- to late-July and spend a majority of their time on sand and mud flats near sandy beaches. They feed on tidal flats during low tide and beaches during high tide.

The piping plover would not be expected to occur along the Point Comfort Pipeline, but could potentially occur on tidal flats near the proposed LNG site and along the waterway for LNG marine traffic. No tidal wetlands or vegetated tidal flats would be impacted at the LNG terminal site; however, approximately 11 acres of intertidal wetland, including 1.6 acres of fringe and 9.4 acres of high marsh, would be permanently filled as a result of proposed dredge material placement within Dredge Island Expansion North and Dredge Island Marsh DMPAs. An estuarine marsh and tidal flat occurs along the southern boundary of the terminal site and outside of the construction area. The closest potential habitat to the LNG terminal site is a wide tidal mudflat along the shoreline of Cox Bay to the east of the site. Calhoun Point Comfort surveyed the proposed LNG terminal site and the adjacent mudflat during a two-day period in early 2005, visiting the site four times at various times of the day and various tide stages. No piping plovers were observed during the surveys of the LNG terminal site and the adjacent tidal mudflat. If piping plovers were to use the habitat adjacent to the site, potential impacts to them would be limited to occasional and temporary displacement from the habitat as a result of construction activity and noise. Piping plover habitat would not be permanently affected.

There is designated critical habitat (winter feeding habitat) for piping plover along the inner and outer shorelines of Matagorda Peninsula, both east and west of the MSC at the inlet to the bay. The waterway for LNG marine traffic would pass in close proximity to this habitat at the entrance to the bay. Portions of this habitat would be within Zones 1, 2, and 3 (see figure 4.4-1 sheet 1).

The potential impacts to piping plovers from normal LNG vessel traffic would include noise from the vessel operations and erosion from vessel wakes. Piping plovers on winter feeding habitat near the entrance to the MSC would be accustomed to noise from passing deep draft ships within the MSC, and noise from LNG vessel traffic in the MSC would be consistent with noise from ongoing ship traffic and that LNG vessels passing through the MSC would not significantly affect shoreline erosion along the MSC (see also section 4.2.3 of this EIS). We believe that during normal operations, LNG vessels using the MSC are not likely to adversely affect the piping plover.

Additionally, an incident involving an LNG release from a vessel while in the vicinity of winter feeding habitat could affect piping plovers. In the case of an LNG release without ignition, impacts would probably be restricted to Zone 1. An incident while passing through the entrance channel through Matagorda Peninsula could result in a vapor cloud that could force birds to flee. An LNG release accompanied by a fire could result in mortality of some birds within Zone 1. However, if an event that leads to a fire is accompanied by an explosion or loud noise, feeding pipeline plovers would probably flee the feeding habitat prior to exposure to a fire. If the reaction time between the noise and the fire is too short, some of the birds may not be able to flee in time, resulting in mortality. Therefore, the circumstances surrounding the release and fire would dictate the severity of the impact on the feeding birds.

Because of the marine transit safety and security measures, the probability of an LNG vessel spill from collisions, allisions, and terrorist attacks would be unlikely. Therefore, the probability of an LNG release, either with or without ignition, is extremely low. The probability that such an event would occur in close proximity to piping plover critical habitat during the winter season is even lower.

Although there is a potential that impacts could occur to piping plovers while on feeding habitats along the waterway for LNG marine traffic, the likelihood is extremely remote.

Based on the characteristics of the piping plover, Calhoun Point Comfort's proposed construction and operation procedures including mitigation, the potential affects to this species occurring from construction and operations-related activities, and the potential affects of LNG vessels to piping plovers found along the transit waterway, we have determined that construction and operation of the proposed Project, including the passage of LNG vessels through the MSC, is not likely to adversely affect this species.

4.6.1.2 Marine Mammals

Whales

Six federally protected species of whales have been identified as occurring or potentially occurring within the Gulf of Mexico.

Sperm whales (*Physeter macrocephalus*) are found throughout the world's oceans in deep waters to the edge of the ice at both poles. They have also been documented in the northern Gulf of Mexico during all seasons. Based on year-round occurrence of strandings, sightings, and catches, it is believed that sperm whales in the Gulf of Mexico may represent a distinct population (NOAA, 2005a). Sperm whales generally occur in waters greater than 590 feet and prefer continental margins, sea mounts, and areas of upwelling where food is abundant.

Sei whales (*Balaenoptera borealis*) and blue whales (*Balaenoptera musculus)* are uncommon in the Gulf of Mexico. The blue whale's range typically extends from the Arctic Ocean to mid-latitude waters and is often sighted off of eastern Canada. The sei whale is also typically found in northern waters, however the southern limits of its spring and summer ranges include the Gulf of Maine and Georges Bank. Sightings of sei whales are rare in the Gulf of Mexico. The sei whale is often found in the deeper waters of the continental shelf edge (NOAA, 2005a).

The fin whale (*Balaenoptera physalus*) is common from Cape Hatteras north to the Gulf of Maine. In this area, fin whales may be the dominant large cetacean species year round, with the largest standing stock, food requirements, and impact on the marine ecosystem. It is likely that fin whales occurring in the eastern Atlantic undergo migrations into Canadian waters, open-ocean areas, and subtropical or tropical regions (NOAA, 2005a). Sightings of fin whales are rare in the Gulf of Mexico.

Humpback whales (*Megaptera novaeangliae*) can be found in their feeding grounds in the Gulf of Maine, Gulf of St. Lawrence, Newfoundland Labrador, and western Greenland during the spring, summer, and fall (NOAA, 2005a). Although humpback whales migrate to the West Indies for the winter, significant numbers of whales can be found in mid- and high-latitude

regions. A number of wintering humpbacks occur in coastal waters of the southeastern United States (NOAA, 2005a).

The North Atlantic right whale (*Eubalaena glacialis*) is the rarest of all large whale species and among the rarest of all marine mammal species (NOAA, 2005a). They are found in the North Atlantic, North Pacific, and Southern Hemisphere regions. The majority of individuals in the western North Atlantic population range from wintering and calving areas in coastal waters off the southeastern United States to summer feeding and nursery grounds in New England waters and north to the Bay of Fundy and Scotian Shelf. Three areas were designated by NMFS in June 1994 as critical habitat for the western North Atlantic population: Coastal Florida and Georgia (Sebastian Inlet, Florida to the Altamaha River, Georgia), Great South Channel (east of Cape Cod), and Massachusetts Bay and Cape Cod Bay (NOAA, 2005a). On January 16, 2005, two North Atlantic right whales, a mother and her calf, were observed near the Corpus Christi ship channel and the Ingleside Naval Air Station, about 80 miles southwest from Point Comfort, Texas. Since 1963, this was the third time a North Atlantic right whale has been reported in the Gulf of Mexico (Hanna, 2006).

West Indian Manatee (*Trichechus manatus*)

The West Indian manatee is federally and state-listed (in Jackson County) as endangered. Collisions with boat and ship hulls and/or propellers; entrapment in floodgates, navigation blocks, fishing nets, and water pipes; poaching; vandalism; ingestion of marine debris; and hunting have all contributed to the population decline of manatees. The low reproductive rate and loss of habitat have made it difficult for manatee populations to recover (NOAA, 2005a).

Manatees prefer rivers or estuaries to marine habitats and inhabit warm, shallow coastal waters, estuaries, bays, rivers, and lakes. They prefer water depth between 3 and 6 feet, and along the coast they may be found in water that is nine to 15 feet deep. They primarily feed on submerged, emergent, and floating vegetation. Manatee populations in the United States primarily occur in Florida, where they are isolated from other populations due to the cooler water of the northern Gulf of Mexico and the deeper waters of the Straits of Florida. Manatees are extremely rare in Texas; however, recent sightings have been reported. On July 25 and 26, 2005, a manatee was sighted near the Dolphin Point subdivision in the Port O'Connor area, and on August 13, 2005, a manatee was sighted at the southwest end of Espiritu Santo Bay, near Port O'Connor.

Marine Mammal Impacts and Mitigation

Based on the characteristics of the identified marine mammals including habitat requirements, the location of the proposed facilities, and Calhoun Point Comfort's proposed construction and operations procedures, we believe that construction and operation of the proposed Project (LNG terminal and pipeline) would not significantly impact federally listed whale species or the West Indian manatee. However, these species could be impacted by LNG vessels operating in the Gulf of Mexico and the MSC.

Although the identified whale species do not generally occur in the relatively shallow waters found near the proposed Project or in the MSC, they could potentially be impacted by collisions with LNG vessels that are transiting to and from the terminal, general shipping operations, or by an incident involving an LNG release from a vessel in transit. While there are no prescribed routes for ships transiting the open waters of the Gulf of Mexico, entrance into the Gulf of

Mexico is through the Straits of Florida, south of the Florida Keys and Florida reefs. From there, a merchant vessel would cross the Gulf by the most direct, safest route to its destination port. A system of shipping safety fairways[6] and fairway anchorages has been established for the Gulf of Mexico and is shown on some, but not all, navigation charts. These fairways are near port entrances and along coastal trade routes, but do not extend across the Gulf of Mexico or into deeper coastal waters. The probability of whales encountering LNG vessels in the open ocean would be inherently low given their ability to avoid oncoming vessels coupled with their overall rarity.

West Indian manatees, like some of the whale species discussed above, generally do not occur within the project area, the MSC, and the nearby Gulf of Mexico, but individuals have been spotted intermittently and may occur in the area. West Indian manatees inhabiting coastal areas near the MSC and/or in the MSC could potentially be impacted by collisions with LNG vessels and LNG support vessels that are transiting to and from the terminal, general shipping operations or by an incident involving an LNG release from a vessel in transit.

In general ship traffic could affect marine mammal behavior; however, the identified species are generally accustomed to shipping traffic and would not be significantly impacted by normal shipping operations in the Gulf of Mexico or the MSC. LNG vessels strikes of marine mammals could result in injury and/or mortality. To reduce the risk associated with vessel strikes or disturbance of protected species, Calhoun Point Comfort would include the NOAA Fisheries *Vessel Strike Avoidance and Injured/Dead Protected Species Reporting Policy* (Vessel Strike Avoidance Policy) (see appendix F), to the extent practicable for large LNG vessels, as part of its Terminal Use Agreement with LNG Ship operators. NOAA Fisheries recently issued this policy to address vessels involved in the transport of LNG in the Gulf of Mexico. This policy includes recommendations for vessel strike avoidance such as using a Gulf of Mexico reference guide that includes and helps identify the 28 species of whales and dolphins, five species of sea turtles, and the single species of manatee that may be encountered in the Gulf of Mexico Outer Continental shelf; maintaining a vigilant watch for marine mammals and sea turtles and slowing down or stopping vessels to avoid striking protected species; maintaining a distance of 150 feet for sea turtles or small cetaceans and 300 feet for whales; maintaining a parallel direction to the animal's course and avoiding excessive speed or abrupt changes in direction when protected species are in the area; reducing vessel speeds to 10 knots or less when pods or large assemblages of cetaceans are observed near an underway vessel; and reducing speed and shifting engines to neutral when protected species are sighted in the vessel's path or near a moving vessel. In addition, the policy requires that crews report sightings of any injured or dead protected species immediately to the Mammal and Sea Turtle Stranding Hotline or the Marine Mammal Stranding Network. The use of these measures would reduce the chance of a marine mammal being struck by an LNG vessel.

In addition to these measures which were designed to avoid LNG vessel strikes, the FWS recommended that other measures be used to avoid and minimize impacts to West Indian manatees potentially occurring within the project area during construction and operation of the proposed Project. Therefore, based on consultation with the FWS, **we recommend that:**

[6] 33 CFR 166.105 defines a shipping safety fairway as "a lane or corridor in which no artificial island or fixed structure, whether temporary or permanent, will be permitted."

- **As part of its environmental training, to be described in its Implementation Plan for review and written approval by the Director of OEP, Calhoun Point Comfort should inform all construction and operation personnel that West Indian manatees may be present in the project area, and that personnel should not feed or water a manatee if encountered; and if encountered the environmental inspector should be informed immediately and the FWS contacted.**

Marine mammals could also be affected by an incident involving an LNG release from a vessel in transit to the proposed terminal. If a marine mammal was in the immediate vicinity of an LNG vessel at the time of an incident and resulting spill, severe injury or death could result from direct contact with LNG. If an LNG spill were accompanied by a pool fire, injury or mortality could occur to a marine mammal within Zones of Concern 1 or 2 if the animal were at the waters surface at the time. Because of the marine transit safety and security measures, the probability of an LNG spill from collisions, allisions, and terrorist attacks would be unlikely. Therefore, the probability of an LNG release, either with or without ignition, is extremely low. The probability that such an event would occur while in close proximity to a marine mammal is even lower.

Due to the characteristics and habitat preferences of the identified marine mammals, the known locations of common occurrences, the locations of major shipping routes into and through the Gulf of Mexico, the implementation of the measures included in the Vessel Strike Avoidance Policy as discussed above and our recommendations concerning threatened and endangered species, we have determined that the proposed Project is not likely to adversely affect protected marine mammals.

4.6.1.3 Marine Reptiles

Loggerhead Sea Turtle (*Caretta caretta*)

The loggerhead sea turtle is federally and state-listed as threatened. Loggerhead sea turtles inhabit continental shelves, bays, estuaries, and lagoons in temperate, subtropical, and tropical waters. Along the Atlantic Coast, their range extends from Newfoundland to as far south as Argentina. Their primary nesting sites are along the east coast of Florida with other sites located on the Gulf Coast of Florida, in Georgia, and along the Carolinas.

After hatching, loggerhead hatchlings move to the sea and commonly float on sargassum masses for three to five years. Subadults occupy near-shore and estuarine habitats, whereas adults occupy a variety of habitats that range from turbid bays to clear water. Loggerhead sea turtles feed on a variety of benthic and pelagic food. Loggerhead sea turtles nest on open, sandy beaches above the high tide mark and seaward of well-developed dunes. They prefer steeply sloped beaches with gradually sloped offshore approaches (NOAA, 2005b).

In Texas, loggerheads are considered to be the most abundant sea turtle, favoring shallow inner continental shelf waters. They may be present in Texas marine waters year-round; however, they are most noticeable during the spring when Portuguese-Man-of-War are abundant. The Texas General Land Office Environmental Sensitivity Index Atlas lists this species as occurring in the Gulf of Mexico but not within Matagorda Bay.

Suitable nesting habitat for this species is not available at the proposed project site or along the MSC.

Green Sea Turtle (*Chelonia mydas*)

The green sea turtle is federally and state-listed as threatened. Green sea turtles inhabit shallow habitats with an abundance of marine algae and seagrass such as lagoons, bays, inlets, shoals, and estuaries. They use coral reefs and rocky outcrops near feeding areas to rest, and they feed on marine plants, mollusks, sponges, crustaceans, and jellyfish. They tend to nest on their natal beach (NOAA, 2005b).

In Texas, small numbers of green sea turtles can been found in Matagorda Bay, Aransas Bay, and the lower Laguna Madre. Green sea turtle nests in Texas are rare (NOAA, 2005b). Suitable nesting habitat for this species is not available at the proposed project site or along the MSC.

Leatherback Sea Turtle (*Dermochelys coriacea*)

The leatherback sea turtle is federally and state-listed as endangered. Leatherback sea turtles spend most of their time in the open sea and come to land to nest. They may be found in coastal waters only when nesting or following jellyfish concentrations. They feed mainly on jellyfish and sea squirts as well as sea urchins, crustaceans, fish, and floating seaweed and prefer sandy beaches with a deepwater approach for nesting (NOAA, 2005b).

This species is rare along the Texas coast and no nest sites have been recorded in more than 60 years (NOAA, 2005b). Suitable nesting habitat for this species is not available at the proposed project site or along the MSC.

Hawksbill Sea Turtle (*Eretmochelys imbricata*)

The hawksbill sea turtle is federally and state-listed as endangered. This species inhabits coastal reefs, bays, rocky areas, estuaries, and lagoons at depths of 70 feet or less. Hawksbill sea turtle hatchlings may be found in the open sea floating on masses of marine plants while juveniles, subadults, and adults may be found near their primary foraging area along coral reefs. Hawksbill sea turtles are omnivorous; however, they prefer to feed on invertebrates such as sponges, mollusks, and sea urchins. Nesting occurs on undisturbed deep-sand beaches, from high-energy beaches to small pocket beaches bounded by crevices of cliff walls with woody vegetation near the waterline (NOAA, 2005b).

Representatives of at least some life history stages of the hawksbill regularly occur in the northern Gulf of Mexico. Post-hatchlings and juveniles are seen with some regularity in Texas particularly in areas primarily associated with stone jetties (NOAA, 2005b). Suitable nesting habitat for this species is not available at the proposed project site or along the MSC.

Kemp's Ridley Sea Turtle (*Lepidochelys kempii*)

The Kemp's ridley sea turtle is federally and state-listed as endangered. The Kemp's ridley sea turtle inhabits shallow coastal and estuarine waters over sand or mud bottoms. Juveniles feed on sargassum while adults are largely shallow-water benthic feeders. Food items include shrimp, snails, bivalves, jellyfish, and marine plants (NOAA, 2005b).

Juvenile Kemp's ridley sea turtle may range throughout the Atlantic Ocean, while adults are restricted to the Gulf of Mexico. The majority of this species nests along an 11-mile-long stretch of coastline near Rancho Nuevo, Tamaulipas, Mexico, about 190 miles south of the Rio Grande

and 380 miles south of the project area, and a secondary nesting area occurs at Tuxpan, Vera Cruz about 500 miles south of the project area. Sporadic reports of nesting areas from Mustang Island, Texas south to Isla Aquada, Campeche have been documented as well. This species occurs in Texas in small numbers. It may be transient between crustacean-rich feeding areas in the northern Gulf of Mexico and breeding grounds in Mexico (NOAA, 2005b). The Texas General Land Office Environmental Sensitivity Index Atlas also lists this species as occurring within Matagorda Bay.

Suitable nesting areas for this species are not found at the proposed project site or along the MSC.

Sea Turtle Impacts and Mitigation

Due to specific nesting habitat requirements, sea turtles are not likely to be present onshore within the project area or along the shoreline adjacent to the MSC. In general, sea turtles would be a rare visitor to the project area. Many of the sea turtles discussed have feeding, swimming, or resting behaviors that keep them near the surface, where they may be vulnerable to LNG vessel strikes.

As described previously, to help reduce vessel strikes and shipping disturbances to protected species, Calhoun Point Comfort has agreed to include the NOAA Fisheries Vessel Strike Avoidance Policy as part of its Terminal Use Agreement with LNG Ship operators. NOAA Fisheries indicated that with this policy implemented, vessel traffic associated with operation of the proposed Project in not likely to adversely affect listed species.

Dredging activities could temporarily disrupt potential foraging grounds supporting federally listed sea turtles. The CCND proposes to dredge the marine basin and berth area using a hydraulic cutterhead dredge. Hydraulic cutterhead dredging is not known to take sea turtles by direct mortality, as with hopper dredging. Dredging activities during construction would be temporary and local in nature because dredging would be confined to CCND's proposed new turning basin and Calhoun Point Comfort's ship berth and maintenance dredging would only occur about once every two years. Dredging actions could potentially result in injury to any sea turtles directly in the area at the time of dredging. However, sea turtle occurrences in the project area would be incidental. Activities at dredge spoil placement areas would similarly not affect sea turtles since suitable nesting areas are not present in the placement areas.

NOAA Fisheries identified pile driving as having the potential to affect sea turtles. Studies have shown that the sound waves from pile driving may result in injury or trauma to fish, sea turtles, or other animals with gas-filled cavities, such as swim bladders, lungs, sinuses, and hearing structures (Abbott and Sawyer, 2002). Although sea turtles would be expected to largely avoid the dredged area during pile driving activities, a potential exists for sea turtles to be injured during the first several strikes of the pile driving hammer. While the CCND has not identified what type of pile driving it would use to install the piles, impact pile driving may be used for some part of pile driving activities. Use of impact pile driving would result in greater acoustic impact on the surrounding aquatic environment than vibratory pile driving. Pile driving activities at the berth area and the dredge disposal area are anticipated to last 180 and 120 days, respectively. To avoid the possibility of harm to sea turtles, as well as marine mammals, CCND on behalf of Calhoun Point Comfort is continuing to consult with NOAA Fisheries, TPWD, and

FWS to identify any additional mitigation measures that have been successfully used to minimize the impact on marine organisms from pile driving activities.

Sea turtles could also be affected by an incident involving an LNG release from a vessel in transit to the proposed terminal. If a sea turtle was in the immediate vicinity of an LNG vessel at the time of an incident and resulting spill, severe injury or death could result from direct contact with LNG. If an LNG spill were accompanied by a pool fire, injury or mortality could occur to a sea turtle within Zones of Concern 1 or 2 if the animal were at the waters surface at the time. Because of the marine transit safety and security measures, the probability of an LNG spill from collisions, allisions, and terrorist attacks would be unlikely. Therefore, the probability of an LNG release, either with or without ignition, is extremely low. The probability that such an event would occur while in close proximity to a sea turtle is even lower.

Due to the characteristics and habitat preferences of the identified sea turtles, the known locations of common occurrences, the locations of major shipping routes into and through the Gulf of Mexico, and the implementation of the measures included in the Vessel Strike Avoidance Policy as discussed above, we have determined that the proposed Project is not likely to adversely affect protected sea turtles.

4.6.2 State-Listed Threatened or Endangered Species

The TPWD annotated county lists of rare species for Calhoun and Jackson Counties include 13 state-listed endangered or threatened species, in addition to those species that are also federally listed and discussed above. Based on our review of these species, we believe that five of these species would not be affected by the proposed Project because the project area is not within the current known range of the species, or because the species would occur in the project area only as an occasional transient. These species are listed in table 4.6.2-1 and are not discussed further in this EIS.

TABLE 4.6.2-1

State-Listed Endangered and Threatened Species Eliminated From Further Consideration for the Calhoun LNG Project

Species	Status a/	Reason for Elimination from Further Consideration b/
Mammals		
Black Bear (*Ursus americanus*)	F – T/SA TX – T	Suitable habitat not present in project area.
Southern Yellow Bat (*Lasiurus ega*)	TX – E	Project is within historic range of this species, but not within current range.
Birds		
Arctic Peregrin Falcon (*Falco peregrinus tundrius*)	TX – T	Occurs in project area only as occasional transient.
Sooty Tern (*Sternafuscata*)	TX – T	Pelagic species that forages off shore. Breed in colonies on coral clays, atolls, rock stacks, cliffs, or sandbanks.
Fish		
Opossum Pipefish (*Microphis brachyurus*)	TX – T	Project is within possible historic range of species, but outside of known current range.

a/ Status: F = Federal, TX = Texas, E = Endangered, T = Threatened.
b/ Calhoun Point Comfort conducted habitat surveys during December 2004 and February, and April 2005.

The remaining eight state-listed species could potentially occur in the vicinity of the proposed Project. These species are listed in table 4.6.2-2 and discussed in the following sections.

TABLE 4.6.2-2

State-Listed Threatened Species Potentially Affected by the Calhoun LNG Project

Species	State Status a/
Birds	
Reddish Egret (*Egretta rufescens*)	T
White-faced Ibis (*Plegadis chihi*)	T
Wood Stork (*Mycteria americana*)	T
White-tailed Hawk (*Buteo albicaudatus*)	T
Reptiles	
Texas Horned Lizard (*Phrynosoma cornutum*)	T
Texas Scarlet Snake (*Cemophota coccinea lineri*)	T
Timber /Canebreak Rattlesnake (*Croatalus horridus*)	T
Texas Tortoise (*Gopherus berlandieri*)	T

a/ Status: T = Threatened.

Reddish Egret (*Egretta rufescens*)

The reddish egret can be found in brackish marshes, shallow salt ponds, and tidal flats along the Texas Gulf Coast. The reddish egret nests mostly on the ground or on oyster shell beaches (TPWD, 2005a). In the project area, the reddish egret could potentially occur as a visitor in the shallow waters immediately adjacent to the proposed LNG terminal site, but would not be expected to occur along the proposed pipeline. The reddish egret has been recorded at Texas Waterbird Colony No. 609-121, a dredged material disposal area that includes Snake Island about 0.3 mile south of the LNG terminal site and about 650 feet from the MSC that would be used by LNG marine traffic. The number of individuals recorded at this colony has declined greatly since 1973 (QuickBase, 2005). The reddish egret is also known to nest on Sundown Island, which is about 1,000 feet from the MSC, about 20 miles south of the LNG terminal site. The proposed Project could potentially impact nesting reddish egrets as a result of noise and possible shoreline erosion caused by normal LNG vessel traffic using the MSC. Although extremely remote, the project could also potentially affect this species in the event of an LNG release. See detailed discussion of these potential impacts in section 4.5.1.1 of this EIS.

White-faced Ibis (*Plegadis chihi*)

The white-faced ibis breeds and winters along the Texas Gulf Coast. It is most commonly found in freshwater marshes, ponds, and rivers. Nesting is colonial on floating mats of dead plants, or in trees. The species could potentially occur within wetland areas on or near the proposed LNG terminal site or the proposed pipeline right-of-way. During 1983, few white-faced ibis were recorded at Texas Waterbird Colony No. 609-120, on Dredge Island between 0.4 and 1.4 miles west and northwest of the LNG terminal site. Larger numbers have been recorded at Texas Waterbird Colony No. 609-121, which includes Snake Island located about 650 feet from the MSC, and with greater consistency since 1973 (QuickBase, 2005). The white-faced ibis is also

known to nest on Sundown Island, which is about 1,000 feet from the MSC, about 20 miles south of the proposed LNG terminal site. The proposed Project could potentially impact nesting white-faced ibis as a result of noise and possible shoreline erosion caused by normal LNG vessel traffic using the MSC. Although extremely remote, the project could also potentially affect this species in the event of an LNG release. See detailed discussion of these potential impacts in section 4.5.1.1 of this EIS.

Wood Stork (*Mycteria americana*)

The wood stork occurs in Texas during the non-breeding season, where it is found in freshwater and brackish marshes, narrow tidal creeks, or flooded tidal pools. The wood stork formerly bred in Texas but breeding in the United States is currently restricted to Florida, Georgia, and South Carolina (FWS, 1996). The species could potentially occur within wetland areas on or near the proposed LNG terminal site or the proposed pipeline right-of-way. The proposed Project could potentially impact the wood stork while feeding in marshes and tidal pools as a result of noise and possible shoreline erosion caused by normal LNG vessel traffic using the MSC. Although extremely remote, the project could also potentially affect this species in the event of an LNG release. See detailed discussion of these potential impacts in section 4.5.1.1 of this EIS.

White-Tailed Hawk (*Buteo albicaudatus)*

In southern and central counties of Texas, and north towards Galveston, white-tailed hawk inhabit coastal grasslands. They prefer saltgrass flats near the Gulf of Mexico and dry grassy mesquite-live oak savannahs inland (USGS, 2004). They perch on bushes, dead trees, fence posts, and utility structures and prey on small mammals, lizards, and insects. Their breeding season is from March to May, and their nest consists of grass-lined sticks in low bushes or small trees or cactus (National Wildlife Federation, 2004b). This species is a possible visitor to the project area. Calhoun Point Comfort would conduct surveys for white-tailed hawk during the breeding and nesting season and consult with TPWD to develop mitigation measures should this species be breeding and nesting within proposed construction work areas.

Texas Horned Lizard (*Phrynosoma cornutum*)

The Texas horned lizard ranges from the south-central United States to northern Mexico. This species historically occurred throughout Texas in arid and semiarid habitats with flat, open terrain, scattered vegetation, and sandy or loamy soils (TPWD, 2004). Suitable habitat for this species was not identified during Calhoun Point Comfort's habitat surveys of the proposed Project.

Texas Scarlet Snake *(Cemophota coccinea lineri)*

The Texas scarlet snake occurs in extreme eastern and south Texas. It prefers hardwood, mixed, or pine forest and adjacent open areas with loose, sandy soils that support thickets of live oaks, honey mesquite, huisache and prickly pear, and watermelon patches (National Wildlife Federation, 2004c). Based on habitat surveys and soil data, suitable habitat for this species would not be crossed by the proposed pipeline. A portion of the LNG terminal site contains potential habitat for this species.

Timber/Canebreak Rattlesnake (*Croatalus horridus*)

The timber/canebreak rattlesnake occurs in the eastern third of Texas. Preferred habitat includes moist lowland forests or upland woods and rocky ridges, near permanent water sources. The snake is active during the day during spring and fall, but becomes nocturnal during the heat of the summer. The timber/canebreak rattlesnake could potentially occur where suitable habitat occurs along the proposed pipeline.

Texas Tortoise *(Gopherus berlandieri)*

The Texas tortoise is found from south Texas into Mexico and inhabits scrub woodlands with sandy soils and chaparral and mesquite habitats. To protect itself from the midday sun, Texas tortoise will modify existing animal burrows or create a vegetative cover by scraping at the base of vegetation. This species nests from April to September and lays its eggs deep under overhanging bushes (National Wildlife Federation, 2004d). Based on general habitat surveys conducted by Calhoun Point Comfort, portions of the pipeline route and LNG terminal site contain potentially suitable habitat for this species.

4.6.3 Conclusions and Recommendations for Threatened, Endangered, and Other Special Status Species

A variety of measures have been proposed by Calhoun Point Comfort to avoid and minimize impacts to federally and state-listed species. Collectively, these measures would reduce the loss of vegetated habitats, minimize marine sediment disturbance and resulting water quality impacts, and minimize delay in restoration of areas temporarily disturbed during construction, such as along the pipeline route. While beneficial to general wildlife, fisheries, and vegetation in the area, these measures would also benefit listed species with the potential to occur in the project vicinity. In addition, Calhoun Point Comfort would employ a wildlife biologist to monitor the construction work areas for state protected reptiles and consult with the TPWD to develop mitigation measures should such species be discovered in the construction work areas of the Project. Construction crews would undergo environmental awareness training for protected species before construction and field activities are initiated.

Nesting and feeding shorebirds along the MSC could potentially be impacted by noise and shoreline erosion caused by LNG vessel traffic calling on the LNG terminal. Shorebirds using areas adjacent to the MSC would be accustomed to noise from passing deep draft ships within the MSC, and noise from LNG vessel traffic in the MSC would be consistent with noise from ongoing vessel traffic. This noise level would occur four to six times per week (two or three vessels per week, inbound and outbound). This area currently experiences similar noise from ongoing deep draft vessels calling at Port of Port Lavaca–Point Comfort and Alcoa multiple times per week. Studies of existing wave energy from current ship traffic in the MSC, as well as predicted wave energy from future LNG vessels, indicate that an LNG vessel passing through the MSC would not significantly affect shoreline erosion along the MSC (see also section 4.2.3 of this EIS). We believe that during normal operations, LNG vessels using the MSC would not significantly affect nesting or feeding shorebirds.

There is also a very remote chance of impact on nesting and feeding shorebirds resulting from an LNG spill. However, because of the marine transit safety and security measures, the probability of an LNG spill from collisions, allisions, and terrorist attacks would be unlikely. Therefore, the probability of an LNG release, either with or without ignition, is extremely low, and the potential for such a release at a location along the MSC that would impact nesting bird colonies is not significant.

Except for areas underlying permanent aboveground facilities, all areas disturbed by construction would be returned to pre-construction conditions, which would restore habitat value of these temporarily disturbed areas. Habitat at sites of permanent aboveground facilities would be converted to industrial use. Implementation of the mitigation measures proposed to protect wildlife, aquatic resources, and habitat as described in section 4.5 of this EIS would be sufficient to prevent significant adverse effects on threatened and endangered species. Therefore, we believe that the Project would have no effect or would not be likely to adversely affect or would not significantly impact any federally or state-listed threatened or endangered species.

4.7 LAND USE, RECREATION, AND VISUAL RESOURCES

As described previously, the proposed Project would be located in Calhoun and Jackson Counties, Texas. The proposed LNG terminal would be located on a 73-acre site that is within an 89-acre site owned by the Port of Port Lavaca–Point Comfort in Calhoun County, Texas. The site is bounded by Lavaca Bay to the west, Cox Bay to the south and east, and industrial facilities owned by Alcoa and Formosa Plastics Corporation to the north (see figure 2.1-1 in section 2.0 of this EIS). The proposed LNG terminal would be on the southeastern shoreline of Lavaca Bay about 3.2 miles south of the City of Point Comfort and 4.4 miles northeast of the City of Port Lavaca. During operation, LNG vessels would reach the terminal by traversing about 22 miles of the existing MSC.

Calhoun Point Comfort proposes to construct a 36-inch-diameter natural gas sendout pipeline to connect the LNG terminal to existing customers as well as existing intrastate and interstate natural gas pipelines. The proposed pipeline would extend from a pig launcher site within the CCND's Port facilities, adjacent to the LNG terminal site and run in a northwesterly direction to its end point southwest of Edna, Texas. About 25.2 miles of the sendout pipeline route (93 percent) would be immediately adjacent to existing rights-of-way while the Formosa Lateral would be immediately adjacent to existing rights-of-way for 0.2 mile (80 percent) and the Transco Lateral would be immediately adjacent to existing rights-of-way for its entire length (see table 2.3.2.1-2 in section 2.0 of this EIS).

4.7.1 Land Use

Most of the land affected by the construction and operation of the proposed Project would be manmade, industrial land at the LNG terminal and open land, including agricultural and range land along the Point Comfort Pipeline and laterals. Other land uses affected along the pipeline and laterals would include industrial, residential, and forest lands. Construction would affect a total of 489.6 acres of land: 73 acres of land for the LNG terminal, 344.8 acres for the pipelines, 3.5 acres for the aboveground facilities, 6.4 acres for access roads, 40.1 acres for additional temporary workspace, and 21.8 acres for a contractor pipe yard. Operation of the proposed

Project would affect about 178.8 acres of land, of which 73.0 acres would be permanently converted for operation of the LNG terminal and 8.9 acres would be permanently converted for operation of the aboveground facilities (3.5 acres) or from forest to nonforest (5.4 acres). Table 4.7.1-1 summarizes the acres of each land use category that would be directly affected by construction and operation of the proposed Project. A variety of land uses occur along the shoreline adjacent to the marine transit route for LNG vessels, the majority of which are over one mile from the shipping channel.

Waterway for LNG Marine Traffic

The waterway for LNG marine traffic would traverse open water along the existing MSC. Uses of the waterway itself include commercial shipping, commercial and recreational fishing, shell fishing, and recreational boating. Zones of Concern along the waterway would encompass primarily open water within Matagorda and Port Lavaca Bays, but also some shoreline habitats, primarily along the western shoreline of Matagorda Bay. Zones of Concern are described in section 2.1.2 of this EIS and shown on figure 2.1-7. The zones would move with the LNG vessel as it transits the MSC. Land areas within Zone 1 are limited to the shorelines adjacent to the channel through Matagorda Peninsula at the entrance to the bay, a small portion of Sundown (or Bird) Island just north of the bay entrance, Snake Island near the intersection of the MSC and the Port Lavaca Channel, and shoreline areas immediately surrounding the proposed LNG berth at the terminal site. Land use within Zone 1 is undeveloped, with the exception of the Port of Point Comfort to the north of the LNG terminal berth.

Land within Zone 2 includes a larger area of those locations included in Zone 1, plus small portions of mainland on the western shoreline of Matagorda Bay at Indian Point/Magnolia Beach and Gallinipper Point. Land use within Zone 2 is also primarily undeveloped shoreline habitats, with the exception of some residential areas at Gallinipper Point and Magnolia Beach.

Land within Zone 3 also includes a larger area of those locations included in Zone 1, the western shoreline of Matagorda Bay from Port O'Connor to Alamo Beach, and Sand Point on the eastern shoreline opposite Indian Point. The northern extent of Zone 3 around the LNG berth would encompass portions of Point Comfort including the Route 35 Bridge. Zone 3 would encompass a variety of land uses, including undeveloped shoreline habitats, and commercial, residential, and industrial developments.

During normal operation, about 120 LNG vessels per year, or two to three per week, would call on the LNG terminal, each traversing the existing MSC. For the majority of the waterway, the LNG vessels would be over 1.0 mile from shore, and would have minimal impact on land use of the adjacent shorelines. At two locations near Magnolia Beach, the waterway is about 0.5 mile from the shoreline. However, the presence of LNG vessels along the existing waterway would generally be consistent with existing large ship traffic using the waterway, and would not be a significant impact on land use adjacent to the waterway. Normal operations of LNG vessel traffic would not significantly impact land uses along the waterway for LNG marine traffic. Potential impact on other vessel traffic and water-based users of the waterway are discussed in section 4.12.5 of this EIS.

TABLE 4.7.1-1

Acres of Land Affected by Construction and Operation of the Proposed Project

Facility	Agricultural/Range Land		Forest		Industrial/Residential		Total	
	Construction	Operation	Construction	Operation	Construction	Operation	Construction	Operation
LNG Terminal a/	-	-	-	-	73.0	73.0	73.0	73.0
Point Comfort Pipeline and Laterals b/	295.7 c/	87.3 c/	23.5	5.4	25.6 d/	6.7	344.8	99.4
Aboveground Facilities								
Pig Launcher and MLV	-	-	-	-	0.3	0.3	0.3	0.3
Formosa Hydrocarbons Interconnect	0.3	0.3	-	-	-	-	0.3	0.3
Formosa Plastics Interconnect	0.3	0.3	-	-	-	-	0.3	0.3
Channel/HPL Interconnect	0.4	0.4	-	-	-	-	0.4	0.4
FGT Interconnect	0.3	0.3	-	-	-	-	0.3	0.3
KM-Tejas Interconnect	-	-	-	-	0.2	0.2	0.2	0.2
Valero Interconnect and MLV	0.3	0.3	-	-	-	-	0.3	0.3
Gulf South/KM Texas Interconnect	0.5	0.5	-	-	-	-	0.5	0.5
NGPL Interconnect	0.3	0.3	-	-	-	-	0.3	0.3
Transco Interconnect	0.3	0.3	-	-	-	-	0.3	0.3
Tennessee Interconnect, Pig Receiver, and MLV	0.3	0.3	-	-	-	-	0.3	0.3
Subtotal Aboveground Facilities	**3.0**	**3.0**			**0.5**	**0.5**	**3.5**	**3.5**
Access Roads	6.2	2.7	-	-	0.2	0.2	6.4	2.9
Additional Temporary Workspace	33.7	-	3.9	-	2.5	-	40.1	-
Contractor Pipe Yard	-	-	-	-	21.8	-	21.8	-
Project Total	**338.6**	**93.0**	**27.4**	**5.4**	**123.6**	**80.4**	**489.6**	**178.8**

a/ The LNG terminal would be entirely on manmade industrial land.
b/ Includes nominal 100- and 75-foot-wide construction right-of-way for the main pipeline and laterals, respectively and a 30-foot- and 25-foot-wide operational right-of-way.
c/ Of this amount, 19.0 acres would be agricultural land and 276.7 acres would be range land.
d/ Of this amount, 22.8 acres would be industrial land and 2.8 acres would be residential land.

While the likelihood of an emergency leading to a marine LNG spill is very low, potential hazards resulting from an ignited or unignited LNG release are considered in this EIS (as detailed in sections 4.12.1 and 4.12.5.3). Due to its physical properties, released LNG would quickly disperse in the atmosphere or, if ignited, burn in a pool of fire. A significant unignited LNG release and dispersion would be a short-lived event that would have no impact on land use along the waterway. Impacts from a significant release of LNG with ignition would depend on the location of the incident within the waterway and the scope of the incident. In general, damage to man-made structures and vegetation would range from mild to severe with the greatest impacts occurring within Zone 1 and decreasing outward through Zones 2 and 3. However, because of the marine transit safety and security measures that would be in place (see section 4.12.5 of this EIS), the probability of an LNG vessel spill from collisions, allisions and terrorist attacks would be unlikely, and the probability of an LNG release, either with or without ignition, is extremely low. Therefore, although there is a potential that significant impacts could occur to land uses along the waterway for LNG marine traffic, the likelihood is extremely remote.

LNG Terminal

Existing land uses at the proposed LNG terminal site include a mixture of open water and industrial land that was created by the placement of dredged material from Lavaca and Cox Bays. In addition to the 73.0 acres of land required for construction and operation of the LNG terminal, construction of the new turning basin and ship berth would require the dredging of a 49-acre area owned by the CCND in Lavaca Bay. Of this amount, 35.8 acres would be required for the construction and operation of the turning basin and 13.2 acres would be required for the ship berth.

All land within 0.25 mile of the proposed LNG terminal site is used for industrial purposes. Industries in the area include the Alcoa PCO, Formosa Plastics Corporation, Formosa Hydrocarbons Company, and Port facilities for handling general cargo, dry bulk, and bulk liquid cargoes. Land access to the LNG terminal site would be by way of FM 1593 and the existing access road for CCND's Port facilities.

Construction and operation of the LNG terminal would have minimal impacts on land use since the site is open, manmade land which is zoned industrial and is associated with the CCND's Port facilities. The open water in Lavaca Bay would be dredged for the turning basin and berth. About 2.0 mcy would be dredged for the turning basin and 0.7 mcy would be dredged for ship berth. These areas would remain open water after the construction. The construction of the turning basin and ship berth would not affect coastal marsh or aquatic vegetation (see section 4.4.1 of this EIS). The only difference in land use after construction of the terminal would be that the 73.0-acre site would no longer be open and a dock would project into Lavaca Bay, along the southeast side of the MSC.

During construction of its LNG terminal, Calhoun Point Comfort would temporarily use one construction yard located at MP 1.6 of the Point Comfort Pipeline. This tract is located about 0.5 mile west of FM 1593 along the west side of Fannin Road and would be used temporarily during construction of the Project. After construction, all excess construction materials would be removed and the site returned to its previous condition. No significant impacts are expected from the use of this site.

In addition, the CCND identified DMPAs within Lavaca Bay (between 1 and 2 miles of the LNG terminal site) where it proposes to dispose of, and permanently store, dredged material.

Pipeline

Existing land uses along the pipeline and laterals right-of-way consist primarily of open land (i.e., agricultural and range land) with some industrial, residential, and forest land. Calhoun Point Comfort proposes to use a 100-foot-wide construction right-of-way in upland areas. The construction rights-of-way would comprise about 328.4 acres for the Point Comfort Pipeline and about 16.4 acres for both the Formosa and Transco Laterals, respectively, for a total of 344.8 acres. Following construction, a 30- and 25-foot-wide permanent right-of-way would be maintained for operation of the respective pipeline and laterals (approximately 97.7 acres for the pipeline, 0.8 for the Formosa Lateral, and 0.9 acres for the Transco Lateral).

Construction of the pipeline would affect a total of about 384.9 acres of land, including the pipeline construction right-of-way and additional temporary extra workspaces (see table 4.7.1-1). Construction of the ten proposed interconnect/delivery points, pig launcher and MLV at MP 0.0, and pig receiver and MLV at MP 27.1, would affect about 3.0 acres of agricultural and range land, and 0.5 acre of industrial land. Calhoun Point Comfort would use 26 access roads related to its proposed pipeline facilities. Of these, 20 are existing roads and six roads would be newly constructed (see table 2.3.2.3-1). Improvement activities including the placement of additional gravel and grading would take place within the existing road footprint, which consist of about 6.2 acres of agricultural and range land and 0.2 acre industrial land.

During construction, Calhoun Point Comfort would use one pipe storage and contractor warehouse yard, a 21.8-acre tract of industrial land at MP 1.6. This is the same site that would be used as a construction yard during the construction of the terminal. No additional impacts would result in the site's use during pipeline construction.

About 19.0 acres of agricultural and 279.7 acres of range land would be the primary land use affected by construction of the pipeline, laterals, and associated aboveground facilities (combined total of 298.7 acres, 85.7 percent). The remaining land uses that would be affected consist of forest lands (23.5 acres, 6.7 percent), and industrial (23.1 acres) and residential (3.0 acres) lands (combined total of 26.1 acres, 7.6 percent).

Typical crops grown in the project area include cotton, corn sorghum, soybeans, rice, and wheat (USDA, 2005). No special crops or orchards were identified along the pipeline route that would require unique construction techniques.

<u>Pipeline Land Use Impacts and Mitigation</u>

Land use impacts associated with the proposed pipeline and laterals would include disturbance of existing land uses within construction work areas along the rights-of-way during construction and creation of new permanent rights-of-way for operation and maintenance of the facilities. There would be a short-term disruption to agricultural land. Calhoun Point Comfort would incorporate the measures included in our Plan, as well as landowner requests, to minimize impacts on agricultural land. Landowners would be compensated for loss of agricultural production in terms agreed upon with the landowners.

About 99.4 acres of land would become part of the permanent right-of-way for Point Comfort's pipeline, the Formosa and Transco Laterals, and related facilities (see table 4.7.1-1). About 3.0 acres of range land and 0.2 acre of residential land would be permanently converted to industrial use for the operation of the meter stations and MLVs. We do not consider this to be a significant impact because the surrounding land remains agricultural. About 416.6 acres of land would be temporarily affected during construction of the pipeline and related facilities. However, after construction, these lands would be restored to their previous condition and use. In the case of agricultural lands, outside aboveground facilities, crops could be planted over both the permanent pipeline right-of-way and the temporary workspace.

About 25.2 miles of the pipeline route (93 percent) would be immediately adjacent to existing rights-of-way. The Formosa Lateral would be immediately adjacent to existing rights-of-way for 0.2 mile (80 percent) and the Transco Lateral would be immediately adjacent to existing rights-of-way for its entire length (see table 2.3.2.1-2 in section 2.0 of this EIS). Following construction, a 30-foot- and 25-foot-wide right-of-way would be maintained adjacent to the existing rights-of-way to operate and maintain the new pipeline and laterals, respectively. Overlap of the proposed right-of-way with existing rights-of-way would occur between MP 1.6 and 2.2 and affect 0.5 acre. No other overlap is anticipated.

Calhoun Point Comfort would construct and maintain the pipeline in accordance with measures contained in our Plan and Procedures. In accordance with our Plan, Calhoun Point Comfort would locate irrigation systems and develop procedures for constructing through irrigated areas, maintaining irrigation systems during construction, and repairing irrigation systems after construction. Our Plan also addresses pre-construction planning, construction, restoration, and right-of-way vegetation maintenance for upland areas, including agricultural lands. Our Plan is discussed in more detail in section 4.2 of this EIS. Our Procedures address pre-construction planning, construction, restoration, and vegetation maintenance for wetlands and waterbodies. Our Procedures are discussed in more detail in sections 4.3 and 4.4.1 of this EIS.

Pipeline Easements

Calhoun Point Comfort would obtain an easement from the landowner in order to construct the pipeline. An easement would be used to convey both temporary (for construction) and permanent rights-of-way to Calhoun Point Comfort. The easement would give Calhoun Point Comfort the right to construct, operate, and maintain the pipeline, and establish a permanent right-of-way. In return, Calhoun Point Comfort would compensate the landowner for use of the land. The easement agreement between the company and the landowner typically specifies compensation for the loss of use during construction, loss of nonrenewable or other resources, and allowable uses and restrictions on the permanent right-of-way after construction. These restrictions can include prohibition of construction of aboveground structures, including house additions, garages, patios, pools, or any other object not easily removable; roads or driveways over the pipeline; or the planting and cultivating of trees or orchards within the permanent easement. The areas used as temporary construction right-of-way and temporary extra workspace would be allowed to revert to pre-construction uses with no restrictions.

The acquisition of an easement is a negotiable process that would be carried out between Calhoun Point Comfort and individual landowners. If the necessary land cannot be obtained through good faith negotiations with property owners and the Project has been certificated by the

Commission, Calhoun Point Comfort may use the right of eminent domain granted under Section 7(h) of the NGA and the Federal Rules of Civil Procedure (Rule 71A) to obtain easements. Calhoun Point Comfort would still be required to compensate the landowner for the right-of-way and damages incurred during construction; however, the level of compensation would be determined by a court according to state or federal law.

4.7.2 Residences and Structures

Waterway for LNG Marine Traffic

No residences are within the Zone of Concern 1 along the proposed LNG waterway. About 40 residences are within the outer limits of Zone 2 at Indian Point and Magnolia Beach, and about 25 residences are within the outer limits of Zone 2 in Alamo Beach at Galliniper Point. Zone 3 would encompass a number of residential areas along the western shoreline of Matagorda Bay within the towns of Port O'Connor, Indianola, Magnolia Beach, and Alamo Beach. Potential impact on residences within Zones of Concern 2 and 3 are discussed above in section 4.7.1.

LNG Terminal

No existing residences or structures are within one mile of the proposed LNG terminal. The nearest existing residential areas to the proposed LNG terminal are about 2.5 miles north of the terminal within the City of Point Comfort and 3.0 miles west within the community of Port Lavaca. The Lavaca Bay Place housing development and Clement Cove Townhouses are west of Port Lavaca near State Route 238 and about 6.0 miles west of the LNG terminal. Both of these residential areas are continuing to be developed. The nearest schools are the Point Comfort Elementary School and Our Little Munchkin Daycare located about 2.5 miles north of the proposed LNG terminal site, and the nearest hospital is the Memorial Medical Center in Port Lavaca, about 4.0 miles west of the LNG terminal site.

Potential impact on these residences as a result of construction and operation of the proposed LNG terminal could include temporary construction-related impacts, and long-term impacts associated with operation. Temporary construction impacts could include inconvenience caused by noise and dust generated by construction equipment. The primary potential impact from noise would include noise generated during pile driving for installation of the LNG ship berth. Potential impact of noise from pile driving would be minimal for those residences located over one mile from the construction site. Additional discussion of noise impacts is included in section 4.11.2 of this EIS.

Calhoun Point Comfort would prepare and implement a dust control plan that would include measures to be implemented during construction to prevent fugitive dust emissions. Given the distance between proposed construction activity and the nearest residences and Calhoun Point Comfort's proposed dust control measures, we believe impact on residences from dust generated during construction would not be significant.

During operation of the proposed LNG terminal, the primary impact to those residences discussed above would be visual. The LNG storage tanks would be about 133 feet tall and would be visible from points east, northwest, west, and south of the terminal site. While the proposed tanks would be visible, they would be viewed against the existing backdrop of the Port

of Port Lavaca–Point Comfort and nearby industries and visual impact would be minimal. See section 4.7.4 for further information on visual resources.

Pipeline

One residence and 15 other structures, including industry buildings, tanks, and a communication tower, would be located within 50 feet of the Point Comfort Pipeline and Formosa Lateral work areas (see table 4.7.2-1). In addition to the structures shown in the table below, eight residences would be within the construction right-of-way between MP 2.5 and MP 2.6. There are no structures or buildings within 50 feet of the Transco Lateral.

TABLE 4.7.2-1

Structures Within 50 Feet of the Proposed Work Areas for the Point Comfort Pipeline and Formosa Lateral

Milepost	Structure	Distance from Construction Work Area (feet)
Point Comfort Pipeline		
0.03	Building (CCND)	22
0.03	Tank (CCND)	Within a/
0.07	Abandoned Meter Run (CCND)	44
0.10	Guard Building (CCND)	Within b/
0.15	Building (CCND)	38
1.49	Building (Formosa Hydrocarbons Company)	50
1.54	Bullet Tank (Formosa Hydrocarbons Company)	35
1.56	Communications Tower (Formosa Hydrocarbons Company)	21
5.58	Air Sampling Equipment (Formosa Plastics Corporation)	Within b/
13.22	Residence	25
13.56	Storage Shed	c/
24.52	Enterprise Production Facility	0
24.73	Enterprise Production Facility	2
26.55	Barn	40
Formosa Lateral		
0.22	Building (Formosa Hydrocarbons Company)	10

a/ Tank is no longer in use and would be removed before construction begins.
b/ Temporary fencing would be installed around these structures to avoid disruption during construction.
c/ Impacts would be avoided due to the HDD method that would be used in this area.

Sea Lake, a defunct development planned in the 1980s, is near MP 4.2 of the Point Comfort Pipeline. This development was abandoned and the land has since been sold to Formosa Plastics Corporation.

In residential areas, the two most significant impacts associated with construction and operation of a natural gas pipeline are disturbance during construction and encumbrance of property for future uses (e.g., the limitation on future permanent structures within the permanent pipeline right-of-way). In our analysis, we consider residences within 50 feet of construction work areas as the most likely to experience the effects of pipeline construction. Temporary construction impacts on residential areas could include inconvenience caused by noise and dust generated by

construction equipment; trenching through roads or driveways; ground disturbance of lawns; removal of landscaping or natural vegetative screening; potential damage to existing septic systems or wells; and removal of aboveground structures, such as sheds or trailers, from within the right-of-way.

To minimize construction noise, Calhoun Point Comfort would construct the proposed Point Comfort Pipeline and laterals during daylight hours and it would implement its dust control plan to minimize potential impact on residences from dust generated during pipeline construction. At MP 13.2, Calhoun Point Comfort would reduce the size of its temporary workspace and be on the south side of an existing tree line, thereby minimizing impacts on the residences near this location. To minimize impacts on the barn at MP 26.5, Calhoun Point Comfort would maintain a 40-foot clearance between the closest corner of the barn and the construction work area.

Calhoun Point Comfort would use the HDD method to cross the area between MP 2.5 and MP 2.6, thereby minimizing impacts on the eight residences within the construction right-of-way. Residences would be notified of HDD activities 48 to 72 hours prior to the start of drilling. Calhoun Point Comfort submitted a draft project-specific HDD Frac-Out Monitoring and Response Plan that addresses how potential frac-outs would be minimized, procedures for detecting a frac-out, measures to be implemented should a frac-out occur, remediation of an affected area, and reporting and notification (see section 4.3.2 of this EIS). To further minimize impacts from a potential frac-out, we have recommended that additional measures be included in this plan.

4.7.3 Recreation and Special Interest Areas

Waterway for LNG Marine Traffic

Recreational fishing occurs in the greater Matagorda Bay system and nearby lakes and rivers. Several public boat ramps and fishing piers occur between 2.1 and 6.1 miles of the LNG terminal site. There is a public boat ramp at Magnolia Beach within Zone 2 of the waterway for marine traffic, and two state parks and a marina are within Zone 3 between Port O'Connor and Indianola.

During the past 30 years, TPWD estimates indicated that the top three recreational fish species for Matagorda Bay are the spotted seatrout, red drum, and southern flounder. Of the eight bay systems assessed by the TPWD, Matagorda Bay typically ranked third in terms of annual recreational catches. Operation of the proposed LNG terminal would not affect recreational fishing. Calhoun Point Comfort estimates that up to about 120 LNG vessels would unload at the LNG terminal each year, or between two and three vessels per week. While in transit or docked, LNG vessels would have a security zone enforced around them. Other vessels, including recreational boats, would be prohibited within the security zone during the arrival and potentially the departure of LNG vessels. These effects would be temporary, occurring only during the transit of the vessel, and is a moving zone which is established by the Coast Guard. Additional discussion of potential impact on other vessel traffic and users of Matagorda and Lavaca Bays is included in sections 4.9.2 and 4.12.5 of this EIS.

LNG Terminal and Pipeline

The land that would be used for the LNG terminal is owned by the Port and most of the land crossed by the pipeline and laterals is privately owned. No Indian reservations, scenic areas, developed recreational facilities, parks, forests, wildlife management areas, wilderness areas, trails, or registered natural landmarks have been identified in the vicinity of the proposed LNG terminal site or natural gas pipeline. At MP 2.2, the pipeline would cross land owned by the City of Point Comfort and used as a baseball field. The field is at the northwest corner of the intersection of State Route 35 and FM 1593 and would be avoided by Calhoun Point Comfort's use of the HDD method. Between MP 3.1 and 3.8, the Point Comfort Pipeline would cross the southern edge of a recreational park owned by Formosa Plastics Corporation. Calhoun Point Comfort would install warning signs and orange safety fence during construction and restore the area in accordance with our Plan.

The Lavaca and Navidad rivers support fishing and general recreation activities such as canoeing and swimming. These rivers are accessible by public boat ramps and private roadways. The Project would not affect uses along these rivers since they would be crossed using the HDD method.

The Lake Texana State Park, a 575-acre park managed by the TPWD, is located about 6.5 miles east of Edna. The proposed Project would not affect this park.

4.7.4 Visual Resources

Waterway for LNG Marine Traffic

During operation, about 120 LNG vessels per year, or two to three per week, would call on the LNG terminal, each traversing the existing MSC. For the majority of the waterway, the LNG vessels would be over 1.0 mile from shore, and would have minimal visual impact from the adjacent shorelines. At two locations near Magnolia Beach and Alamo Beach, the waterway is about 0.5 mile from the shoreline, and the LNG vessels would be most visible from these locations. However, the presence of LNG vessels along the existing waterway would generally be consistent with existing large ship traffic using the waterway, and the addition of two to three additional vessel passages per week would not result in a significant visual impact.

LNG Terminal and Pipeline

The degree of visual impact that may result from a proposed Project is typically determined by considering the general character of the existing landscape and the visually prominent features of the proposed facilities. The proposed LNG terminal would be constructed in a historically industrial area along the southeastern shoreline of Lavaca Bay. The LNG terminal would be within the CCND's Port and south of the industrial facilities of Alcoa PCO and Formosa Plastics Corporation.

The most prominent visual feature of the proposed LNG terminal would be two LNG storage tanks, each about 133 feet above the current grade and 262 feet in diameter. In addition to the LNG storage tanks, the LNG vessel berth and process area would contain several additional structures of a lower profile.

We evaluated estimated views of the proposed LNG storage tanks from seven surrounding observation points to determine potential impact on the existing landscape. Observation points are shown on figure 4.7-1 and include:

- State Route 35 bridge over Lavaca Bay (about 2.0 miles northwest of the LNG terminal);
- Public waterfront access along southeastern side of Port Lavaca (about 4.0 miles southwest of the LNG terminal); Magnolia Beach south of Port Lavaca (about 5.0 miles south of the LNG terminal);
- Miller's Point south of Port Lavaca (about 6.0 miles south of the LNG terminal);
- Public beach commemorating Indianola (about 10.0 miles south of the LNG terminal);
- Public waterfront access in Olivia (about 6.0 miles southeast of the LNG terminal); and
- Lighthouse Beach in Port Lavaca (about 3.0 miles west-northwest of the LNG terminal).

Calhoun Point Comfort prepared photo simulations of views of the proposed LNG storage tanks from each observation point to assist us in our analysis. Potential visual impact from each observation point is discussed below.

The observation point on the State Route 35 bridge over Lavaca Bay is about 2.0 miles northwest of the LNG terminal site. The simulated observation point in figure 4.7-2 is from a high point on the bridge looking southeast at the terminal site. As shown on the visual simulation, the LNG storage tanks would be visible from vehicles traveling over the State Route 35 bridge. Although the LNG storage tanks would be a prominent feature in the views from this area, we believe they would not represent a significant visual impact from this observation point.

The public waterfront access along the southeastern side of Port Lavaca is about 4.0 miles southwest of the LNG terminal site. The simulated observation point in figure 4.7-3 is looking northeast at the terminal site. As shown on the visual simulation, the LNG storage tanks would be visible from the southeastern side of the City of Port Lavaca at this location; however, they would be visible along with nearby industries to the north including the Alcoa PCO, Formosa Plastics Corporation, Formosa Hydrocarbons Company, and Port facilities. We believe the LNG storage tanks would not represent a significant visual impact to viewers from the public waterfront access along the southeastern side of Port Lavaca.

The third observation point of the LNG storage tanks is from Magnolia Beach south of the City of Port Lavaca, looking north to the LNG terminal site, about 5.0 miles south of the site. The visual simulation of the proposed LNG storage tanks from this observation point is depicted in figure 4.7-4. While the LNG storage tanks would be visible from Magnolia Beach, they would be visible against a backdrop of the existing industries including the Alcoa PCO, Formosa Plastics Corporation, Formosa Hydrocarbons Company, and Port facilities located north of the proposed LNG terminal. The proposed LNG storage tanks would not dominate the landscape. We believe the LNG storage tanks would not represent a significant visual impact to viewers from Magnolia Beach.

Non-Internet Public

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The observation point from Miller's Point south of the City of Port Lavaca is about 6.0 miles south of the LNG terminal site and looks north-northwest at the terminal site. The visual simulation of the proposed LNG storage tanks from this observation point is depicted in figure 4.7-5. As with the views from Magnolia Beach, the proposed LNG storage tanks would be visible from Miller's Point against a backdrop of the existing area industries located north of the proposed LNG terminal site. From this observation point, the proposed LNG storage tanks would not dominate the landscape and we believe they would not represent a significant visual impact to viewers from Miller's Point.

The fifth observation point of the proposed LNG storage tanks is from a public beach commemorating Indianola located about 10.0 miles south of the LNG terminal site. The visual simulation of the proposed LNG storage tanks from this observation point is depicted in figure 4.7-6 and looks in a north-northwesterly direction towards the terminal site. As with the views from Magnolia Beach and Miller's Point, the proposed LNG storage tanks would be visible; however, at this distance they would be difficult to discern from other area industry structures located north of the LNG terminal site. We believe the LNG storage tanks would not represent a significant visual impact to viewers from the public beach commemorating Indianola.

The public waterfront access in Olivia is about 6.0 miles east of the LNG terminal site. The observation point of the LNG storage tanks from this area is shown in figure 4.7-7, looking westerly at the terminal site. Although the proposed LNG storage tanks would be visible from this location, they would not be a prominent feature in the views from this area. We believe the proposed LNG storage tanks would not represent a significant visual impact from the public waterfront access in Olivia.

The Lighthouse Beach observation point in Port Lavaca is about 3.0 miles west-northwest of the proposed LNG terminal site near the west end of the State Route 35 bridge. The visual simulation of the proposed LNG storage tanks from this observation point is depicted in figure 4.7-8. As shown in this figure, the proposed LNG storage tanks would be visible from Lighthouse Beach with a backdrop of existing area industries located north of the proposed LNG terminal. Although the proposed LNG storage tanks would be a prominent feature in the views from this area, we believe they would not represent a significant visual impact from Lighthouse Beach.

Construction and operation of the proposed pipeline may affect visual resources by altering the terrain and vegetation patterns during construction or right-of-way maintenance and from the presence of new aboveground facilities. The landscape setting along the proposed pipeline route is generally flat. Impacts on visual resources due to the pipeline would be primarily temporary and short-term, occurring during construction. During construction, the cleared and graded right-of-way, as well as the construction equipment could be visible from any surrounding residences and local roads. Because the terrain over much of the project area is flat, views of the construction activities may extend for some distance. Following construction, the right-of-way would be restored and, on agricultural lands, farmers would be allowed to grow crops over the pipeline. Construction work areas would normally be difficult to distinguish from surrounding areas. Therefore, no long-term visual impacts would result from construction and operation of the pipeline.

Non-Internet Public

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Pages 4-102 through 4-105
Figures 4.7-5 through 4.7-8

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Calhoun Point Comfort proposes to install several aboveground facilities associated with the pipeline, including ten interconnect/delivery points, pig launcher and pig receiver, and three MLVs. A typical station would include perimeter fencing, piping, MLVs, and flowmeters. Because some of the facilities would be collocated, aboveground facilities would be constructed at eleven separate locations along the pipeline (see section 2.1.3 of this EIS).

The aboveground facilities would be located along rural farm roads primarily traveled by local farmers or rural residents. The landscape along the proposed pipeline route and the location of the metering stations is dominated by industrial, agricultural, and range land uses. No sensitive visual resources, such as schools or residential subdivisions, or public lands were identified within the project area or in the vicinity of these aboveground facilities. Therefore, the visual impact of the proposed aboveground facilities would not have a significant impact on the aesthetics of the landscape along the proposed pipeline route.

4.7.5 Coastal Zone Management

The Texas CZMP boundary delineates the coastal zone. The inland limit of the boundary is a state-defined line that in Texas generally encompasses the area within several miles of the Gulf Coast. The proposed LNG terminal lies within the designated coastal zone management area, as does a portion of the proposed pipeline. The entire waterway for LNG marine traffic along the MSC would also be within the designated coastal zone.

Activities and development affecting Texas coastal resources that involve a federal permit or license are evaluated for compliance with the CZMA through a process called "federal consistency." In order to obtain a consistency determination for the Project, Calhoun Point Comfort must first obtain a COE 404 Permit and State Section 401 Water Quality Certification.

Calhoun Point Comfort submitted its application with the COE during June and July 2005, but has not received its consistency determination from the TRRC. A determination that the Project is consistent with the Texas CZMP must be received by the FERC before we could issue a notice to proceed with construction of the LNG terminal. Therefore, **we recommend that:**

- **Calhoun Point Comfort should not begin construction of any component of its Project <u>until</u> it files with the Secretary a copy of the coastal zone consistency determination issued by the Railroad Commission of Texas**.

4.7.6 Hazardous Waste Sites

As part of Calhoun Point Comfort's determination of the likelihood to encounter contaminated soils at the LNG terminal site or along the pipeline route, EDR conducted a search of available environmental database records within 0.25 mile of the LNG terminal site and pipeline route. EDR found that eight potentially contaminated sites and facilities with historic releases of hazardous substances occur in the vicinity of the Project (table 4.2.2-1). Seven sites would be between 260 and 2,270 feet of the pipeline route. In addition, although the proposed pipeline would cross through the Alcoa (Point Comfort)/Lavaca Bay Superfund Site from approximately MP 0.29 to MP 2.27, the releases of hazardous materials that caused the site to be classified as a Superfund site occurred about 0.5 mile west of the pipeline route. Calhoun Point Comfort would consult with Alcoa and the EPA, Region 6, regarding any contaminated soils issues within this Superfund site.

The proposed LNG terminal site would be located on 73 acres of manmade, industrial land that was created by the placement of dredged material from Lavaca Bay and Cox Bay. Calhoun Point Comfort sampled the soils at four locations within the LNG terminal site, one at each LNG tank site and two within the process area, including the firewater tank site, and the samples were tested for PAHs and mercury. The results of the analyses revealed that PAHs did not exceed the reportable limit; however, mercury did exceed the reportable limit in one sample, taken at a depth between 13 and 15 feet from the process area.

Calhoun Point Comfort would implement its *Contaminated Soils Management Procedures* should contaminated soils be encountered within the LNG terminal site and along the pipeline construction right-of-way. In addition, Calhoun Point Comfort has developed a draft *Water Quality Management Plan* and SPCC Plan that would describe spill prevention practices, spill handling and emergency notification procedures, and training requirements. Implementation of its *Contaminated Soils Management Procedures* would address steps that would be taken should soil contamination be encountered. We believe that using the measures detailed in this procedure would minimize spread of contaminated soils.

4.8 SOCIOECONOMICS

Several potential socioeconomic effects may result from construction and operation of the proposed Project. Many of these potential effects are related to construction and include the number of local and non-local construction workers who would work on the Project; their income and local expenditures; and their impact on population, public services, and temporary housing during construction. Other potential effects related to construction include local construction expenditures by Calhoun Point Comfort. Potential economic benefits associated with operation of the proposed Project include increased property tax revenue, increased job opportunities and income, and ongoing local expenditures by the company.

A discussion of the effects of the proposed Project on local population, employment, the economy, housing, public services, property values, and tax revenue is provided below.

4.8.1 Population

Waterway for LNG Marine Traffic

The LNG traffic would pass within 2.2 miles (Zone of Concern 3) of several small towns along the MSC. These towns are with 2000 census numbers in parentheses: Port O'Connor (1,078); Indianola, Magnolia Beach, and Alamo Beach (combined population of 1,641). A portion of Magnolia Beach and Alamo Beach fall within Zone of Concern 2. Also see figure 2.1-7 sheets 2 through 5 for density of populations and Zones of Concern. All these towns are on the western shore of the bay. The City of Port Lavaca (12,035) is on the western shore of Lavaca Bay across from the Port of Port Lavaca–Point Comfort, but is outside of Zone 3. The City of Point Comfort is located on the eastern shore of Lavaca Bay. The city's southern boundary falls within Zone 2; however, the portion of the city falling into Zone 2 is occupied by the Formosa Hydrocarbons plant. All residences of Point Comfort are north of Highway 35 and are outside of Zone 3. There are no residences within Zone of Concern 1.

In the event of an LNG release, the severity of potential impacts on populations within Zones 1-3 would depend on the location of the incident relative to the population, the scope of the incident, and whether the LNG released ignited or evaporated. This could be a significant impact, with injuries ranging from mild to fatal, being most severe in Zone 1 and decreasing outward through Zones 2 and 3. However, because of the implementation of safety and security measures during marine transit (see section 4.12 of this EIS), the likelihood of a marine LNG spill is extremely remote, and significant socioeconomic impacts are not expected.

The only populated areas that lie within the Zones of Concern are to the southwest of the MSC along Matagorda Bay, and includes the towns of Alamo Beach, Magnolia Beach, Indianola, and Port O'Connor. U.S. Census data from 2000 was analyzed to determine if these areas have a disproportionately high minority or low income population. Alamo Beach, Magnolia Beach, and Indianola are in Census Tract 9904, and Port O'Connor is in Census Tract 9905. The percentage of minority persons in Tract 9904 is 45.7 percent and percentage of persons below the poverty line ($17,029 in 1999) is 15.1 percent. These percentages of minority and low income persons are similar to (but lower than) the percentages of the state of Texas (47.6 percent and 15.4 percent, respectively; USBOC, 2000). Minority and low income persons make up an even smaller percentage of Tract 9905 (29.2 percent and 14.1 percent respectively), so are also lower than for the state of Texas (table 4.8.1-1).

No disproportionate effects would be experienced by minority and low-income populations. The percentages of minority and low income persons are lower in the two census tracts that are within the Zone of Concern 3 than the average for the state.

TABLE 4.8.1-1

Minority and Low Income Persons in Zone of Concern

Census Tract	Towns	Zone of Concern	% Minority	% Below Poverty
9904	Alamo Beach and Magnolia Beach	2 and 3	45.7	15.1
9904	Indianola	2 and 3	45.7	15.1
9905	Port O'Connor	3	29.2	14.1
	State of Texas		47.6	15.4

LNG Terminal and Pipeline

The proposed Project would be located in Calhoun and Jackson Counties, Texas along the southeastern shoreline of Lavaca Bay, south of Point Comfort, Texas. The proposed project site is part of the Victoria Metropolitan Statistical Area (VMSA), which includes Calhoun and Jackson Counties. Nearby cities and towns include Port Lavaca, Point Comfort, Olivia, Lolita, and Edna. Table 4.8.1-2 provides a summary of selected population and socioeconomic statistics for the State of Texas, Calhoun County, Jackson County, and cities surrounding the project area. Both Calhoun and Jackson Counties had a slight population decline from 2000 to 2005. However, the cities of Port Lavaca, Edna, and Victoria grew although at a much lower rate than the state, 1.2, 1.5, and 1.4 percent, respectively. The cities of Lolita and Edna experienced a population decline during this period. The population density in Calhoun and Jackson County continued to be lower than the state density.

TABLE 4.8.1-2

Existing Socioeconomic Conditions in the Vicinity of the Proposed Calhoun LNG Project

State/County/Town	Population			Population Density (person/ sq. mi.)	Per Capita Income		Civilian Labor Force (monthly average)	Unemploy-ment Rate (percent)
	2000	2005 (Estimate)	Percent Change	2000	1999	2002	2004	2004
Texas	20,851,820	22,859,968	9.6	80	$26,250	$29,039	11,069,100	5.4
Calhoun County	20,647	20,606	-0.2	40	$20,082	$21,151	8,497	8.7
Jackson County	14,391	14,339	-0.4	17	$22,471	$22,279	7,873	4.4
City of Port Lavaca	12,035	11,885	1.2	1,228	NA	NA	NA	NA
City of Point Comfort	781	722	-7.6	601	NA	NA	NA	NA
City of Lolita	548	544	-0.7	211	NA	NA	NA	NA
City of Edna	5,899	5,987	1.5	1,512	NA	NA	NA	NA
City of Victoria	60,603	61,454	1.4	1,836	NA	NA	NA	NA

NA - data not available
Sources: US Census Bureau (2006); Texas Data Center and Office of the State Demographer (2006); Texas Health and Human Services Commission (2006); Texas Water Development Board (2006); City-data.com (2006), ESRI (2004);.

Project area population impacts are expected to be temporary and relatively minor. The total population change would equal the total number of non-local construction workers, plus any family members accompanying them. The Project would be located near the Cities of Point Comfort, Port Lavaca, and Edna. It is assumed that workers could find housing in these communities, as well as Port O'Connor and Ganado, or in Victoria County, including the City of Victoria. As discussed further in section 4.8.2, Calhoun Point Comfort expects to utilize predominately local workers. Therefore, the estimated number of people who would temporarily relocate to the area during construction would not constitute a major impact on the local population of the area. Once completed, operation of the proposed LNG terminal and pipeline would require approximately 43 and 2 full-time positions, respectively. This small staff could be comprised of existing residents or non-local personnel, but would not have a significant impact on the local population.

4.8.2 Economy and Employment

The manufacturing, government, and construction sectors are the largest economic sectors in the project area. Alcoa PCO, Formosa Plastics Corporation, Formosa Hydrocarbons Company, and the Port of Port Lavaca–Point Comfort are the primary employers in the area. There has been a 40 percent reduction of manufacturing jobs in the project area due to mergers, acquisitions, and declining market conditions in the minerals and petrochemical industry. The 2002 per capita income in Calhoun and Jackson Counties was less than the 2002 state per capita income, at $21,151 and $22,279, respectively. The 2004 unemployment rate in Calhoun County was higher than the state average of 5.4 percent, at 8.7 percent, whereas the unemployment rate in Jackson County was lower, at 4.4 percent (Texas Workforce Commission, 2004).

The Calhoun LNG Project would be constructed over a 35-month period. During construction of the LNG terminal, Calhoun Point Comfort estimated it would employ an average of about 270 workers. A maximum of approximately 513 workers would be employed during the peak

construction period, during the last five months, when the LNG terminal and Point Comfort Pipeline, and associated facilities, are both under construction.

The average workforce requirements for pipeline and meter station construction are estimated at approximately 112 persons, and anticipated to peak at a combined total of approximately 132 personnel. Construction of the proposed 27.1-mile, 36-inch-diameter pipeline and meter stations would be performed by one contractor spread over a 5-month time period.

Calhoun Point Comfort expects to utilize predominately local workers who reside within 50 miles of the Project. The use of local workers is dependent on various factors, such as the construction contractor hired for the Project, the methods the construction contractor uses to hire subcontractors, as well as union agreements. Additional construction personnel hired from outside the project area would include highly skilled mechanical, electrical, and instrumentation and control tradesmen who would temporarily relocate to the project area. An average of approximately 140, with a peak of 350, non-resident personnel would be required for the construction of the LNG terminal, whereas an average of 56, with a peak of 66, non-resident personnel would be required for the construction of the Point Comfort Pipeline and associated facilities.

During the proposed 35-month construction period, Calhoun Point Comfort estimates that the total project payroll would amount to about $33 million. Of this amount, about $30 million would be for the LNG terminal and $3.0 million would be for the Point Comfort Pipeline and associated facilities. During this period, some portion of the construction payroll would be spent locally for the purchase of housing, food, gasoline, entertainment, and luxury items. The dollar amount would depend on the number of construction workers in a given area and the duration of their stay. Sales tax would be paid on any construction materials as well as any goods and services purchased with payroll monies. Calhoun Point Comfort estimates that $78 million would be spent on materials and services during construction of the Project. Of this amount, about $54 million would be spent during construction of the LNG terminal and $24 million would be spent during construction of the Point Comfort Pipeline and associated facilities. Direct payroll and materials expenditures would have a positive impact on local economies and would stimulate indirect expenditures within the region.

Indirect sales, jobs, and salaries would be created in new or existing businesses and organizations such as construction companies, parts and equipment suppliers, and other businesses that supply goods and services to the facility during construction and operation. In addition, jobs and salaries would be created in establishments that would supply goods and services to the project's employees and their families, such as restaurants, retail stores, grocery stores, and banks.

Following construction, the proposed LNG terminal and natural gas pipeline would be subject to state, county, and local property taxes. The local tax rate is levied against part of the assessed value of the facility, and is based on estimated future costs and revenues for each town for the entire year. Local tax rates are determined by town officials according to estimated budget needs at the beginning of each year. Tax revenues are used to support road and bridge programs, school districts, safety, and general county administration. The assessed value of the proposed facilities would be established by the municipalities crossed by the Project.

Construction of the Project would result in increased tax revenue. Calhoun Point Comfort estimated that total franchise taxes to be paid to the State of Texas would be approximately $156,400 annually. Estimated property taxes of $238,372 would be received by Calhoun County and $1.1 million would be received by Jackson County. Also, during construction of the LNG terminal and pipeline, the state and county would benefit from estimated payroll taxes of $30 million and $3.0 million, respectively. During operation of the proposed Project, property taxes would be paid for the land that the LNG terminal occupies.

4.8.3 Housing

Housing statistics are presented in table 4.8.3-1. The median values of owner-occupied units in Calhoun and Jackson Counties have a lower median rent than the state median and were more than $26,100 lower than the state median value of $82,500. Calhoun and Jackson Counties had a higher percentage of vacant housing units than the state, estimated during the 2004 Census at 2,796 and 1,209 units, respectively.

TABLE 4.8.3-1

2000 Housing Characteristics in the State of Texas and Calhoun and Jackson Counties

State/County	Total Housing Units	Vacant Housing Units	Median Value, Owner-Occupied Units	Median Contract Monthly Rent	Vacancy Rate (Percent)
Texas	8,157,575	764,221	$82,500	$602	9
Calhoun County	10,238	2,796	$56,400	$440	27
Jackson County	6,545	1,209	$52,700	$406	18

Source U.S. Census Bureau, 2006; ESRI, 2004.

Temporary housing is available in the form of daily, weekly, and monthly rentals in numerous motels, hotels, campgrounds, and RV parks located within commuting distance of the project site. It is assumed that workers could find housing in the Cities of Point Comfort, Port Lavaca, and Edna as well as Port O'Connor and Ganado, or in Victoria County, including the City of Victoria. During 2004 and 2005, Calhoun, Jackson and Victoria Counties had combined vacant housing units of 7,055, including 4,586 units available for rent (apartment, motel, and/or hotel) and 2,269 units available for seasonal, recreational, or occasional use (table 4.8.3-2).

TABLE 4.8.3-2

Vacant Housing Units in the Calhoun LNG Project Area

Type of Housing Unit	Calhoun County	Jackson County	Victoria a/
Apartment Rental	352	342	3,892
Motel or Hotel	509	86	718
Seasonal, Recreational, or Occasional Use (Campground and Recreational Vehicle Sites)	390	452	314
Total	**1,251**	**880**	**4,924**

a/ Victoria County is adjacent to and north and west of Calhoun and Jackson Counties, respectively.

On average, approximately 43 percent of the construction workers for Calhoun Point Comfort's primary construction contractor would come from within 50 miles of the project site and would not require temporary housing. The remaining 57 percent of the workers for the LNG terminal and Point Comfort Pipeline would require temporary housing in the project vicinity during construction. The average number of non-local workers for the LNG terminal and pipeline would be 196 in any given month, and possibly 416 at peak construction. Assuming double occupancy, these workers would require an average of 98 to 208 hotel and/or motel rooms per month.

Based on the information above, there is an adequate supply of local housing and temporary accommodations in Calhoun, Jackson, and Victoria Counties for the expected project demand. In addition, a significant number of employees are expected to be hired locally and therefore already have housing, which would reduce the overall demand from the project workforce. The proposed construction schedule for the Project could coincide with other demands for housing and temporary accommodations from tourism and other unrelated construction projects. Because the demand (in both number and time) from these other users would be influenced by factors such as weather and economic conditions, such demand would be unpredictable. At present, it is reasonable to assume that the facilities available near the project area would be able to accommodate the expected workforce. Few new permanent employees would be anticipated for operation of the LNG terminal and pipeline; therefore, no long-term major impacts on local housing are anticipated.

4.8.4 Public Services

Calhoun, Jackson and Victoria Counties have well-developed infrastructure to provide health, police, fire, emergency, and social services near the project site. Public health infrastructure in Calhoun, Jackson, and Victoria Counties includes five acute care hospitals and about 29 licensed emergency vehicles.

Police, ambulance, fire, and hazardous materials (HAZMAT) services are provided by county or municipal jurisdictions, as well as volunteer organizations, and private hospitals. In addition to these services, Alcoa PCO, Formosa Plastics Corporation, Formosa Hydrocarbons Company, and the Port have firefighting equipment and trained emergency response personnel. As a group, these companies have procedures in place to cooperate and assist each other during an emergency response.

The nearest hospital, ambulatory service, and fire station to the proposed LNG terminal is located in Port Lavaca about 4.0 miles from the terminal site. The Cities of Lolita, La Ward, Vanderbilt, and Victoria each have a fire department and are within 30 miles of the LNG terminal. The Cities of Point Comfort and Port Lavaca have police departments. The Calhoun County Sheriff's Office is located in Port Lavaca as are four Calhoun County Constable Precincts. The closest Texas Department of Public Safety patrol dispatch is in the City of Victoria.

Project demands on local agencies could include increased enforcement activities associated with issuing permits for vehicle load and width limits, local police assistance during construction to facilitate traffic flow, and emergency medical services to treat injuries resulting from construction accidents. There are adequate providers of professional and commercial services

near the project area in the communities of Point Comfort, Port Lavaca, Lolita, La Ward, Vanderbilt, and Victoria, capable of meeting the needs of the project workforce. Because the non-local workforce would be small relative to the current population of the area, the proposed Project would not have a significant impact on local infrastructure and public services.

4.8.5 Property Values

The proposed Project is not anticipated to negatively impact property values. The surrounding area is an industrialized zone with existing petroleum and chemical processing plants, which are indicative of the residential property values in the project vicinity. Based on the location of the LNG terminal on an existing industrially zoned site, it is unlikely that the proposed LNG terminal would negatively affect property values in the surrounding area.

The proposed pipeline may have an impact on the property values of the surrounding area; however, valuation depends on many factors, including the size of the parcel, the values of adjacent properties, the presence of other utilities, the current value of the land, and the current land use. Similar pipeline rights-of-way are present in the surrounding area; therefore, the property values in the general area of the proposed pipeline would already reflect the presence of underground utilities.

Property taxes are generally based on the actual use of the land. Construction of the pipeline would not change the general use of the land, but would preclude construction of aboveground structures on the permanent right-of-way. If a landowner feels that the presence of a pipeline easement reduces the value of his or her land, resulting in an overpayment of property taxes, they may appeal the issue of the assessment and subsequent property taxation to the local property tax agency. This issue is beyond the scope of this EIS.

4.9 TRANSPORTATION AND TRAFFIC

4.9.1 Land Transportation

The local road and highway system in the project area is well developed, consisting of U.S. highways, state highways, county roads, FM roads, and local streets. From the proposed LNG terminal site, FM 1593 proceeds north, crosses State Route 35 and FM 616, passes through Lolita, and terminates at State Route 111, about 8.0 miles east-southeast of Edna. Once on the west side of the City of Port Lavaca, State Route 35 provides access to U.S. Highway 87 and other roadways. From the City of Victoria, about 30 miles northwest of the LNG terminal site, U.S. Highway 87 provides access to U.S. Highways 59 and 77. San Antonio, about 90 miles northwest of Victoria, is accessible from U.S. Highway 87 and Houston, about 126 miles northeast of Victoria, is accessible from U.S. Highway 59 (the Point Comfort Pipeline would terminate about 0.3 mile north of U.S. Highway 59). Hallettsville, about 40 miles north of Victoria, is accessible from U.S. Highway 77.

Existing roads would provide land access to the LNG terminal site via FM 1593 and the existing access road for CCND's Port facilities. These roads would provide primary access to the proposed LNG terminal site during construction and operation. Existing roads in the vicinity of the pipeline include FM 1593, FM 616, FM 1822, FM 234, and State Route 59.

Construction workers commuting to the project area are expected to add an average of no more than approximately 834 vehicle trips per day (to and from the work site). At the peak of construction, a maximum of 1,410 construction worker vehicle trips are expected.

During construction of the LNG terminal, FM 1593 would experience an increase in vehicular traffic as would State Route 35 and other local roadways. Near the LNG terminal site, these roads are currently used by workers from Alcoa PCO, Formosa Plastics Corporation, Formosa Hydrocarbons Company, the Port, and other industries.

Construction of the proposed pipeline and associated facilities would increase traffic on local roadways for the delivery of equipment and materials, and for construction worker transportation. These roads are primarily two-lane local roads that cross mostly rural agricultural and range land. Calhoun Point Comfort would use 26 access roads related to its proposed pipeline facilities. Of this amount, 20 are existing roads and six roads would be newly constructed (see table 2.3.2.3-1). There may be some minor inconveniences for local traffic on lightly traveled and unimproved county roads crossed by the pipeline that would be open-cut. All construction operations, including repair and surface restoration, normally would be completed in one day. Where the pipeline crosses paved or improved roads, a hole will be bored under the road and the pipe would be installed in accordance with state and local regulatory requirements.

During peak construction, Calhoun Point Comfort estimates that there would be a maximum of 60 and 20 heavy truck deliveries a day to the proposed LNG terminal site and proposed Point Comfort Pipeline, respectively.

Calhoun Point Comfort notified the Texas Department of Transportation of its proposed Project and indicated that, one year prior to the start of construction, it would consult with the City of Point Comfort, Calhoun and Jackson County officials, and major industries in the project area to develop a traffic mitigation plan.

Assuming one worker per vehicle, the operational workforce for the LNG terminal and pipeline would be about 43 and 2 workers, respectively, who would generate a maximum total of 45 vehicle trips per day (round trip). We believe that the additional traffic generated by these employees on a daily basis would not result in a significant increase in traffic volume, and would not adversely affect traffic on area roadways. Truck deliveries during operation of the LNG terminal are expected to be minimal.

The Union Pacific Railroad and Burlington Northern/Santa Fe Railway service the project area with railroad transportation. The Union Pacific Railroad is the region's primary rail carrier. Local industrial railroad lines in the vicinity of the project area include Formosa Plastics Corporation’s 0.5-mile-long rail that parallels FM 1593 to local area industries.

The nearest commercial airport to the project area is the Victoria Airport, about 35 miles northwest of the LNG terminal site. General aviation facilities include the Calhoun County Airport, located about 3.0 miles northwest of Port Lavaca, and the Jackson County Airport, located about 5.0 miles northeast of the City of Edna, adjacent to U.S. Highway 59.

4.9.2 Marine Transportation

In its application, Calhoun Point Comfort indicated that materials required for construction of the LNG terminal may be delivered to the site by barge about two to three times per week. While there would be minimal water transportation impacts during construction of the terminal, operation of the terminal would result in regular LNG vessel traffic in the MSC.

Waterway for LNG Marine Traffic

Tables 4.9.2-1 and 4.9.2-2 summarize marine traffic by vessel transits and by freight tonnage, respectively, for the MSC in 2003.

TABLE 4.9.2-1

Matagorda Ship Channel Traffic for the Year 2003

Type of Traffic	Total Vessel Transits
Total Number of Inbound and Outbound Traffic per year	6,346
Large Draft Vessels (Draft > 18 feet)	636
Small Draft Vessels (i.e., Barges)	5,710

Source: COE, 2003

The numbers listed in table 4.9.2-1 reflect both inbound and outbound traffic. Thus, in 2003, the number 636 for "Large Draft Vessels" represents 318 vessels making roundtrips into and out of the Port and Alcoa, the only two destinations for large draft vessels in the bay. Likewise, the number 5,710 for "Small Draft Vessels" represents 2,855 small draft vessels and barges making roundtrips along the MSC, but with multiple destinations besides the Port and Alcoa. There are multiple other small draft channels branching off the MSC; thus, the final destination for these vessels is not as well defined. However, one of the main destinations for barges with liquid cargo is the Port.

Table 4.9.2-2 presents the types of cargoes that are transported along the MSC.

TABLE 4.9.2-2

Matagorda Ship Channel Freight by Tonnage for the Year 2003

Commodity	Total (thousand short tons)
Coal	0
Petroleum Products	1,919
Chemicals	3,601
Crude Materials	6,132
Manufactured Goods	0
Food and Farm Products	22
Manufactured Equipment	0

Source: COE, 2003

In addition to bulk and chemical carriers and barges, Matagorda and Lavaca Bays are also used by commercial fishing vessels. Information was obtained from the TPWD, which licenses fishing vessels for inshore Texas waters. For 2003, the number of bay/bait shrimp licenses were 167 in Calhoun County and 176 in Matagorda County. The number of Gulf shrimp licenses (approximately 87 percent of Gulf license holders have both types of licenses) were 15 in Calhoun County and 103 in Matagorda County. The number of oyster licenses (from 2004) were 14 in Matagorda, 41 in Palacios, 53 in Port Lavaca, 10 in Port O'Connor, 69 in Seadrift, and 4 in Sargent.

The LNG vessel berth is located adjacent to the proposed new turning basin. Traffic would continue to transit past the berth to other existing berths within the Port. At the LNG vessel berth, the channel width would be approximately 800 feet. The distance from berthed vessels to the channel would be approximately 400 feet for other vessels at the centerline of the channel. As the existing berths are located in proximity to the end of the channel, vessels transiting near the LNG carrier berth would be at low speed (generally less than 3 knots).

All ship traffic in the vicinity of the LNG turning basin or LNG berth, which includes both deep-draft vessels in transit to Alcoa and deep-draft vessels in transit to the Port, are tug-assisted when they enter either the Alcoa Ship Channel or the Port.

Area boaters are accustomed to commercial ship traffic in the MSC in transit to Alcoa and the Port; therefore, the issue of deep-draft vessel traffic in the MSC is not a new issue to commercial shrimpers or recreational boaters that frequent Matagorda Bay or Lavaca Bay.

Discussion of marine traffic and transportation as it relates to marine safety is included in section 4.12.5 of this EIS.

4.10 CULTURAL RESOURCES

Section 106 of the NHPA, as amended, requires the FERC to take into account the effect of its undertakings (including authorizations under Sections 3 and 7 of the NGA) on properties listed, or eligible for listing, on the NRHP, and to provide the ACHP an opportunity to comment. Calhoun Point Comfort, as a non-federal party, is assisting the FERC in meeting its obligations under Section 106 and the ACHP's implementing regulations at 36 CFR 800.

4.10.1 Waterway for LNG Marine Traffic

An examination of the Atlas and the Office of Coast Survey's Automated Wreck and Obstruction Information System (AWOIS) databases indicates that 8 historic markers, 6 shipwrecks, and 36 archaeological sites have been recorded within the Zones of Concern along the waterway for LNG marine traffic (tables 4.10.1-1 and 4.10.1-2). There are no sensitive cultural resources, such as buildings or other structures, within the Zones of Concern. No historic markers recommended for listing on the National Register of Historic Sites are within the Zones of Concern. Town sites and cemeteries (sites that are below ground) would not be impacted by vessel transit and operation, and are unlikely to be impacted by a spill or fire.

No significant impact on cultural resources (archaeological sites or historic structures) is expected as a result of routine LNG and support vessel transit. The MSC already experiences a

high volume of vessel traffic, and wave induced erosion resulting from increased vessel traffic is expected to be minimal. Similarly, no significant impact on cultural resources is expected as a result of an unignited release of LNG, since LNG is less dense than water and would vaporize upon contact with water and air.

TABLE 4.10.1-1

Historical Markers in the Study Radius

Marker Number	Site Name	Site Type	Quadrangle	Temporal Affiliation	NRHP Eligibility	Within Zone of Concern
1101	Cox's Point	Town site	Point Comfort	1836-1840	Unknown	3
2642	Indianola	Town site	Keller Bay	1844-1875	Unknown	3
2643	Indianola Cemetery	Cemetery	Port Lavaca East	1852-	Unknown	3
3508	Angelina Bell Peyton Eberly	Marker	Port Lavaca East	ca.1800-1860	Unknown	3
3825	Old Town Cemetery	Cemetery	Port Lavaca East	1851-	Unknown	2
4243	Rene Robert Cavelier, Sieur de La Salle	Marker	Port Lavaca East	1643-1687	Unknown	3
4938	Site of the Town of Indianola	Town site	Keller Bay	1844-1886	Unknown	3
5952	Zimmerman Cemetery	Cemetery	Port Lavaca East	1858-	Unknown	3

TABLE 4.10.1-2

Identified Shipwrecks in the Project Vicinity

Record	Vessel Name	Chart	Registered Archaeological Site	Within Zone of Concern
8	Gram Kirk	11319	No	1
2501	Fina V	11317	No	1
5313	Mary Ethel	11317	No	3
5363	Bildot	11317	No	1
5443	Grand Prize	11319	No	3
5509	Cheetah	11319	No	1

4.10.2 LNG Terminal and Pipeline

Calhoun Point Comfort initiated consultation with the Texas Historical Commission (the SHPO) on December 10, 2004, requesting comments on its scope of work for cultural resources investigations for the Project.

The combined overview and survey of the proposed Project, specifically the Point Comfort Pipeline, resulted in the discovery of one isolated lithic find at MP 25.2; one historic surface scatter along an existing access road at MP 4.3; and four historic standing structures including a mobile home at MP 3.9, a water pumping shed and concrete water trough at MP 7.7, a windmill, elevated cistern and well at MP 11.2, and a collapsed/destroyed barn at MP 12.6 (Goodwin, 2005a, 2005b). These resources were recommended as not significant and not potentially eligible to the NRHP. The SHPO concurred with these findings (Goodwin, 2005c, 2005d).

Calhoun Point Comfort conducted a literature review of its proposed LNG terminal site and concluded that, since the proposed LNG terminal would be constructed entirely on manmade, industrial land that was created by the placement of dredged material from Lavaca Bay and Cox Bay, no further archeological investigations should be required. In addition, an aerial photographic review of the Point Comfort Pipeline between MP 0.0 and MP 1.2 and the Formosa Lateral revealed that these locations are within areas of extensive previous industrial disturbance and that no further archeological surveys should be necessary. The SHPO concurred with Calhoun Point Comfort's assessment that no additional surveys are required at these locations (Goodwin, 2005e).

Calhoun Point Comfort has filed an acceptable Unexpected Discoveries and Emergency Procedure Plan.

4.10.3 Native American Consultations

Our NOI for the Project, issued on July 7, 2005, was sent to Indian tribes and Native Americans who may have historically occupied or used the project area, and who may attach religious or cultural significance to sites in the region. The NOI went to the Alabama-Coushatta Tribe of Texas, Caddo Nation, Comanche Penateka Tribe, Comanche Tribe, Comecrudo Nation, Kiowa Tribe, Lipan Apache Band of Texas, Mescalero Apache Tribe, People of LaJunta, Tap Pilum Coahuiltecan Nation, Wichita and Affiliated Tribes, and Ysleta del Sur Pueblo. In addition, Calhoun Point Comfort sent notification about the Project, in letters dated January 21, 2005 and April 8, 2005, and results of its archeological overview and surveys, in letters dated February 23, 2005 and May 13, 2005, to the above tribes and the Kickapoo Traditional Tribe of Texas and Tonkawa Tribe. No responses to our NOI or these letters have been received.

4.10.4 Compliance with the NHPA

We agree with the SHPO that no historic properties have been identified in the project areas inventoried to date. However, the CCND, on behalf of Calhoun Point Comfort, needs to document an underwater cultural resources survey of the CCND's new turning basin and Calhoun Point Comfort's ship berth that would be dredged in Lavaca Bay.

4.11 AIR QUALITY AND NOISE

4.11.1 Air Quality

4.11.1.1 Regional Climate

The climate in the project area is predominately marine with periods of modified continental influence during the colder months when cold fronts from the northwest sometimes reach the coast. Because of its coastal location and relatively low latitude, cold fronts that do reach the area seldom have severe temperatures. Below freezing temperatures, on average, are seldom recorded. Normal monthly high temperatures range from about 63°F in January to 94°F in August. Average monthly low temperatures range from about 44°F in January to 70°F in September. The lowest and highest temperature on record in the project area was 9°F and 111°F during December 1989 and September 2000, respectively.

The prevailing winds are from the southeast, except when weather fronts move through the area and the prevailing winds are from the north or northwest. Wind speeds range from 6 to 8 miles per hour (mph) throughout the year with an annual average wind speed of about 7.1 mph. From 2002 to 2004, the highest and lowest monthly average wind speeds were 23.6 and 0.4 mph, recorded during July and November and December, respectively.

The average annual precipitation totals approximately 40 inches and is generally well distributed throughout the year. The highest amount of rainfall, about 5 inches, occurs during May and June and September and October. During the past 50 years, two hurricanes and four tropical storms have been recorded in the project area.

4.11.1.2 Existing Air Quality

Ambient Air Quality Standards and Attainment Status

The EPA has established National Ambient Air Quality Standards (NAAQS) for criteria pollutants for the purpose of protecting human health (primary standards) and welfare (secondary standards). The NAAQS set limits for ambient (outdoor) levels of the following criteria pollutants: nitrogen dioxide (NO_2), carbon monoxide (CO), ozone (O_3), sulfur oxides (SO_2), lead (Pb), inhalable particulate matter with an aerodynamic diameter less than or equal to 10 microns (PM_{10}), and particulate matter with an aerodynamic diameter less than or equal to 2.5 microns ($PM_{2.5}$). The NAAQS are codified in 40 CFR 50 and summarized in table 4.11.1.2-1.

In 2004, EPA provided designations for a new 8-hour O_3 standard. The new 8-hour standard is now effective and the 1-hour O_3 standard became ineffective after June 15, 2005 in most areas including the project area. EPA revoked the PM_{10} annual standard due to a lack of evidence linking health problems to long-term exposure to coarse particle pollution, effective on December 17, 2006. Also, EPA lowered the $PM_{2.5}$ 24-hour standard to 35 ug/m^3 effective on December 17, 2006.

Air Quality Control Regions

Air quality control regions (AQCRs) are areas in which implementation plans describe how ambient air quality standards will be achieved and maintained. AQCRs were defined by EPA and state agencies in accordance with Section 107 of the CAA. The AQCRs are intra- and interstate regions such as large metropolitan areas where the improvement of the air quality in one portion of the AQCR requires emission reductions throughout the AQCR. The proposed Project would be in the Corpus Christi-Victoria Intrastate air quality control region (AQCR 214) as defined at 40 CFR 81.136. Based on the NAAQS for each criteria pollutant, the EPA classifies airsheds throughout the country as attainment areas and non-attainment areas. Attainment areas are airsheds that comply with NAAQS, while non-attainment areas are those that do not. A given area can be classified as both attainment and non-attainment since the NAAQS are pollutant-specific.

The TCEQ has adopted the NAAQS as the ambient air quality standards within the State of Texas. In addition, the TCEQ has established property line standards that limit ambient air quality at the property line of facilities. Calhoun and Jackson Counties are both classified as attainment areas for all criteria pollutants for which EPA has made attainment designations.

TABLE 4.11.1.2-1

National Ambient Air Quality Standards

Pollutant	Averaging Time	National Standards	
		Primary Standard ($\mu g/m^3$)	Secondary Standard ($\mu g/m^3$)
SO_2	Annual a/	80 (0.030 ppm)	-
	24-Hour b/, d/	365 (0.14 ppm)	-
	3-Hour c/, d/	-	1,300 (0.5 ppm)
PM_{10}	Annual a/, e/	revoked	revoked
	24-Hour b/, d/	150	150
$PM_{2.5}$	Annual a/, f/	15	15
	24-Hour b/, g/	35	35
CO	8-Hour b/, d/	10,000 (9 ppm)	10,000 (9 ppm)
	1-Hour b/, d/	40,000 (35 ppm)	40,000 (35 ppm)
Ozone	8-Hour c/, h/	157 (0.08 ppm)	157 (0.08 ppm)
	1-Hour b/	revoked	revoked
NO_2	Annual a/	100 (0.05 ppm)	100 (0.05 ppm)
Lead	Quarter a/	1.5	-

a/ Arithmetic mean.
b/ Block average.
c/ Rolling average.
d/ Not to be exceeded more than once per year.
e/ To attain this standard, the 3-year average of the weighted annual mean PM_{10} concentration at each monitor within an area must not exceed 50 $\mu g/m^3$.
f/ To attain this standard, the 3-year average of the weighted annual mean $PM_{2.5}$ concentrations from single or multiple community-oriented monitors must not exceed 15.0 $\mu g/m^3$.
g/ To attain this standard, the 3-year average of the 98th percentile of 24-hour concentrations at each population-oriented monitor within an area must not exceed 65 $\mu g/m^3$.
h/ To attain this standard, the 3-year average of the fourth-highest daily maximum 8-hour average ozone concentrations measured at each monitor within an area over each year must not exceed 0.08 ppm.
$\mu g/m^3$ = micrograms per cubic meter. ppm = parts per million.

Air Quality Monitoring and Existing Air Quality

The TCEQ maintains an extensive network of air quality monitors located throughout the state for a variety of purposes. At monitoring stations around the state, the four gaseous criteria pollutants (NO_2, SO_2, CO, and O_3) are monitored continuously, with 1-hour averages measured each hour, every day. PM_{10} and Pb are measured at least once every six days for a 24-hour averaging period, although some sites in Texas are monitored more frequently. The TCEQ has also instituted a new continuous monitoring network of $PM_{2.5}$ monitors around the state to measure compliance with the new $PM_{2.5}$ standard. Data from many of those monitors are reported to the EPA AirData database (AirData).

Calhoun and Jackson Counties are within the TCEQ Corpus Christi Region where monitoring of several criteria pollutants is conducted at seven active continuous air-monitoring stations. Six of these stations are in Nueces and one is Victoria Counties. Pollutants including O_3, hydrogen sulfide, SO_2, $PM_{2.5,}$ methane, and non-methane organics have been recorded at the stations in Nueces County while only O_3 has been recorded at the Victoria County station.

4.11.1.3 Regulatory Requirements for Air Quality

The proposed LNG terminal would generate air emissions through both short-term construction activities and long-term operation of the stationary emission units at the facility. Emissions from all phases of construction and operation of the emission units would be subject to applicable state and federal air regulations. The new stationary air emission sources associated with operating the proposed LNG terminal would include the following:

- six natural gas fired Submerged Combustion Vaporizers (SCVs) with low NOx burners and a maximum heat input capacity of 50.1 million British thermal units per hour (MMBtu/hr);
- six natural gas fired SCVs with low NOx burners and a maximum heat input capacity of 79.2 MMBtu/hr;
- three 15.70 MMBtu/hr natural gas fired heating medium heaters;
- two 11,459 BTU/kW-hr backup natural gas generators;
- one 670 horsepower (hp) backup diesel generator;
- three 660 hp diesel firewater pumps;
- emergency flare;
- cold vent system for loading arms; and
- fugitive emission sources (valves, flanges, and other equipment).

The CAA of 1970, 42 USC 7401 et seq., as amended in 1977 and 1990, and 40 CFR 50-99 are the basic federal statutes and regulations governing air pollution in the United States. We have reviewed the following federal requirements to determine their applicability to the proposed Calhoun LNG Project.

The TCEQ is the lead air permitting authority for the Project. The TCEQ's air permitting requirements are codified in Title 30 of the Texas Administrative Code (30 TAC). These requirements incorporate the federal program requirements listed in 40 CFR Parts 50-99, and establish permit review procedures for all facilities that can emit pollutants to the ambient air. New facilities are required to obtain an air quality permit prior to initiating construction. No other pre-construction air quality permits are generally required.

Facilities can trigger additional review by EPA if emissions exceed the major source thresholds listed in 40 CFR 52.21(b)(1)(i). Emission control devices would be installed at the proposed LNG terminal to prevent potential emissions from the facility from exceeding these major source thresholds. The federal and state regulations established as a result of the CAA and the TCEQ that are potentially applicable to the Project include:

- New Source Review/Prevention of Significant Deterioration;
- New Source Performance Standards;
- Title V Operating Permit;
- National Emission Standards for Hazardous Air Pollutants;
- Maximum Achievable Control Technology;
- General Conformity;

- Chemical Accident Prevention Provisions;
- Control of Air Pollution from Marine Compression-Ignition Engines;
- State Regulations; and
- Best Available Control Technology.

New Source Review (NSR)

Separate procedures have been established for federal pre-construction review of certain large proposed projects in either attainment areas or non-attainment areas. The federal pre-construction review for new or modified sources located in attainment areas is Prevention of Significant Deterioration (PSD). The review process is intended to prevent the new source from causing existing air quality to deteriorate beyond acceptable levels. The federal pre-construction review for new or modified major sources located in non-attainment areas is commonly called Non-Attainment New Source Review (NNSR). NNSR only applies to the pollutants or their precursors that are classified as non-attainment. A new facility can undergo both PSD and NNSR review, depending on the emissions of various pollutants and the attainment status of the area. Calhoun and Jackson Counties are both classified as attainment areas for all criteria pollutants. Therefore, the proposed project area is not subject to NNSR permitting.

Prevention of Significant Deterioration

One of the factors considered in the PSD permit review is potential impacts on protected Class I airsheds located throughout the country. Class I areas are specifically designated as pristine wilderness areas. The LNG terminal would not be located in a Class I area, nor would it be located within 100 kilometers (62 miles) of a Class I area; therefore, a full Class I analysis would not be required to be included in the permit application. The closest Class I areas to the LNG terminal site are the Breton National Wildlife Refuge in Louisiana and Wichita Mountains National Park in Oklahoma, both approximately 535 miles from the site. Big Bend National Park, located in west Texas, is approximately 607 miles west-northwest of the project area.

"Major sources" that produce a significant emissions increase are reviewed for compliance with the PSD regulations. PSD review for major stationary sources includes: an assessment of the existing air quality; the use of analytic dispersion models to demonstrate compliance with the NAAQS and applicable PSD increments; a demonstration that control of emissions through use of best available control technology (BACT) has been applied to the subject emission sources; and an assessment of the impact of new emissions on the environmental resources such as soils and vegetation.

The emission threshold for "major stationary sources" varies under PSD according to the type of facility. As defined by 40 CFR 52.21 (b)(1)(i), a facility is considered major under PSD if it emits or has the potential to emit 250 tons per year (tpy) or more of any criteria pollutant or 100 tpy for specified source categories. There are no processes at any of the proposed facilities that are included as a specified source category; therefore, the PSD threshold for the proposed facilities is 250 tpy. The proposed facility emissions would not exceed the 250 tpy threshold any criteria pollutant and would not be considered a "major stationary source." Therefore, the proposed Project would not be subject to PSD permitting requirements.

New Source Performance Standards

New Source Performance Standards (NSPS), codified at 40 CFR 60, establish emission limits and associated requirements for monitoring, reporting, and recordkeeping for specific emission source categories. NSPS apply to new, modified, or reconstructed sources. The following NSPS requirements were identified as potentially applicable to the specified sources at the facility.

Subpart Dc of 40 CFR Part 60, Standards of Performance for Small Industrial-Commercial-Institutional Steam Generating Units, lists affected emission sources as fuel-fired steam-generating units with a heat input capacity of 10 million British thermal units MMBtu/hr to 100 MMBtu/hr. The definition of an applicable unit includes sources that produce steam or that heat water or any other heat transfer medium. The SCVs at the LNG facility are rated at 50.1 MMBtu/hr and 79.2 MMBtu/hr heat input; therefore, these units would be subject to the requirements of Subpart Dc.

Subparts Ka and Kb of 40 CFR Part 60, Standards of Performance for Volatile Organic Liquid (VOL) Storage Vessels, list affected emission sources as storage vessels containing VOL with regulatory applicability being dependent on the construction date of the storage vessel and the type and vapor pressure of the petroleum liquid. The new facility would have LNG storage tanks. Subpart Kb defines VOL as any organic liquid which can emit volatile organic compounds (VOCs) (as defined in 40 CFR 51.100) into the atmosphere. This would include the components contained in LNG (i.e., propane and butane). Therefore, Subpart Kb potentially could be applicable.

However, 40 CFR 60.116b(b) states that Subpart Kb does not apply to storage vessels with a capacity greater than or equal to 151 m^3, storing a liquid with a maximum true vapor pressure less than 3.5 kilopascals (kPa) (approximately 0.5 psi absolute). By definition, the maximum true vapor pressure is the equilibrium partial pressure exerted by the VOCs in the stored VOL. The VOC content of LNG is less than 10 percent by volume with the two largest VOC constituents being propane and butane. The partial pressure of the components of LNG representing butane and propane range maintained at -260°F is less than 3.5 kPa. Therefore, the proposed LNG tanks are exempt from the Subpart Kb requirements.

Subpart GG of 40 CFR Part 60, Standards of Performance for Stationary Gas Turbines, defines effected stationary gas turbines as those that have a heat input at peak load equal to or greater than 10 MMBtu/hr. The proposed LNG terminal would have stationary gas turbines with greater than 10 MMBtu/hr heat input; therefore, these units would be subject to the requirements of Subpart GG.

Subpart KKK of 40 CFR Part 60, Standards of Performance for Equipment Leaks of VOC from Onshore Natural Gas Processing Plants, includes a compressor station, dehydration unit, sweetening unit, underground storage tank, field gas gathering system, or LNG unit if it is located at an onshore natural gas processing plant. The proposed LNG terminal would have LNG units; therefore, would be subject to the requirements of Subpart KKK.

Title V Operating Permit

The Title V Operating Permit Program, as described in 40 CFR 70, requires major sources of air emissions and certain affected non-major sources to obtain a federal operating permit. In Texas,

authority to issue Title V operating permits has been delegated by EPA to the TCEQ. The major source emissions thresholds for determining the need for a Title V operating permit are: 100 tpy of any regulated air pollutant, 10 tpy of any individual hazardous air pollutant (HAP), or 25 tpy for all HAPs. Emissions from the proposed Calhoun LNG Project are expected to exceed 100 tpy and would therefore require Title V permit. Calhoun Point Comfort would prepare and submit an abbreviated Title V permit application once final facility designs are complete and emission sources are fully defined for the Calhoun LNG Project.

National Emissions Standards for Hazardous Air Pollutants

The National Emissions Standards for Hazardous Air Pollutants (NESHAPs), codified in 40 CFR Parts 61 and 63, regulate HAP emissions. Part 61 was promulgated prior to the 1990 Clean Air Act Amendments (CAAA) and regulates only eight types of hazardous substances (asbestos, benzene, beryllium, coke oven emissions, inorganic arsenic, mercury, radionuclides, and vinyl chloride). LNG storage and processing facilities do not fall under one of the source categories regulated by Part 61; therefore, the requirements of Part 61 are not applicable.

Maximum Achievable Control Technology

The 1990 CAAA established a list of 189 HAPs; resulting in the promulgation of Part 63. Part 63, also known as the Maximum Achievable Control Technology (MACT) standards, regulates HAP emissions from major sources of HAP emissions and specific source categories that emit HAPs. Part 63 defines a major source of HAPs as any source that has the potential to emit 10 tpy of any single HAP or 25 tpy of HAPs in aggregate. Emissions of HAPs from the proposed Project would not exceed the associated major source thresholds; therefore, no MACT standards apply to the proposed facility.

General Conformity

A conformity determination must be conducted by the lead federal agency if a federal action would generate emission that would exceed the conformity threshold levels (*de minimis*) of the pollutant(s) for which an air basin is in non-attainment. According to Section 176(c)(1) of the CAA (40 CFR 51.853), a federal agency cannot approve or support any activity that does not conform to an approved State Implementation Plan. Conforming activities or actions should not through additional air pollutant emissions: cause or contribute to new violations of the NAAQS in any area; increase the frequency or severity of any existing violation of any NAAQS; or delay timely attainment of any NAAQS or interim emission reductions. Emissions from sources subject to NSR or PSD requirements are exempt and are deemed to have conformed. The requirements for a conformity determination are listed in 40 CFR Parts 6, 51, and 93, and became effective March 15, 1994. Since the project area is classified as in attainment for all criteria pollutants, a General Conformity Determination is not required.

Chemical Accident Prevention Provisions

40 CFR Part 68, Chemical Accident Prevention Provisions, is a federal regulation designed to prevent the release of hazardous materials in the event of an accident and minimize impacts when releases do occur. The regulation contains a list of substances and threshold quantities for determining applicability of the rule to a facility. If a facility stores, handles, or processes one or more substances on this list and at a quantity equal to or greater than specified in the regulation,

the facility must prepare and submit a risk management plan (RMP). If a facility does not have a listed substance on-site, or the quantity of a listed substance is below the applicability threshold, the facility does not have to prepare a RMP. However, it still must comply with requirements of the general duty provisions in Section 112(r)(1) of the CAA 1990 Amendments if it has any regulated substance or other extremely hazardous substance on-site. The general duty of the provision is as follows:

> "The owners and operators of stationary sources producing, processing, handling and storing such substances have a general duty ... To identify hazards which may result from such releases using appropriate hazard assessment techniques, to design and maintain a safe facility taking such steps as are necessary to prevent releases, and to minimize the consequences of accidental releases which do occur."

With the exception of natural gas constituents (e.g., methane, ethane, propane, etc.), no regulated substance would be handled or stored in quantities greater than the applicability threshold. Natural gas pipelines are not covered if they are regulated by the DOT or an equivalent state natural gas program certified by DOT in accordance with 49 CFR 6010.5. In addition, storage of natural gas incidental to transportation (e.g., gas taken from a pipeline during non-peak periods and placed in storage, then returned to the pipeline when needed) is not covered. Consequently, an RMP is not required for this Project. The Calhoun LNG Terminal would maintain awareness of hazard issues and meet the goals of the above-listed general duty provisions.

Control of Air Pollution from Marine Compression-Ignition Engines

Regulation 40 CFR 94 (*Federal Register*, 2/28/03, 9746-9789) imposes regulations on marine compression-ignition engines manufactured on or after January 1, 2004. This standard does not apply to engines rated <37 kW, or engines on foreign vessels. Calhoun Point Comfort would require that U.S. flagged or registered vessels equipped with affected compression ignition engines manufactured after January 1, 2004 meet all applicable requirements of this subpart. It should be noted that most, if not all, LNG vessels are foreign flagged vessels, and not subject to this regulation.

Applicable State Air Quality Requirements

The TCEQ is the lead air permitting authority for the proposed Project. The TCEQ's air quality regulations are codified in Section 30 of the TAC Chapters 100-122. They incorporate the federal program requirements listed in 40 CFR 50-99 and establish permit review procedures for all facilities that can emit pollutants to the ambient air. Any new facility is required to obtain an air quality permit prior to initiating construction. Facilities can trigger additional review by EPA if emissions exceed the major source thresholds listed in 40 CFR Section 52.21(b)(1)(i).

Chapter 101 – General Rules. Chapter 101 includes the general rules that are applicable to all sources. The Project would comply with applicable requirements of this chapter. The applicable sections within this chapter include: 101.3 – Circumvention; 101.4 – Nuisance; 101.5 – Traffic Hazards; 101.8 – Sampling; 101.9 – Sampling Ports; 101.10 – Emissions Inventory Requirements; 101.13 – Use and Effect of Rules; 101.14 – Sampling Procedures and Terminology; 101.18 – Remedies Cumulative; 101.19 – Severability; 101.20 – Compliance with EPA Standards; 101.21 – The National Primary and Secondary Ambient Air Quality Standards; 101.22 – Effective Date; 101.24 – Inspection Fees; and 101.27 – Emission Fees.

It should be noted that the majority of the general rules would not apply until the facility has started operation. The proposed Project would minimize off-site impacts during the construction process as intended by the Texas Clean Air Act.

Chapter 106 – Exemptions from Permitting. The proposed Project has not claimed an exemption from permitting for any of the emission units at this facility.

Chapter 111 – Control of Air Pollution From Visible Emission and Particulate Matter. Construction activities for both the LNG terminal and Point Comfort Pipeline would be conducted pursuant to the applicable requirements of 111.145 – Construction and Demolition. The proposed Project would operate in compliance with 111.111 – Visible Emissions, Requirements for Specified Source, 111.153 – Emission Limits for Steam Generators, and 111.1555 – Ground Level Concentrations.

Chapter 112 – Control of Air Pollution from Sulfur Compounds. The proposed Project would comply with all applicable sections of this chapter. Applicable sections include: 112.2 – Sulfur Dioxide, Compliance Reporting and Recordkeeping; 112.3 – Sulfur Dioxide Net Ground Level Concentrations; 112.9 – Allowable Emission Rates – Combustion of Liquid Fuels; 112.31 – Hydrogen Sulfide Allowable Emissions – Residential, Business or Commercial Property; 112.33 – Hydrogen Sulfide Calculation Methods; 112.41 – Sulfuric Acid Emission Limits; and 112.42 – Sulfuric Acid Calculation Methods.

Chapter 113 – Standards of Performance for Hazardous Air Pollutants and for Designated Facilities and Pollutants. The proposed Project would not be a major source of HAPs; therefore, this regulation does not apply.

Chapter 114 – Controls of Air Pollution from Motor Vehicles. The proposed Project would not maintain a fleet on site; therefore, this regulation does not apply.

Chapter 115 – Control of Air Pollution from Volatile Organic Compounds (VOCs). The proposed Project would comply with all applicable sections of this chapter. Applicable sections include: Subchapter B – General VOC Sources, Division I – Storage of VOCs and Division 2, Vent Gas Control; Subchapter C – VOC Transfer Operations, Division I – Loading and Unloading of VOCs; and Subchapter J – Administrative Provisions, Division I – Alternative Means of Control and the provisions therein; 115.112 – Control Requirements; 115.113 – Alternate Control Requirements; 115.114 – Inspection Requirements; 115.115 – Approved Test Methods; 115.116 – Monitoring and Recordkeeping Requirements; 115.117 – Exemptions; 115.119 – Counties and Compliance Schedules; 15.120 – Vent Gas Definitions; 115.121 – Emission Specifications; 115.122 – Control Requirements; 115.123 – Alternate Control Requirements; 115.125 – Testing Requirements; 115.126 – Monitoring and Recordkeeping Requirements; 115.127 – Exemptions; 115.129 – Counties and Compliance Schedules; 115.211 – Emission Specifications; 115.212 – Control Requirements; 115.213 – Alternate Control Requirements; 115.214 – Inspection Requirements; 115.215 – Approved Test Methods; 115.216 – Monitoring and Recordkeeping Requirements; 115.217 – Exemptions; 115.219 – Counties and Compliance Schedules.

The proposed Project would control VOC emissions from tanks and vent stacks in accordance with the regulations and conduct the applicable inspections, testing, monitoring and

recordkeeping as required. Since the facility would be storing the natural gas as a cryogenic liquid (LNG), a majority of the provisions do not apply.

Chapter 116 – Control of Air Pollution by Permits for New Construction of Modification. The proposed Project is complying with this chapter by applying for and obtaining a permit to construct prior to initiating construction of the proposed facility.

Chapter 117 – Control of Air Pollution from Nitrogen Compounds. No specific requirements would apply to the proposed.

Chapter 118 – Control of Air Pollution Episodes. The proposed Project would operate the facility in compliance with the applicable sections of this chapter. An Emission Reduction Plan, pursuant to 118.5, is not required to be prepared because the facility does not exceed the emission threshold presented in this chapter.

Chapter 119 – Control of Air Pollution from Carbon Monoxide. The proposed Project would generate CO during the combustion process; however, these emissions would be minimized using proper combustion techniques and operating practices.

Chapter 120 – Control of Air Pollution from Hazardous Waste from Solid Waste Management Facilities. The proposed Project would not be a hazardous or solid waste management facility.

Chapter 122 – Federal Operating Permits. Emissions from the proposed Calhoun LNG Project are expected to exceed 100 tpy of any regulated air pollutant. Calhoun Point Comfort would prepare and submit an abbreviated Title V permit application once final facility designs are complete and emission sources are fully defined for the Calhoun LNG Project.

Best Available Control Technology – 30 TAC 116.111 (a)(2)(C)

Calhoun Point Comfort would utilize BACT for primary pollution control at the facility. A detailed BACT analysis is included in the facility's New Source Review Air Quality Permit application, which considers the technical practicability and economic reasonableness for reducing or eliminating the emissions for each major source pollutant generated by the facility. A summary of the facility's proposed BACT limits is provided below.

Best Achievable Control Technology Analysis. As part of the New Source Review Air Quality Permit application, Calhoun Point Comfort conducted a top-down BACT analysis for the SCVs, natural gas generators, diesel generator, firewater pumps, and flare. Calhoun Point Comfort submitted a BACT analysis to the TCEQ; the conclusion and requirements of this analysis are described below.

For the SCVs, the use of recirculated bath water for water injection to the burner flame and good combustion practices requiring the use of natural gas in the burners and limiting NO_x emissions from the SCVs to 125.76 tpy total from all 12 units is proposed as BACT. Good combustion control, which would limit CO emissions, is proposed as BACT. Good combustion practices and the use of natural gas are proposed as BACT for VOC, PM, and SO_2 emissions.

The natural gas and diesel generators would use low sulfur diesel fuel and would only be used to supply power to the facility when external electrical power is not available. Both generators would be limited to 100 hours per year of annual operation. The firewater pumps would supply water to the fire protection system in the event of an emergency. Good engine design and good combustion practices are proposed as BACT for CO, VOC, and PM emissions. The use of low sulfur fuel is proposed as BACT for SO_2 emissions. An emergency flare would be available with a continuous pilot. The flare would be fueled by natural gas and would be used under low sendout conditions while unloading the LNG vessel. Control efficiency for the flare would be at least 98 percent, which is standard BACT.

The New Source Review Air Quality permit application did not include a state property line air quality impact analysis. However, the TCEQ will verify prior to New Source Review Air Quality permit issuance that Texas state property line limits for particulate matter and sulfur oxides would not be violated by the proposed Project.

4.11.1.4 Air Quality Impacts and Mitigation

Construction Air Pollutant Emissions

Construction of the Calhoun LNG Terminal would occur over a period of approximately 35 months. Air emissions would result from non-road sources such as construction and dredging equipment operation operating within the terminal property boundary, Lavaca Bay, and the pipeline right-of-way. Air emissions would also be generated from delivery vehicles bringing supplies and equipment to the facility site, construction workers commuting in their personal vehicles, and other construction trucks that travel on roads. In addition, construction activities could generate an increase in fugitive dust (airborne dust that escapes from a construction site) from earthmoving and other construction vehicle movement.

Air emissions generated during construction are not subject to any permitting requirements. Air emissions during construction are only subject to state regulations limiting nuisance conditions (30 TAC Section 101.4, Nuisance) such as fugitive dust.

The estimated construction emissions during construction are shown in table 4.11.1.4-1 excluding fugitive dust emissions (see further explanation below).

TABLE 4.11.1.4-1

Total Estimated Construction Emissions (tpy)

Emission Activity a/	NO_2	VOC	CO	SO_2	PM_{10}	Operating Days
Construction Equipment						
Terminal facility construction	298.72	35.19	138.11	23.97	37.70	800
Haul trucks	18.24	1.64	5.31	1.69	1.52	800
Dredging activities	240.43	19.53	53.73	143.87	21.60	500
Dock and bulkhead construction	25.44	2.77	13.86	2.24	3.00	480
Pipeline	79.7	10.4	50.5	6.3	9.6	177

a/ Construction is anticipated to be completed within approximately 35 months.

The primary source of emissions would be from equipment utilized during the construction of the marine terminal, because this phase would take the longest period of time to complete and would involve the largest number of sources. Construction equipment would include marine construction equipment; cranes; earthmoving equipment; forklifts and man-lifts; air compressors; welding machines; bulldozers, graders, backhoes, front-end loaders; generator; and drilling, dredging, and pile driving equipment. The pipeline construction would also include welding trucks, boring machines, small engines and pumps, and fill and test pumps. The non-road sources are primarily diesel-fueled units.

Vehicular and marine vessel exhaust and crankcase emissions from gasoline and diesel engines would comply with applicable EPA mobile source emission regulations (40 CFR 85) by using equipment manufactured to meet these specifications.

Diesel engine emission standards and mandatory reductions in diesel fuel sulfur content have been adopted that would reduce emissions from heavy-duty construction vehicles. However, the diesel sulfur fuel reductions are not required until mid-2006, and the engine emission standards would be implemented in two stages that are not scheduled to be completed until 2007. To decrease emissions in the immediate future, the EPA created a voluntary diesel retrofit program to encourage the use of various technologies such as diesel particulate filters and oxidation catalysts. These controls require all construction equipment with diesel engines greater than or equal to 60 horsepower in size that are on the project for more than 30 days to be outfitted with emission control devices (such as oxidation catalysts) and/or use clean fuels. These controls also limit the idling of diesel vehicles to three minutes or less. Calhoun Point Comfort has stated that it would take all reasonable measures to reduce air emissions at the construction site. Calhoun Point Comfort, in conjunction with its construction contractor, would evaluate all feasible options for reducing emissions during construction.

Fugitive Dust

The existing industrial activities near the proposed LNG terminal area and vicinity currently generate dust as part of their ongoing operations, and this dust generation is expected to continue. Fugitive dust would be produced from equipment operating during construction of the proposed LNG terminal and pipeline. Calhoun Point Comfort would prepare a dust control plan to prevent fugitive dust generation during construction. If construction of the proposed LNG terminal and pipeline generates dust that causes a nuisance, then a surface wetting plan would be implemented to minimize dust generation. Water trucks, with a capacity of 2,000 to 4,000 gallons, would be used for dust suppression. There are no permanent residences located within 1.0 mile of the proposed LNG terminal.

Dust from the DMPAs is not anticipated to be a source of nuisance dust. Once the dredged material dries and is stable enough to be manipulated with equipment, the areas would be seeded with grasses for temporary and permanent stabilization. Until the areas are stabilized and if dust generation becomes a nuisance, the areas would be wetted as necessary until the temporary or final stabilization becomes established.

Air Pollutant Emissions from Operation

LNG Terminal Stationary Sources

New stationary air emissions sources associated with operation of the proposed Calhoun LNG Terminal include:

- six first-stage and six second-stage SCVs;
- three natural gas heaters;
- standby diesel and natural gas generators;
- three diesel driven firewater pumps; and
- emergency flare.

Anticipated annual emission levels for operation of the proposed stationary sources at the LNG terminal are shown in table 4.11.1.4-2. The emission data presented in this table are based on manufacturer-supplied emission factors supplemented with EPA default emission factors.

TABLE 4.11.1.4-2

Estimated Yearly Emissions from Terminal Operations – Stationary Sources (tons)

Equipment	NO_2	CO	SO_2	PM_{10}	VOC
Stationary Sources					
SCVs a/	125.76	101.94	1.98	25.32	18.30
Natural Gas Heaters b/	18.57	15.27	0.12	1.53	1.11
Standby Diesel Generator c/	0.45	0.04	0.07	0.01	0.01
Standby Natural Gas Generator c/	1.12	1.36	0.96	0.08	0.38
Diesel Firewater Pump c/	1.83	0.09	0.21	0.18	0.03
Emergency Flare d/	0.17	0.34	0.01	0	0.94
Fugitive Emissions e/	0.00	0.00	0.00	0.00	6.38
Cold Vent f/	0.00	0.00	0.00	0.00	0.01
Facility Total	**147.90**	**119.04**	**3.35 g/**	**27.12**	**27.16**
PSD Threshold	250.00	250.00	250.00 g/	250.00	250.00
Title V Threshold	100	100	100 g/	100	100

a/ Total emissions based on 12 SCVs operating continuously year round.
b/ Annual emissions based on 3 natural gas heaters operating continuously year round.
c/ Annual emissions for standby equipment based on 100 hours per year per source.
d/ Annual emissions based on a continuous natural gas pilot supplied by natural gas produced at the LNG terminal.
e/ Fugitive emissions are VOCs associated with minor equipment leaks at valves, flanges, seals, etc.
f/ Annual emissions based on loading arm venting every 3 days for about 5 minutes and an estimated 120 episodes per year.
g/ SO_2 emissions based on the presence of sulfur in the fuel and calculated for those sources to be operated by diesel fuel.

LNG Vessels and Tugboats

Operation of the proposed Project would result in emissions from LNG vessel vessels during receiving and handling and from the tugboats used to assist in the docking of the LNG vessels. It is anticipated that up to about 120 LNG vessels per year would be unloaded at the proposed facility. At least two tugboats would be available to assist each LNG vessel, although up to three tugboats may be used as needed. LNG unloading would be conducted using electric-driven submerged pumps powered by an onboard diesel generator. Each LNG vessel would be in the project area less than 24 hours.

The LNG vessels would be fueled with LNG and/or residual oil to provide steam to turbines, and there may also be diesel fueled auxiliary power generators on the vessels to provide power during offloading operations. The vessels would be fueled primarily with LNG while in transit from the LNG production point to the proposed terminal, although vessel propulsion would be switched primarily to residual oil when a vessel nears the docking area.

The primary pollutants that LNG vessels and tugboats would emit are SO_2 and NO_2, along with smaller amounts of CO, PM_{10}, $PM_{2.5}$, and VOCs, as shown in table 4.11.1.4-3. At 120 calls per year, the SO_2 emissions from LNG vessels would be about 568.33 tpy, and the emissions from tugboats working with the LNG vessels would be approximately 327.02 tpy, for a total of 859.35 tpy. The NO_2 emissions from LNG vessels would be about 313.45 tpy, and the emissions from tugboats working with the LNG vessels would be approximately 408.51 tpy, for a total of 721.96 tpy.

TABLE 4.11.1.4-3

Estimated Yearly Emissions from Terminal Operations – Mobile Sources (tons) a/

Equipment		NO_2	CO	PM_{10}	$PM_{2.5}$	SO_2	VOC
Mobile Sources							
LNG Vessels		313.45	24.61	20.65	16.60	568.33	9.57
Tug Boats		408.51	105.79	10.70	8.57	327.02	17.28
	Total	**721.96**	**130.4**	**31.35**	**25.17**	**859.35**	**26.85**

a/ Total mobile emissions of HAPs would be 37.22 tpy.

Waterway for LNG Marine Traffic

During normal operation, air emissions from LNG marine traffic and escort vessel traffic would occur all along the transit route; however, emissions affecting any one localized area would be temporary and transient and occur at distances allowing for considerable dispersion before reaching any sensitive receptors. Generally speaking, the LNG vessel transit route does not pass through or near any "non-attainment areas." The vessel and tug emissions, as mobile sources, are exempt from PSD or NNSR permitting.

Pipeline

Calhoun Point Comfort's supporting documentation does not provide any information specific to air quality for operation of the proposed pipeline. Operation emissions from the pipeline would be expected to be limited to fugitive dust generated by an occasional (weekly) maintenance vehicle driving on pipeline access roads. Impact on air quality from operation of the pipeline would be insignificant.

Operational Impact Assessment

In order to provide a more thorough evaluation of the potential impacts on air quality in the vicinity of the proposed project, the FERC asked Calhoun LNG, L.P. to conduct a quantitative assessment of project air emissions. The assessment included air dispersion modeling analyses to predict off-site (i.e., ambient) concentrations in the vicinity of the project for both criteria pollutants (PM_{10}, SO_2, NO_2, and CO) and HAPs resulting from the proposed emissions associated with operation of the project for comparison to appropriate federal air quality standards. A summary of the methodology and results of the analyses is provided below.

Assessment Methodology Overview

The air quality dispersion modeling analysis was conducted to determine cumulative impacts of emissions from both terminal stationary sources and mobile marine sources. Emission estimates from the stationary sources at the terminal have been modeled and approved by the TCEQ. Mobile marine emissions were modeled under two scenarios, docking/undocking and unloading/hotelling. The model used for the analysis was BEE-Line Software's BEEST for Windows ISCST3/ISC-Prime/AerMod modeling system. The BEEST system also employs EPA's Building Profile Input Program algorithms to develop downwash parameters of nearby structures for input to the dispersion model. The meteorological data set used in the analysis was the "1 Year Met Set" for Calhoun County in the Victoria area, and consisted of Victoria surface and upper air data for 1988. This data set recommended and approved by TCEQ.

All mobile sources were modeled as a point source at a single location located approximately 250 yards from dock (in the center of the 500-yard radius moored safety/security zone as defined by FERC staff). Impact concentrations were predicted at the closest non-industrial receptor (NIR) and at receptors along the terminal property boundary closest to the NIR using air dispersion modeling. The "property line" for the marine model is an area of 350 meters x 100 meters which includes emission sources from the LNG vessel as well as assisting tugboats. The receptor array consisted of 25 meter spaced receptors which began 25 meters beyond the property line boundaries along the water and extended out 1,700 meters to include near and far field areas for stationary and mobile sources. A discrete receptor was placed at the nearest off-site public access site (a local convenience store). A detailed list of modeling assumptions, emission sources, emission rates, and stack parameters is provided in the *June 2007 Marine Mobile Source Air Dispersion Modeling Analysis During Docking and Undocking Conditions* and the *June 2007 Marine Mobile Source Air Dispersion Modeling Analysis During LNG Unloading and Hotelling Conditions* reports for Calhoun LNG Terminal prepared by Hill County Environmental, Inc. filed on July 2, 2007.

Modeling Results

Tables 4.11.1.4-4 through 4.11.1.4-8 summarize the dispersion model predicted impact concentrations, the stationary terminal sources, the mobile marine sources, and all sources. These results are compared to State and NAAQS and health effects screening limits (ESLs). Modeled impacts from cumulative sources are less than ESLs for all contaminants. Maximum predicted criteria pollutant concentrations over the entire project area, at the terminal property boundary, and at the non-industrial receptor have been compared to the NAAQS primary standards as a benchmark. The maximum concentrations over the entire project area are located over water and in some cases exceed the NAAQS; however, the maximum concentration at the closest non-industrial receptor and property boundary are below the benchmark. The mobile marine sources modeled in this study are not typically compared to the NAAQS as a threshold comparison, but instead as a gauge of impacts. The LNG vessels would be non-U.S. flagged ships, and therefore do not currently have any U.S. standards to comply with and compare to, nor are there mitigation requirements. There are no U.S. flagged LNG vessels currently built or in operation. Also, as described below, the project was conservatively modeled under most scenarios, and therefore actual impacts should be lower.

TABLE 4.11.1.4-4

Calhoun LNG Predicted 1-Hour HAP Concentrations

Pollutant	Max. Concentration ($\mu g/m^3$)			Concentration at Property Boundary ($\mu g/m^3$)			Concentration at NIR ($\mu g/m^3$)			Annual ESL ($\mu g/m^3$)
	Stationary	Mobile	All	Stationary	Mobile	All	Stationary	Mobile	All	
Acetaldehyde	0.07038	0.04287	0.11325	0.03713	0.03017	0.0673	0.01463	0.00826	0.02289	90
Acrolein	0.05958	0.01336	0.07294	0.03145	0.0094	0.04085	0.01242	0.00257	0.01499	2.3
Benzene	0.12682	1.32	1.44682	0.06694	0.9255	0.99244	0.02641	0.25336	0.27977	75
Formaldehyde	0.2735	0.1336	0.4071	0.14437	0.09401	0.23838	0.057	0.02575	0.08275	15
Naphthalene	0.00659	0.22017	0.22676	0.00347	0.15493	0.1584	0.00137	0.04243	0.0438	440
Toluene	0.58192	0.47447	1.05639	0.30691	0.33388	0.64079	0.12086	0.0915	0.21236	1,880
Xylene	0.39394	0.32713	0.72107	0.20847	0.2302	0.43867	0.0804	0.06304	0.14344	3,700

TABLE 4.11.1.4-5

Calhoun LNG Predicted Annual HAP Concentrations

Pollutant	Max. Concentration ($\mu g/m^3$)			Concentration at Property Boundary ($\mu g/m^3$)			Concentration at NIR ($\mu g/m^3$)			Annual ESL ($\mu g/m^3$)
	Stationary	Mobile	All	Stationary	Mobile	All	Stationary	Mobile	All	
Acetaldehyde	0.00303	0.00218	0.00521	0.00119	0.00009	0.00128	0.00008	0.00004	0.00012	9
Acrolein	0.00257	0.00068	0.00325	0.00101	0.00003	0.00104	0.00007	0.00001	0.00008	0.23
Benzene	0.00546	0.06689	0.07235	0.00215	0.00283	0.00498	0.00014	0.00132	0.00146	3
Formaldehyde	0.01179	0.00679	0.01858	0.00464	0.00029	0.00493	0.00031	0.00014	0.00045	1.5
Naphthalene	0.00028	0.0112	0.01148	0.00011	0.00047	0.00058	0.00001	0.00022	0.00023	44
Toluene	0.02506	0.02415	0.04921	0.00987	0.00103	0.0109	0.00065	0.00049	0.00114	188
Xylene	0.0171	0.01663	0.03373	0.00661	0.00071	0.00732	0.00044	0.00033	0.00077	370

TABLE 4.11.1.4-6

Calhoun LNG Predicted Criteria Pollutant Concentrations – Stationary Sources Only

Pollutant / Averaging Period	Background Concentration ($\mu g/m^3$)	Max. Concentration ($\mu g/m^3$)	Max. Concentration w/ Background ($\mu g/m^3$)	Concentration at Property Boundary ($\mu g/m^3$)	Concentration at Property Boundary w/ Background ($\mu g/m^3$)	Concentration at NIR ($\mu g/m^3$)	Concentration at NIR w/ Background ($\mu g/m^3$)	NAAQS Primary ($\mu g/m^3$)
CO 1-hr	4,000	594	4594	313	4,313	129	4129	40,000
CO 8-hr	1,000	271	1271	193	1,193	21.94	1,021.94	10,000
NO_2 Annual	20	32.48	52.48	13.47	33.47	0.87	20.87	100
SO_2 24-hr	75	87.15	162.15	39.66	114.66	4.42	79.42	365
SO_2 Annual	12	12.52	24.52	4.93	16.93	0.33	12.33	80
PM_{10} 24-hr	25	41.47	66.47	18.98	43.98	2.1	27.1	150
$PM_{2.5}$ Annual	NA	6.32	NA	2.49	NA	0.16	NA	15

TABLE 4.11.1.4-7

Calhoun LNG Predicted Criteria Pollutant Concentrations – Mobile Marine Sources Only a/

Pollutant / Averaging Period	Background Concentration ($\mu g/m^3$) b/	Max. Concentration ($\mu g/m^3$)	Max. Concentration w/ Background ($\mu g/m^3$)	Concentration at Property Boundary ($\mu g/m^3$)	Concentration at Property Boundary w/ Background ($\mu g/m^3$)	Concentration at NIR ($\mu g/m^3$)	Concentration at NIR w/ Background ($\mu g/m^3$)	NAAQS Primary ($\mu g/m^3$)
CO 1-hr	4,000	1251	5251	880	4,880	231	4231	40,000
CO 8-hr	1,000	792 c/	1,792	130.5 c/	1130.5	37.02 c/	1,037.02	10,000
NO_2 Annual	20	609	629	26.18	46.18	12.34	32.34	100
SO_2 24-hr	75	1477.22 c/	1552.22	171.07 c/	246.07	56.14 c/	131.14	365
SO_2 Annual	12	469	481	21.43	33.43	10.83	22.83	80
PM_{10} 24-hr	25	48.39 c/	73.39	5.17 c/	30.17	1.69 c/	26.69	150
$PM_{2.5}$ Annual	NA	12.43	NA	0.57	NA	0.29	NA	15

a/ It is assumed that out of any 24 hour period, it takes 1 hour to dock, secure the vessel and shut down the main engines once the LNG vessel and tug boats are in the 500 yard radius moored safety/security zone. It is also assumed that out of any 24-hour period, it takes 1 hour to unsecure the vessel and start up the main engines and exit the 500 yard radius moored safety/security zone.
b/ Background concentrations are from Region 14. No data for Calhoun County was available.
c/ Maximum predicted ground level concentrations for the mobile marine sources have been reduced to account for the expected source operating time. The following reduction levels were applied: 87.5% for 8-hour concentrations (corresponds to 1 hour per 8 hour period), 91.67% for 24-hour concentrations (corresponds to 2 hours per 24-hour period).

TABLE 4.11.1.4-8

Calhoun LNG Predicted Criteria Pollutant Concentrations – All Sources a/

Pollutant / Averaging Period	Background Concentration (µg/m3) b/	Max. Concentration (µg/m3)	Max. Concentration w/ Background (µg/m3)	Concentration at Property Boundary (µg/m3)	Concentration at Property Boundary w/ Background (µg/m3)	Concentration at NIR (µg/m3)	Concentration at NIR w/ Background (µg/m3)	NAAQS Primary (µg/m3)
CO 1-hr	4,000	1845	5845	1193	5193	360	4360	40,000
CO 8-hr	1,000	1063 c/	2063	323.5 c/	1323.5	58.96 c/	1058.96	10,000
NO_2 Annual	20	641.48	661.48	39.65	59.65	13.21	33.21	100
SO_2 24-hr	75	1564.37 c/	1639.37	210.73 c/	285.73	60.56 c/	135.56	365
SO_2 Annual	12	481.52	493.52	26.36	38.36	11.16	23.16	80
PM_{10} 24-hr	25	89.86 c/	114.86	24.15 c/	49.15	3.79 c/	28.79	150
$PM_{2.5}$ Annual	NA	18.75	NA	3.06	NA	0.45	NA	15

a/ It is assumed that out of any 24 hour period, it takes 1 hour to dock, secure the vessel and shut down the main engines once the LNG vessel and tug boats are in the 500-yard radius moored safety/security zone. It is also assumed that out of any 24 hour period, it takes 1 hour to unsecure the vessel and start up the main engines and exit the 500 yard radius moored safety/security zone.
b/ Background concentrations are from Region 14. No data for Calhoun County was available.
c/ Maximum predicted ground level concentrations for the mobile marine sources have been reduced to account for the expected source operating time. The following reduction levels were applied: 87.5% for 8-hour concentrations (corresponds to 1 hour per 8 hour period), 91.67% for 24-hour concentrations (corresponds to 2 hours per 24-hour period).

All NAAQS exceedances shown above occur at the maximum concentration which would be located over water. At the property boundary and beyond all concentrations including background levels would be below the NAAQS.

For the short-term 1-hour averaging time, both of the mobile marine scenarios would not occur at the same time; therefore, the results below reflect the greater concentration of either scenario for each individual pollutant. All other averaging times (8-hour, 24-hour and annual) mobile results reflect the maximum result of each scenario added together. This is conservative for the overall maximum concentration since the maximum would occur at a different location for each of these two scenarios. The stationary and mobile sources combined impacts (All) conservatively reflect the stationary maximums added to the mobile source maximums. This is especially conservative for the overall maximum concentration since the maximum for each scenario would occur at a different location. Also, annual concentration results are conservative since continuous operation was modeled, when there would not be LNG vessels and tugs in the turning basin 365 days a year. PM_{10} annual results were not included in this analysis since the PM_{10} annual NAAQS was revoked on December 17, 2006.

4.11.2 Noise

Noise would affect the local environment during both the construction and operation of the proposed Calhoun LNG Terminal and Point Comfort Pipeline. At any location, both the magnitude and frequency of environmental noise may vary considerably over the course of the day and throughout the week. This variation is caused in part by changing weather conditions and the effects of seasonal vegetative cover. Two measures used by federal agencies to relate the time-varying quality of environmental noise to its known effect on people are the 24-hour equivalent sound level ($L_{eq(24)}$) and the day-night sound level (L_{dn}). The $L_{eq(24)}$ is the level of steady sound with the same total (equivalent) energy as the time-varying sound of interest, averaged over a 24-hour period. The L_{dn} is the $L_{eq(24)}$ with 10 decibels on the A-weighted scale (dBA) added to the nighttime sound levels between the hours of 10 p.m. and 7 a.m., to account for the greater sensitivity of people to sound during the nighttime hours.

4.11.2.1 Regulatory Requirements

In 1974, the EPA published *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety* (EPA, 1974). This publication evaluates the effects of environmental noise with respect to health and safety. The document provides information for state and local governments to use in developing their own ambient noise standards. The EPA has determined that in order to protect the public from activity interference and annoyance outdoors in residential areas, noise levels should not exceed an L_{dn} of 55 dBA. The FERC has adopted this criterion for new compression and associated pipeline facilities, and it is used here to evaluate the potential noise impact from operation of the Calhoun LNG Terminal. An L_{dn} of 55 dBA is equivalent to a continuous noise level of 48.6 dBA for facilities that operate at a constant level of noise. Because neither the State of Texas nor Calhoun County has noise regulations that would limit noise from the Calhoun LNG Terminal, the FERC criterion is the basis for determining the acceptability of expected facility noise levels at the noise sensitive areas (NSAs).

The City of Point Comfort has a noise ordinance that provides limitations for noise disturbances created by construction, demolition, and drilling equipment during evening hours, weekends, and holidays. The ordinance allows variances for these time-of-day limitations imposed in Article VI, Section B(5)(a). In addition to noise restrictions, the ordinance also prohibits perceptible vibration beyond the property line of the source.

4.11.2.2 Existing Noise Levels

The nearest NSA to the Calhoun LNG Terminal is along the southern edge of the City of Point Comfort and consists of several residences on the south side of the city, north of State Route 35, about 12,000 feet north of the LNG terminal site. The Calhoun LNG Terminal would be separated from this NSA by the Alcoa PCO and Formosa Hydrocarbons Company industrial facilities and State Route 35.

The acoustical engineering company Hoover & Keither, Inc. (H&K) determined that no NSAs are located within 1 mile of the site. The nearest NSA near the LNG terminal consists primarily of residences in the city of Point comfort, located more than 2 miles (about 12,000 feet) north of the LNG terminal site. H&K conducted an ambient noise survey at the nearest NSA on September 21, 2005, and measured an L_{dn} level of 52.4 dBA (H&K, 10/12/05).

4.11.2.3 Impact and Mitigation

Potential impacts from the proposed Project would be caused by temporary increases in noise during construction and permanent increases in noise due to operation of the Project. These potential noise increases were compared with the FERC standard for permissible noise at NSAs.

Waterway for LNG Marine Traffic

Noise-sensitive receptors in the vicinity of the MSC are located in the City of Port Lavaca and the communities of Port O'Connor, Magnolia Beach, Indianola, Alamo Beach, and Point Comfort. These are within Zones 2 and 3. The existing noise environment of these communities is affected by a number of sources, most of which are transportation-related (i.e., barges, roadway, etc.). Waterborne transportation activities that currently contribute to the region's ambient noise environment include vessel traffic, barges, commercial fishing/shrimping vessels, sport and recreation boats, and periodic maintenance dredging of the channel. Other sources that contribute to the existing noise environment of these communities include activities at nearby commercial enterprises, such as restaurants, marinas, and commercial fishing and shrimping businesses, as well as light industrial activities.

The transit of LNG vessels is not expected to result in long-term noise impacts. No permanent noise sources would be installed along the waterway, with the exception of the LNG terminal itself. In the short-term, however, the proposed action could result in slightly elevated noise levels at noise-sensitive receivers located at Magnolia Beach and Alamo Beach. LNG vessels would be guided through the channel by three 80-tonne bollard pull (approximately 9,000 hp), azimuthing stern drive tractor tugboats. There would be approximately 120 LNG vessels transported through the channel per year (i.e., three LNG vessels per week). The primary source of noise would be emitted by the tugboats' engines. Noise emissions for large tugboats have been measured at 87 dBA at 50 feet from the source (Epsilon Associates, 2006).

The channel is located a great distance from the shoreline and noise-sensitive receivers. The nearest noise sensitive receivers, which are located at Magnolia Beach, lie approximately 3,000 feet from the channel. This large distance between the noise source and receivers would greatly reduce LNG vessel traffic-related noise levels at these receivers. Table 4.11.2.3-1 summarizes the approximate distances of noise-sensitive receivers from the ship channel and the calculated noise levels from LNG vessel transit at the receivers. Existing ambient noise levels within the project area range between 52.4 and 65.1 dBA (L_{dn}). Noise levels at sensitive receivers would be less than the existing ambient conditions beyond 4,100 feet from the channel as LNG vessels are transported through the channel. Short-term impacts related to the LNG vessel transit operations therefore would be nearly identical to the short-term impacts that occur during the transit of other vessels. Transit of LNG vessels along the MSC would not substantially increase ambient noise levels at noise sensitive receivers.

TABLE 4.11.2.3-1

Calculated Noise Level of LNG Vessel Transit

Noise Sensitive Receiver Location	Distance From Channel (feet)	Calculated Noise Level of LNG Vessel Transit (L_{eq})
Port O'Connor	8,100	50 dBA
Indianola	8,000	50 dBA
Magnolia Beach	3,000	57 dBA
Alamo Beach	4,100	55 dBA
Port Lavaca	16,500	43 dBA
Point Comfort	10,000	48 dBA

LNG Terminal

A noise impact analysis was conducted that considered the maximum operational noise produced by all significant sound sources associated with the LNG terminal that could potentially impact the sound level at the NSA. The analysis was based on current operating design conditions and project drawings, and noise source level data for the equipment was obtained from direct measurements of similar equipment at other LNG terminals. The sound power levels of the equipment, after considering the quantities of each type, ranged from a low of 99 dBA to a high of 125 dBA. The estimated sound level attributable to the Calhoun LNG Terminal at the nearest NSA and the estimated total L_{dn} and potential noise increase above ambient is summarized in table 4.11.2.3-2.

TABLE 4.11.2.3-2

Noise Impact Analysis at the Nearest Noise Sensitive Area

NSA Distance and Direction from Terminal Site	Ambient L_{dn} at nearest NSA (dBA)	Calculated L_{dn} of the Calhoun LNG Terminal (dBA)	Estimated Total L_{dn} (dBA)	Potential Noise Increase (dBA)
12,000 feet North	52.4	38.0	52.6	0.2

The calculated operational noise level of 38.0 dBA is less than the measured ambient L_{dn} level of 52.4 dBA. The addition of the LNG terminal's maximum operating capacity noise level to the existing environment would raise the ambient noise level by only 0.2 dBA, which would not be perceptible. An increase of 3 dBA is generally considered to be the smallest increase that is perceptible. In addition, the predicted level of 38.0 dBA is significantly below the 55 dBA level required by the FERC. Thus, noise from operation of the LNG terminal facility should not create a significant noise impact at the NSAs along the south side of the City of Point Comfort.

Construction activities for the Calhoun LNG Terminal could contribute short-term noise increases at the NSAs, but these would largely be masked by industrial noise from the Alcoa PCO and Formosa Hydrocarbons Corporation facilities and Port activities which occur 24 hours a day 7 days a week. Construction activities could proceed for 35 months and would normally be limited to daylight hours.

The highest level and most distinguishable source of construction noise would be a pile driver required for construction of the LNG ship berth. Other construction activities that would produce noise include dredging for the new turning basin and ship berth, and earthwork (e.g., grading/clearing/grubbing), foundation excavation and concrete pouring, steel erection, equipment installation, and startup and testing for the LNG terminal.

The predicted sound level contributed by construction activities was calculated from measured A-weighted sound levels of the types, sizes, and quantities of construction equipment expected to be in operation during each phase of construction. To produce a conservative result, this analysis was based on the most equipment intensive phase of each activity. The results of this analysis are presented in table 4.11.2.3-3 below. Pile driving would produce the highest level at 34 dBA at the NSA, but would only occur during daylight hours. Construction of the LNG terminal and dredging would produce L_{eq} levels of 30 dBA and 26 dBA, respectively at the NSAs. Construction of the LNG terminal would also be conducted only during the daytime hours.

Dredging activities would be continuous and take place over a four-month period. Expected noise levels at the NSA would be about 8 dBA lower than for the other construction activities since less equipment would be needed. However, the L_{dn} level would be about the same as for the other activities that would only occur during the day. Dredging noise and much of the normal terminal construction noise would be indistinguishable from existing noise from the Port.

The highest predicted L_{dn} level is only 34 dBA, which is significantly below the 55 dBA level identified by the FERC as significant. It is also below the existing L_{dn} of about 52.4 dBA at the NSAs, which means that the sound would likely not be noticeable. Therefore, construction of the LNG terminal is not expected to result in a significant noise impact at any NSA.

TABLE 4.11.2.3-3

Expected Construction Noise Levels at NSAs

LNG Terminal Construction (12,000 feet to NSA)		**Pile Driving Operations (12,000 feet to NSA)**		**Dredging Operations (12,000 feet to NSA)**	
L_{eq}	**L_{dn}**	**L_{eq}**	**L_{dn}**	**L_{eq}**	**L_{dn}**
30.0 dBA	30.0 dBA a/	34.0 dBA	34.0 dBA a/	26.0 dBA	32.4 dBA

a/ Same as L_{eq} since there would be no nighttime construction or pile driving.

Because the existing and construction noise levels discussed above are based on measured levels, and the predicted levels due to construction are well below the existing ambient level, we believe that a construction noise mitigation plan would not be required. In fact, due to the logarithmic nature of decibel addition, one hundred times as much equipment would be required to raise the predicted levels 20 dBA to near the 55 dBA limit that would be considered a significant impact.

During operation of the LNG terminal, noise would also be generated by the LNG vessels transiting the MSC. Noise generated from the LNG vessels would be similar to noise generated from large vessels that currently traverse the ship channel. In addition, noise from LNG vessels transiting the ship channel would not be additive with noise from existing marine traffic because the Coast Guard would likely impose a moving safety zone around LNG vessels (see sections 4.12.5.3 through 4.12.5.6). A moving safety zone would result in only one large vessel traversing any one location along the channel at any point in time. Therefore, it is expected that LNG marine traffic would not result in an increase in noise levels above the existing levels along the MSC.

Pipeline

During construction of the Point Comfort Pipeline, neighbors in the vicinity of the construction right-of-way would hear construction noise. Traffic and farm machinery are the primary sources of ambient noise. Pipeline construction would proceed at rates of from several hundred feet to 1.0 mile per day. However, due to the assembly line nature of construction, activities in any area could last from several weeks to several months on an intermittent basis.

Construction equipment would be operated on an as-needed basis. Exact noise levels cannot be determined; however, we can estimate noise levels as a function of the distance of the receptor from the equipment. Assuming the operation of a piece of equipment results in typical noise levels of 88 dBA at 50 feet, the noise impact of that equipment would be 82 dBA at 100 feet and 72 dBA at 300 feet from the equipment. Noise would diminish rapidly as the distance from the noise source increases.

Normally there would be no nighttime noise from construction. Most construction, except for HDD operations, would be limited to daytime hours. HDD operations are usually 24-hour per day operations requiring up to two weeks for completion. While individual receptors in the immediate vicinity would experience an increase in noise, the effect would be temporary and local.

H&K, on behalf of Calhoun, prepared an acoustical assessment to establish expected noise levels from HDD operations at NSAs along the pipeline route within 1.0 mile of the HDD sites. The acoustical assessment was based on operating conditions of HDD equipment, project drawings, and ambient sound survey measurements recorded at HDD locations (Kiteck, 2005b). Seven HDD locations were evaluated (see figure 4.11-1) and consist of the following:

- HDD 1 (MP 0.2 to 0.3) – Two NSAs located 10,500 feet and 9,500 feet north-northwest of the HDD entry and exit point, respectively. These are houses are on Wood Street in the City of point Comfort; however, the HDD would occur within an industrialized area (see figure 4.11-2).

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- HDD 2 (MP 0.7 to 0.8) – Two NSAs located 8,000 feet and 7,000 feet north-northwest of the HDD entry and exit point, respectively. These are houses on Wood Street in the City of point Comfort; however, the HDD would occur within an industrialized area (see figure 4.11-2).
- HDD 3 (MP 2.2 to 2.8) – Two NSAs located 800 feet northwest and 600 feet south-southwest of the HDD entry and exit point, respectively. These are homes along Jones Street and Julia Street, respectively (see figure 4.11-3).
- HDD 4 (MP 13.5 to 13.7) – Two NSAs located 400 feet northwest and 700 feet south-southeast of the HDD entry and exit point, respectively. These include a house and railroad office on FM 616, respectively (see figure 4.11-4).
- HDD 5 (MP 16.3 to 17.0) – Two NSAs located 2,000 feet east and 5,000 feet east-southeast of the HDD entry and exit point, respectively. These are houses on the east side of the Navidad River (see figure 4.11-5).
- HDD 6 (MP 22.8 to 23.5) – Two NSAs located 2,200 feet east and 1,600 feet south-southwest of the HDD entry and exit point, respectively. These are house on the east and west side of the Lavaca River, respectively (see figure 4.11-6).
- HDD 7 (MP 25.2 to 25.6) – Two NSAs located 2,000 feet west and 1,000 feet southwest of the HDD entry and exit point, respectively. These include houses along FM 234 (see figure 4.11-7).

The ambient sound survey was conducted on September 21, 2005 (Kiteck, 2005b). Sound levels were measured during the late morning and mid-afternoon to establish average daytime L_{eq} levels. Nighttime ambient sound surveys were not conducted due the arrival of Hurricane Rita. As a result, these levels were estimated based on the daytime measurements and observed surrounding environment. These were then used to calculate the L_{dn} levels. In addition to noise level measurements, H&K identified and recorded the contributing noise sources, along with the prevailing meteorological conditions.

The measured existing ambient sound levels, calculated sound levels attributable to HDD activities at the seven HDD locations at the nearest NSA, the estimated total dBA $L_{dn,}$ and the potential noise increase above ambient are summarized in table 4.11.2.3-4. HDD activity noise levels at NSAs near location 1, 2, 5, 6, and 7 are expected to be below 55 dBA L_{dn} without mitigation. However, at locations 3 and 4, the levels could be as high as 70.7 dBA L_{dn} if no mitigation measures are employed. Consequently, Calhoun Point Comfort has developed a comprehensive HDD noise mitigation plan that describes proposed mitigation measures for these two sites. The plan includes conducting sound surveys at NSAs near locations 3 through 7 during HDD activities to document actual noise levels, as well as a plan to further mitigate any levels that are found to be above 55 dBA L_{dn}. Initial mitigation measures include erection of temporary sound barriers and relocation of some equipment. For any locations found to exceed 55 dBA, Calhoun Point Comfort would:

a. immediately stop drilling and mitigate the noise at the affected NSAs to reduce the noise levels at those NSAs to 55 dBA $L_{\mathbf{dn}}$ or below; or
b. offer temporary housing until L_{dn} levels at the NSAs are 55 dBA or below, or offer equivalent monetary compensation.

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We believe that Calhoun Point Comfort's proposed HDD noise mitigation plan would adequately avoid or minimize noise generated by HDD construction activities.

TABLE 4.11.2.3-4

Noise Impact Analysis at the Nearest Noise Sensitive Area

HDD Location	NSA Distance and Direction from HDD Entry and Exit Point	Ambient L_{dn} at the HDD Entry and Exit Point (dBA)	Calculated Sound Contribution of HDD Activity (dBA)	Potential Noise Increase (dBA)
1	10,500 feet and 9,500 feet north-northwest	52.4	a/	a/
2	8,000 feet and 7,000 feet north-northwest	52.4	a/	a/
3	800 feet northwest and 600 feet south-southwest	52.4 – 52.8	53.5	0.7
4	400 feet northwest and 700 feet south-southeast	46.6 – 48.2	51.3	3.1
5	2,000 feet east and 5,000 feet east-southeast	46.9	50.7 – 33.7	3.8 - (13.2)
6	2,200 feet east and 1,600 feet south-southwest	38.7 – 38.0	48.0 – 48.8	9.3 – 10.8
7	2,000 feet west and 1,000 feet southwest	45.9	50.7 – 54.4	4.8 – 8.5

a/ Sound contribution of HDD location not calculated since NSAs are great than 7,000 feet from the HDD that would occur in a highly industrial area.

Operational noise impacts from the pipeline would be limited to the vicinity of the metering stations. The buried pipeline would not contribute to aboveground noise levels, and noise from metering stations would be insignificant. The metering stations would primarily be in rural/agricultural areas of Calhoun and Jackson Counties; however, the Formosa Hydrocarbons interconnect, at MP 1.7, would be in an industrial area. Calhoun Point Comfort indicated that it would employ noise mitigation measures to ensure that the predicted levels at its metering/interconnect sites are below an L_{dn} of 55 dBA.

4.12 RELIABILITY AND SAFETY

Three federal agencies share in the oversight of the safety and security of LNG import terminals: the FERC, the Coast Guard, and the DOT. The FERC authorizes the siting and construction of LNG import terminals and is the lead federal agency under NEPA to analyze the environmental, safety, security, and cryogenic design of proposed facilities. The Coast Guard has authority over the safety of LNG vessels and the marine transfer area. The Coast Guard also has authority over security of LNG vessels and the entire LNG facility. In conjunction with this, the Coast Guard determines the suitability of waterways for LNG marine traffic by issuing an LOR. The DOT has exclusive authority to promulgate and enforce safety regulations and standards over the onshore LNG facilities beginning at the last valve immediately before the LNG storage tank(s).

In February 2004, the three participating agencies entered into an Interagency Agreement to assure that they work in a coordinated manner to address the full range of issues regarding safety and security at LNG import terminals, including the terminal facilities and tanker operations, and to maximize the exchange of information related to the safety and security aspects of the LNG

facilities and related marine operations. The FERC closely coordinates its pre-authorization review of the proposal with the Coast Guard and the DOT to ensure a seamless safety and security review.

The operation of the proposed Calhoun LNG Terminal poses a potential hazard that could affect the public safety without strict design and operational measures to control potential accidents. The primary concerns are those events that could lead to an LNG spill of sufficient magnitude to create an off-site hazard including events occurring during the course of but not limited to LNG vessel transits. However, it is also important to recognize the stringent requirements for the design, construction, operation and maintenance of the facility as well as the extensive safety systems to detect and control potential hazards.

With the exception of the October 20, 1944 fire at the LNG facility in Cleveland, Ohio, the operating history of U.S. LNG facilities has been free of LNG safety-related incidents resulting in adverse effects to the public or the environment. The 1944 Cleveland incident was attributed to the use of materials inadequately suited for cryogenic temperatures and the lack of spill impoundments at the site.[7] More recently, an operational accident occurred in 1979 at the Cove Point LNG facility in Lusby, Maryland, when a pump seal failed, resulting in gas vapors entering an electrical conduit and settling in a confined space. When a worker switched off a circuit breaker, the gas ignited, resulting in heavy damage to the building and a worker fatality. Lessons learned from this accident resulted in changing the national fire codes, with the participation of the FERC, to ensure that the situation would not occur again. The proposed facilities would be designed, constructed, and operated in compliance with these codes.

On January 19, 2004, a blast occurred at Sonatrach's Skikda, Algeria LNG liquefaction facility that killed 27 and injured 56 workers. No members of the public were injured. Preliminary findings of the accident investigation suggest that a cold hydrocarbon leak occurred at Liquefaction Train 40 and was introduced to the high-pressure steam boiler by the combustion air fan. An explosion developed inside the boiler firebox which subsequently triggered a larger explosion of the hydrocarbon vapors in the immediate vicinity. The resulting fire damaged the adjacent liquefaction process and liquid petroleum gas (LPG) separation equipment of Train 40, and spread to Trains 20 and 30. Although Trains 10, 20, and 30 had been modernized in 1998-1999, Train 40 had been operating with its original equipment since start-up in 1981.

Although there are major differences between the equipment involved in the accident at Skikda and that of the proposal by Calhoun Point Comfort (i.e., high-pressure steam boilers that power refrigerant compressors would not be used here nor are they used at any LNG facility under FERC jurisdiction), the sequence of cascading events identifies potential failure modes that warrant further evaluation. To ensure that all potential hazards are addressed, we have provided a recommendation in section 4.12.2, *Cryogenic Design and Technical Review,* to address this issue.

[7] For a description of the incident and the findings of the investigation, see "U.S. Bureau of Mines, Report on the Investigation of the Fire at the Liquefaction, Storage, and Regasification Plant of the East Ohio Gas Co., Cleveland, Ohio, October 20, 1944, February 1946."

A discussion of the principal properties and hazards associated with LNG is presented in section 4.12.1. A summary of our preliminary design and technical review of the cryogenic aspects of the LNG terminal is presented in section 4.12.2. Storage and retention systems are discussed in section 4.12.3. An analysis of the thermal radiation and flammable vapor cloud hazards resulting from a credible land-based LNG spill is presented in section 4.12.4, while the safety aspects of LNG transportation by ship is discussed and summarized in section 4.12.5. A discussion on security awareness related to terrorism is presented in section 4.12.6. Conclusions on marine safety are provided in section 4.12.7. The reliability and safety issues related to the natural gas pipeline are discussed in section 4.12.8.

4.12.1 LNG Hazards

LNG's principal hazards result from its cryogenic temperature (-260°F), flammability, and vapor dispersion characteristics. As a liquid, LNG will neither burn nor explode. Although it can cause freeze burns and, depending on the length of exposure, more serious injury, its extremely cold state does not present a significant hazard to the public, which rarely, if ever, comes in contact with it as a liquid. As a cryogenic liquid, LNG will quickly cool materials it contacts, causing extreme thermal stress in materials not specifically designed for ultra-cold conditions. Such thermal stresses could subsequently subject the material to brittleness, fracture, or other loss of tensile strength. These hazards, however, are not substantially different from the hazards associated with the storage and transportation of liquid oxygen (-296°F) or several other cryogenic gases that have been routinely produced and transported in the United States.

LNG vaporizes rapidly when exposed to ambient heat sources such as water or soil. When released from its containment vessel and/or transfer system, LNG will generally produce 620 to 630 standard cubic feet of natural gas for each cubic foot of liquid. A large quality of LNG spilled without ignition would form a vapor cloud that would travel with the prevailing wind until it either dispersed below the flammable limits or encountered an ignition source. If a large quantity of LNG is spilled in the presence of an ignition source, the resulting pool fire would produce high levels of radiant heat in the area surrounding the LNG pool.

A rapid phase transition (RPT) can occur when a portion of LNG spilled onto water changes from liquid to gas, virtually instantaneously. Unlike an explosion that releases energy and combustion products from a chemical reaction, an RPT is the result of heat transferred to the liquid inducing a change to the vapor state. The rapid expansion from the liquid to vapor state can cause locally large overpressures. RPTs have been observed during LNG test spills onto water. In some test cases, the events were strong enough to damage test equipment in the immediate vicinity of the LNG release point. The sizes of the overpressure events have been generally small and are estimated to be equivalent to several pounds of trinitrotoluene (TNT). Although, such a small overpressure is not expected to cause significant damage to an LNG vessel, the RPT may increase the rate of LNG pool spreading and the LNG vaporization rate for a spill on water.

Methane vapors, the primary component of natural gas, are colorless, odorless and tasteless, and are classified as a simple asphyxiant. Methane vapors may cause extreme health hazards, including death, if inhaled in significant quantities within a limited time. Although very cold methane vapors could cause freeze burns, any cloud resulting from an LNG spill would be continuously mixing with the warmer air surrounding the spill site. Dispersion modeling

indicates the majority of the cloud would generally be within 25°F of the surrounding atmospheric temperature, with colder temperatures closest to the spill source. In addition, this modeling estimates that most of the cloud would be below concentrations resulting in oxygen deprivation effects, including asphyxiation, with the highest methane concentrations closest to the spill source. Therefore, asphyxiation and freezing normally represent a negligible risk to the public from LNG facilities.

Although LNG will not burn, methane vapors in a 5 to 15 percent mixture by volume with air are flammable. Once a flammable vapor-air mixture from an LNG spill has been ignited, the flame front will propagate back to the spill site if the vapor concentration along this path is in a range sufficient to support the combustion process. Combustible materials within the flammable portion of the cloud may be within the flame and could be ignited. However, any events leading to a containment failure would most likely be accompanied by a number of ignition sources. The result would be an LNG pool fire, and subsequent radiant heat hazards, rather than the formation of a large unconfined vapor cloud.

Although LNG is not explosive as it is normally transported and stored, natural gas vapors (primarily methane) can explode if contained within a confined space, such as a building or structure, and ignited. Occasionally, various parties have expressed the energy content of an LNG storage tank, or LNG ship, in equivalent tons of TNT as an implied measure of its explosive potential. However, such a simplistic analogy fails to consider that explosive forces are not just a function of the total energy content but also of the rate of energy release. For a detonation to occur, the rate of energy release must be nearly instantaneous, such as with a TNT charge initiated by a blasting cap. Unlike TNT or other explosives which inherently contain an oxidizer, an unconfined vapor cloud must be mixed with oxygen within the flammability range of the fuel for combustion to occur. For a large unconfined vapor cloud, the flammability range tends to exist at the mixing zone at the edges of the cloud. When ignited, flame speeds of about 20 to 25 meters per second (66 to 82 feet per second) and local over pressures up to 0.2 psig have been estimated for unconfined methane-rich vapor clouds, well below the flame speeds and over pressures associated with detonation.

The potential for unconfined LNG vapor cloud detonations was investigated by the Coast Guard in the late 1970s at the Naval Weapons Center at China Lake, California. These experiments, as well as other subsequent tests, are mentioned in Appendix C of the Sandia National Laboratories report entitled, *Guidance on Risk Analysis and Safety Implications of a Large Liquefied Natural Gas (LNG) Spill Over Water, December 2004* (Sandia Report). Using methane, the primary component of natural gas, several experiments were conducted to determine if unconfined vapor clouds would detonate. The tests indicated unconfined methane-air mixtures could be ignited, but no test produced unconfined detonation. There is no evidence suggesting that methane-air mixtures will detonate in unconfined open areas.

Further tests were conducted in the late 1970s to examine the level of sensitivity of an unconfined cloud to the presence of heavier hydrocarbons such as ethane and propane. As stated in Section 5 of Appendix C of the Sandia Report, detonation sensitivity is affected by the level of refinement of natural gas stored as LNG. The series of tests on ambient-temperature fuel mixtures of methane-ethane and methane-propane indicated that the addition of heavier hydrocarbons influenced the tendency of an unconfined vapor cloud to detonate. Less processed product with greater amounts of heavier hydrocarbons is more sensitive to detonation. During

these experiments, all successful detonations were initiated with an explosive charge in well-mixed vapor clouds at correct stoichiometric proportions. These are not representative of conditions which would be expected during a large scale LNG spill. The precise timing, necessary mixing, and required amount of initiating explosives render the possibility for detonation of a large unconfined vapor cloud as unrealistic. Detonation of the unconfined natural gas cloud is extremely difficult to achieve and is generally considered by scientists and researchers to be very unlikely to occur during an LNG spill.

Consequently, the primary hazards to the public from an LNG spill either on land or water would be from dispersion of the flammable vapors or from radiant heat generated by a pool fire.

4.12.2 Cryogenic Design and Technical Review

As part of its application and in response to FERC staff's data requests, Calhoun Point Comfort provided a front-end engineering design for the proposed project. The front-end engineering design and technical review emphasizes the engineering design and safety concepts as well as the projected operational reliability of the proposed facilities. The principle areas of coverage include: materials in cryogenic environments; insulation systems; cryogenic safety; thermodynamics; heat transfer; instrumentation; cryogenic processes; and other relevant safety systems.

Study and evaluation of information for the proposed design and installation of the Calhoun LNG Terminal has been performed by the FERC staff. The front-end engineering design and specifications submitted for the proposed facility to date are considered to be preliminary but would be the basis for any detailed design to follow. Although preliminary, this filed information provides an adequate basis to evaluate the safety and reliability of the proposed project. A significant amount of the design involving final selection of equipment manufacturers, process conditions, and resolution of some safety related issues would be completed in the next phase of the project development if authorization is granted by the Commission. This information would need to be submitted to FERC staff for review and approval.

As a result of the technical review of the information provided by Calhoun Point Comfort in the submittal documents, a number of concerns were identified by staff relating to the reliability, operability, and safety of the proposed design. In response to staff's questions, Calhoun Point Comfort provided written answers prior to the technical conference held on November 15, 2005. As discussed at that technical conference, Calhoun Point Comfort was in the process of revising the facility design, which was subsequently re-submitted on January 31, 2006. After review of the revised information, staff notes several areas of concern that required additional consideration and/or action on behalf of the company. Calhoun Point Comfort submitted a series of design revisions to address staff concerns. The final revision involved the LNG storage tank design changing from single containment to full containment. A summary of Calhoun Point Comfort's design revisions is presented in section 4.12.3. Follow up on those items requiring additional action should be documented in reports to be filed with the FERC. As a result, **we recommend that:**

The following measures should apply to Calhoun LNG Terminal design and construction details. Information pertaining to these specific recommendations should be filed with the

Secretary for review and approval by the Director of OEP either: prior to initial site preparation; prior to construction of final design; prior to commissioning; or prior to commencement of service as indicated by each specific condition. Specific engineering, vulnerability, or detailed design information meeting the criteria specified in Order No. 683 (Docket No. RM06-24-000), including security information, should be submitted as critical energy infrastructure information (CEII) pursuant to 18 CFR 388.112. *See Critical Energy Infrastructure Information*, Order No. 683, 71 Fed. Reg. 58,273 (October 3, 2006), FERC Stats. & Regs. ¶ 31,228 (2006). Information pertaining to items such as: off-site emergency response; procedures for public notification and evacuation; and construction and operating reporting requirements would be subject to public disclosure. This information should be submitted a minimum of 30 days before approval to proceed is required.

- **Complete plan drawings and a list of the hazard detection equipment should be filed <u>prior to initial site preparation</u>. The list should include the instrument tag number, type and location, alarm locations, and shutdown functions of the proposed hazard detection equipment. Plan drawings should clearly show the location of all detection equipment.**

- **Calhoun Point Comfort should provide a technical review of its proposed facility design that:**

  a. **Identifies all combustion/ventilation air intake equipment and the distances to any possible hydrocarbon release (LNG, flammable refrigerants, flammable liquids and flammable gases).**

  b. **Demonstrates that these areas are adequately covered by hazard detection devices and indicate how these devices would isolate or shutdown any combustion equipment whose continued operation could add to or sustain an emergency.**

Calhoun Point Comfort should file this review <u>prior to initial site preparation</u>.

- **Complete plan drawings and a list of the fixed and wheeled dry-chemical, fire extinguishing, and high expansion foam hazard control equipment should be filed <u>prior to initial site preparation</u>. The list should include the equipment tag number, type, size, equipment covered, and automatic and manual remote signals initiating discharge of the units. Plan drawings should clearly show the planned location of all fixed and wheeled extinguishers.**
- **Facility plans showing the proposed location of, and area covered by, each monitor, hydrant, deluge system, hose, and sprinkler, as well as piping and instrumentation diagrams, of the fire water system should be filed <u>prior to initial site preparation</u>.**
- **A copy of the hazard design review and list of recommendations that are to be incorporated in the final facility design should be filed <u>prior to initial site preparation</u>.**
- **Drawings of the storage tank piping support structure and support of horizontal piping at grade should be filed <u>prior to initial site preparation</u>.**

- **The design pressure of the fractionation system should be not less than the maximum shut off pressure from the low pressure LNG pumps, the same design pressure as the LNG/Gas exchangers, tube side of the process vaporizers and the LNG surge drum. The revised piping and instrumentation diagrams (P&IDs) and design information for the NGL fractionation system should be submitted prior to initial site preparation.**
- **Procedures should be developed for off-site contractors' responsibilities, restrictions, limitations and supervision of these contractors by Calhoun Point Comfort staff, prior to initial site preparation.**
- **The final design should provide LNG drain and LNG relief valve discharge piping to the LNG tank, to contain LNG within the storage system as the LNG containment design philosophy and minimize the discharge of liquid and cryogenic vapor to the cold vent system.**
- **The final design should include details of the pipe supports and restraints designed to prevent damage to piping systems and equipment in the event of a storm surge anticipated for a class 4 hurricane.**
- **The final design of the hazard detection equipment should identify manufacturer and model.**
- **The final design of the fixed and wheeled dry-chemical, fire extinguishing, and high expansion foam hazard control equipment should identify manufacturer and model.**
- **The final design should specify that unloading line check valves should be located upstream of the block valve and adjacent to the manifold isolation valves as per note 15 of the P&ID.**
- **The final design should specify that check valves be installed in the LNG drain lines around the unloading arm SDVs.**
- **The final design should specify that the unloading recycle line 4"-P-1031 should be connected at the end of the unloading header.**
- **The final design should include provisions to install LNG transfer pumps at Jetty LNG sump, V-603.**
- **The final design should include detailed drawings of the spill control system to be applied to the LNG tank roof.**
- **The final design should include details of the LNG tank tilt settlement and differential settlement limits between each LNG tank and piping and procedures to be implemented in the event that limits are exceeded.**
- **The final design should include LNG tank fill flow measurement with high flow alarm for each tank.**
- **The final design should include details of the boiloff gas flow and temperature measurement provided for each tank.**
- **The final design should include check valves in the intank LNG pump discharge piping downstream of the minimum flow recycle connection.**

- **The final design should include LNG recycle from the recondenser to the LNG storage tank, designed to allow the vessel to be stabilized prior to LNG pump operation and recycle to storage for LP LNG pumps start up and testing.**
- **The final design should specify that the LP and HP LNG pump recycle lines to the storage tanks, P-2019 and P-2511, shall be the same pressure class as the LNG pump discharge piping including the final block valve to the tank.**
- **The final design should include provisions to recycle LNG from the suction header of the LP LNG pumps to storage.**
- **The final design should specify that the LNG surge drum, V-241, should be equipped with weld-end connections for piping.**
- **The final design should minimize the use of flanged nozzles for connection of piping to high pressure vessels containing LNG and NGL.**
- **The final design should specify that 4”-P-2143 be connected to the 24” bottom outlet line, to eliminate the connection to the vessel and provide drainage for the 24” outlet and elbow.**
- **The final design should include provisions to recycle LNG from the suction header of the HP LNG pumps to storage.**
- **The final design should specify that relief valves in the discharge piping of the HP LNG pumps and sendout vaporizers be designed and set for the system design pressure, consistent with the maximum shutoff pressure of the LNG pumps.**
- **The final design should include dual low low temperature alarm and shutdown at the discharge of the vaporizer.**
- **The final design should consider locating the vaporizer flow measurement device upstream of the vaporizer.**
- **The final design should specify that redundant pressure transmitters for high pressure alarm and shutdown should be provided for the fractionation system and for protection of the pipeline.**
- **The final design should specify that all piping with service temperature at or below -20°F shall be stainless steel.**
- **The final design should specify that piping specifications should state that spiral wound gaskets should be of type CGI, to include both outer and inner retaining rings.**
- **The final design should specify that cryogenic piping and equipment should be designed for cool down with liquid nitrogen.**
- **The final design should include P&IDs and drawings of the meter station.**
- **The final design should include a fire protection evaluation carried out in accordance with the requirements of NFPA 59A, chapter 9.1.2.**
- **The final design should include details of the shut down logic, including cause and effect matrices for alarms and shutdowns.**

- **The final design should include emergency shutdown of equipment and systems activated by hazard detection devices for flammable gas, fire, and cryogenic spills, when applicable.**
- **The final design should include details of the air gaps to be installed downstream of all seals or isolations installed at the interface between a flammable fluid system and an electrical conduit or wiring system. Each air gap should vent to a safe location and be equipped with a leak detection device that should: continuously monitor for the presence of a flammable fluid; alarm the hazardous condition; and shutdown the appropriate systems.**
- **The final design should include a HAZOP review of the completed design. A copy of the review and a list of the recommendations should be filed with the Secretary.**
- **The P&IDs in the final design should show and number all valves including drain, vent, main, and car sealed.**
- **The final design should include safeguards to be installed to protect above ground fire water piping, including post indicator valves, from inadvertent damage.**
- **The final design should specify that all hazard detection equipment should include redundancy and fault detection and fault alarm monitoring in all potentially hazardous areas and enclosures.**
- **All valves including drain, vent, main, and car sealed valves should be tagged in the field during construction and prior to commissioning.**
- **The design details and procedures to record and to prevent the tank fill rate from exceeding the maximum fill rate specified by the tank designer should be filed prior to commissioning.**
- **Plans and a tabulated list of the proposed hand-held fire extinguishers should be filed prior to commissioning. The list and drawings should identify the equipment number, type, size, number, and location.**
- **Operation and Maintenance procedures and manuals, as well as safety procedure manuals, should be filed prior to commissioning.**
- **The contingency plan for failure of the LNG tank outer containment approved by the tank manufacturer should be filed prior to commissioning.**
- **A copy of the criteria for horizontal and rotational movement of the inner vessel for use during and after cool down should be filed prior to commissioning.**
- **The maintenance procedures to be filed prior to commissioning should state that a foundation elevation survey of all LNG tanks should be made on an annual basis.**
- **The FERC staff should be notified of any proposed revisions to the security plan and physical security of the facility prior to commencement of service.**
- **Progress on the construction of the LNG terminal should be reported in monthly reports filed with the Secretary. Details should include a summary of activities, projected schedule for completion, problems encountered and remedial actions**

taken. Problems of significant magnitude should be reported to the FERC within 24 hours.

In addition, we recommend that the following measures should apply throughout the life of the facility:

- **The facility should be subject to regular FERC staff technical reviews and site inspections on at least an annual basis or more frequently as circumstances indicate. Prior to each FERC staff technical review and site inspection, Calhoun Point Comfort should respond to a specific data request including information relating to possible design and operating conditions that may have been imposed by other agencies or organizations. Up-to-date detailed piping and instrumentation diagrams reflecting facility modifications and provision of other pertinent information not included in the semi-annual reports described below, including facility events that have taken place since the previously submitted annual report, should be submitted.**
- **Semi-annual operational reports should be filed with the Secretary to identify changes in facility design and operating conditions, abnormal operating experiences, activities (including ship arrivals, quantity and composition of imported LNG, vaporization quantities, boil-off/flash gas, etc.), plant modifications including future plans and progress thereof. Abnormalities should include, but not be limited to: unloading/shipping problems, potential hazardous conditions from off-site vessels, storage tank stratification or rollover, geysering, storage tank pressure excursions, cold spots on the storage tanks, storage tank vibrations and/or vibrations in associated cryogenic piping, storage tank settlement, significant equipment or instrumentation malfunctions or failures, non-scheduled maintenance or repair (and reasons therefore), relative movement of storage tank inner vessels, vapor or liquid releases, fires involving natural gas and/or from other sources, negative pressure (vacuum) within a storage tank and higher than predicted boiloff rates. Adverse weather conditions and the effect on the facility also should be reported. Reports should be submitted within 45 days after each period ending June 30 and December 31. In addition to the above items, a section entitled "Significant plant modifications proposed for the next 12 months (dates)" also should be included in the semi-annual operational reports. Such information would provide the FERC staff with early notice of anticipated future construction/maintenance projects at the LNG facility.**
- **In the event the temperature of any region of any secondary containment, including imbedded pipe supports, becomes less than the minimum specified operating temperature for the material, the Commission should be notified within 24 hours and procedures for corrective action should be specified.**
- **Significant non-scheduled events, including safety-related incidents (i.e., LNG or natural gas releases, fires, explosions, mechanical failures, unusual over pressurization, major injuries) and security related incidents (i.e., attempts to enter site, suspicious activities) should be reported to FERC staff. In the event an abnormality is of significant magnitude to threaten public or employee safety, cause significant property damage, or interrupt service, notification should be made**

immediately, without unduly interfering with any necessary or appropriate emergency repair, alarm, or other emergency procedure. In all instances, notification should be made to FERC staff within 24 hours. This notification practice should be incorporated into the LNG facility's emergency plan. Examples of reportable LNG-related incidents include:

a. fire;

b. explosion;

c. estimated property damage of $50,000 or more;

d. death or personal injury necessitating in-patient hospitalization;

e. free flow of LNG that results in pooling;

f. unintended movement or abnormal loading by environmental causes, such as an earthquake, landslide, or flood, that impairs the serviceability, structural integrity, or reliability of an LNG facility that contains, controls, or processes gas or LNG;

g. any crack or other material defect that impairs the structural integrity or reliability of an LNG facility that contains, controls, or processes gas or LNG;

h. any malfunction or operating error that causes the pressure of a pipeline or LNG facility that contains or processes gas or LNG to rise above its maximum allowable operating pressure (or working pressure for LNG facilities) plus the build-up allowed for operation of pressure limiting or control devices;

i. a leak in an LNG facility that contains or processes gas or LNG that constitutes an emergency;

j. inner tank leakage, ineffective insulation, or frost heave that impairs the structural integrity of an LNG storage tank;

k. any condition that could lead to a hazard and cause a 20 percent reduction in operating pressure or shutdown of operation of a pipeline or an LNG facility;

l. safety-related incidents to LNG vessels occurring at or en route to and from the LNG facility; or

m. an event that is significant in the judgment of the operator and/or management even though it did not meet the above criteria or the guidelines set forth in an LNG facility's incident management plan.

In the event of an incident, the Director of OEP has delegated authority to take whatever steps are necessary to ensure operational reliability and to protect human life, health, property or the environment, including authority to direct the LNG facility to cease operations. Following the initial company notification, FERC staff would determine the need for an on-site inspection by FERC staff; and the timing of an initial incident report (normally within 10 days) and follow-up reports.

All critical structures at the Calhoun LNG terminal would be designed per Title 49, CFR, Part 193.2067 for an assumed sustained wind velocity of not less than 150 miles (183 mph 3-second wind gust speed). Calhoun Point Comfort states that a maximum storm surge height of

approximately 15 feet has been modeled for industrial sites to the north of the proposed facility using the Estuarine and Coastal Ocean Model (a similar model to SLOSH). In addition, Hurricane Carla, a 1961 Category 3 hurricane which came ashore at Lavaca Bay, produced a storm surge approximately 19 feet. The proposed location of the Calhoun LNG Terminal is at an approximate elevation of 30 feet above sea level. All process areas and major equipment would be located at or above 29 feet over sea level. In addition, the impoundment berm around the LNG storage tanks would be constructed to an elevation of 36 feet above sea level. Based on Calhoun Point Comfort's equipment elevations and the recommendation above regarding storm surge for a class 4 hurricane, we believe the facility would be appropriately designed for anticipated storm surge conditions.

4.12.3 Storage and Retention Systems

LNG storage tanks come in a variety of categories. The following are descriptions of the tank designs most commonly used worldwide:

- single containment cylindrical metal tanks (predominately used in the United States);
- spherical storage tanks (predominately used in LNG carriers);
- double containment cylindrical metal inner tank and metal or concrete outer tank (commonly thought of as an LNG tank with a high wall dike);
- full containment cylindrical metal inner tank and metal or concrete outer tank (several authorized by the Commission; several applications currently proposed to the Commission, including this project);
- pre-stressed cylindrical concrete tank with an internal metal membrane (membrane tank) (none in the United States); and
- cryogenic cylindrical concrete tank, internal cryogenic tank, and prestressed concrete outer tank (one operational in the United States; the remainder worldwide).

These tank categories are described in Annex H of the European Standard for LNG facilities (EN 1473) and are summarized below for the LNG storage tanks commonly found in proposals before the Commission.

H.1 Single containment tank

A single primary container and generally an outer shell designed and constructed so that only the primary container is required to meet the low temperature ductility requirements for storage of the product.

The outer shell (if any) of a single containment storage tank is primarily for the retention and protection of insulation and to contain the purge gas pressure, but is not designed to contain refrigerated liquid in the event of leakage from the primary container.

An aboveground single containment tank shall be surrounded by a bund (dike) wall to contain any leakage. Examples of single containment are given in figure H.1.

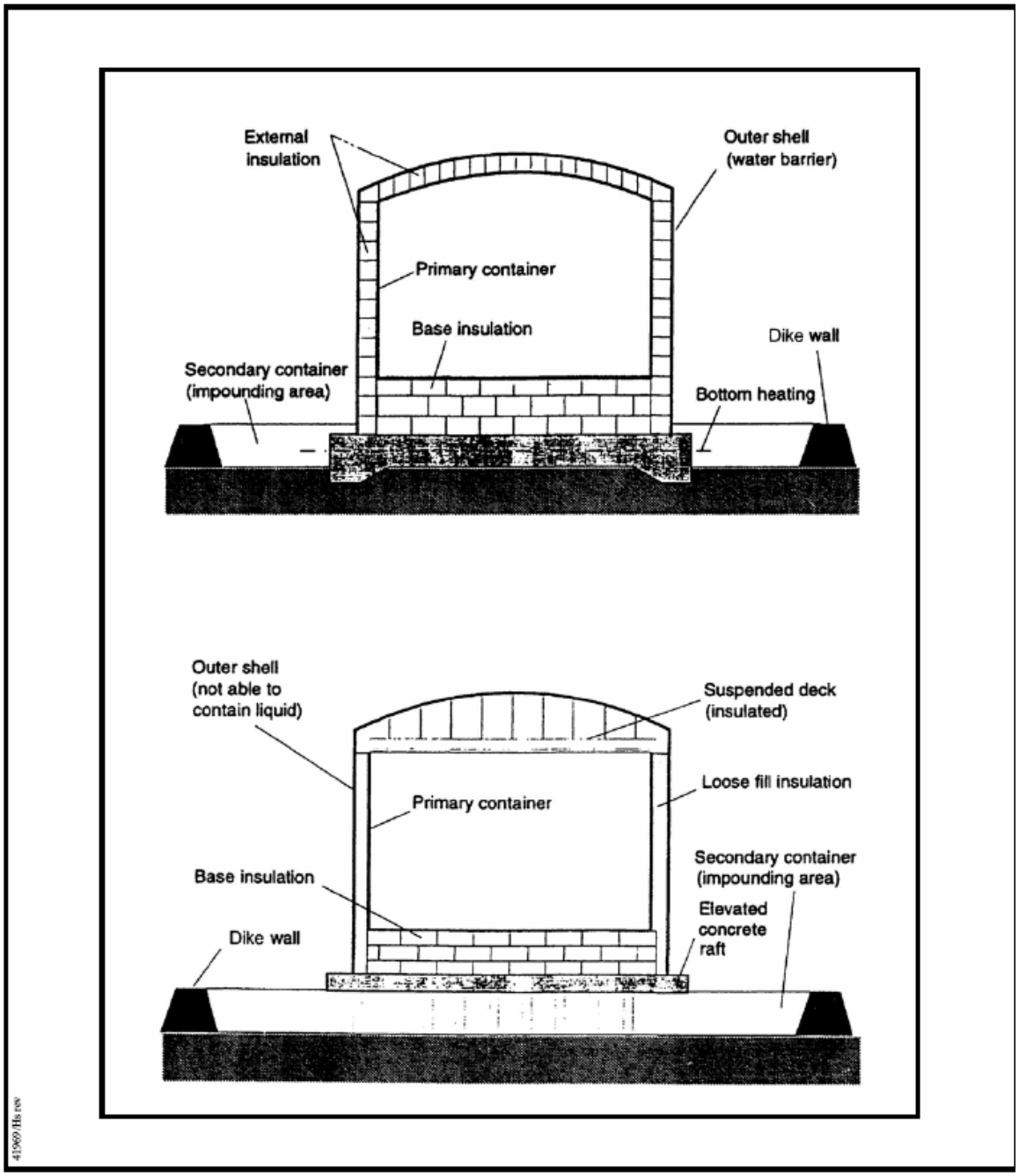

Figure H-1
Examples of Single Containment Tanks

H.3 Double containment tank

A double containment tank is designed and constructed so that both the inner self-supporting primary container and the secondary container are capable of independently containing the refrigerated liquid stored. To minimize the pool of escaping liquid, the secondary container should be located at a distance not exceeding 6 meters from the primary container.

The primary container contains the refrigerated liquid under normal operating conditions. The secondary container is intended to contain any leakage of the refrigerated liquid, but it is not intended to contain any vapor resulting from this leakage.

Examples of double containment tanks are given in figure H.3. Figure H.3 does not imply that the secondary container is necessarily as high as the primary container.

H.4 Full containment tank

A tank designed and constructed so that both self supporting primary container and the secondary container are capable of independently containing the refrigerated liquid stored and for one of them its vapor. The secondary container can be 3 to 6 feet (1 to 2 meters) in distance from the primary container.

The primary container contains the refrigerated liquid under normal operating conditions. The outer roof is supported by the secondary container. The secondary container shall be capable both of containing the refrigerated liquid and of controlled venting of the vapor resulting from product leakage after a credible event. Examples of full containment tanks are given in figure H.4.

Single, double and full containment LNG storage tanks have been authorized by the Commission for use at new LNG import facilities or expansions of existing terminals; and single and double containment tanks have been constructed and operated. To date, only single and double containment tanks have been constructed and operated. Several full containment tanks have started construction in the United States, while approximately 50 have been constructed worldwide.

Calhoun Point Comfort's original design consisted of two single containment LNG storage tanks located within a common impoundment. After review of the original design, FERC staff requested Calhoun Point Comfort to provide measures to effectively prevent fire exposure from leakage in one tank affecting an adjacent tank. On August 21, 2006, Calhoun Point Comfort submitted a revision in the fire protection system to protect each LNG storage tank by installing a seawater spray system to assure that an adjacent LNG storage tank would be protected in the event of a fire resulting from a spill within the common impoundment area. However, staff continued to question the ability of the common LNG storage tank impoundment system to adequately maintain the integrity of the tanks during an impoundment fire. On November 28, 2006, Calhoun Point Comfort proposed to modify the design to incorporate two full containment LNG storage tanks.

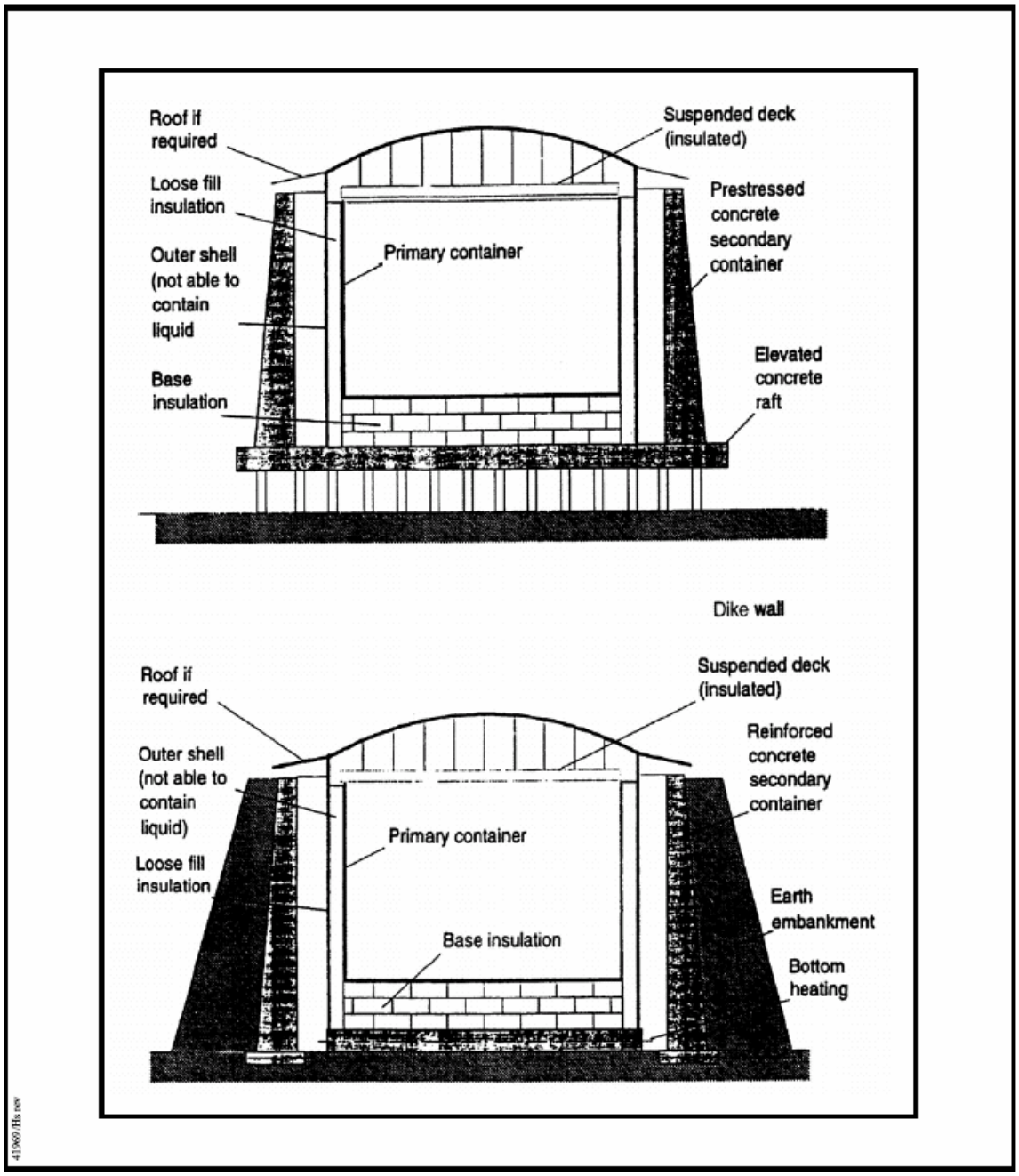

Figure H-3
Examples of Double Containment Tanks

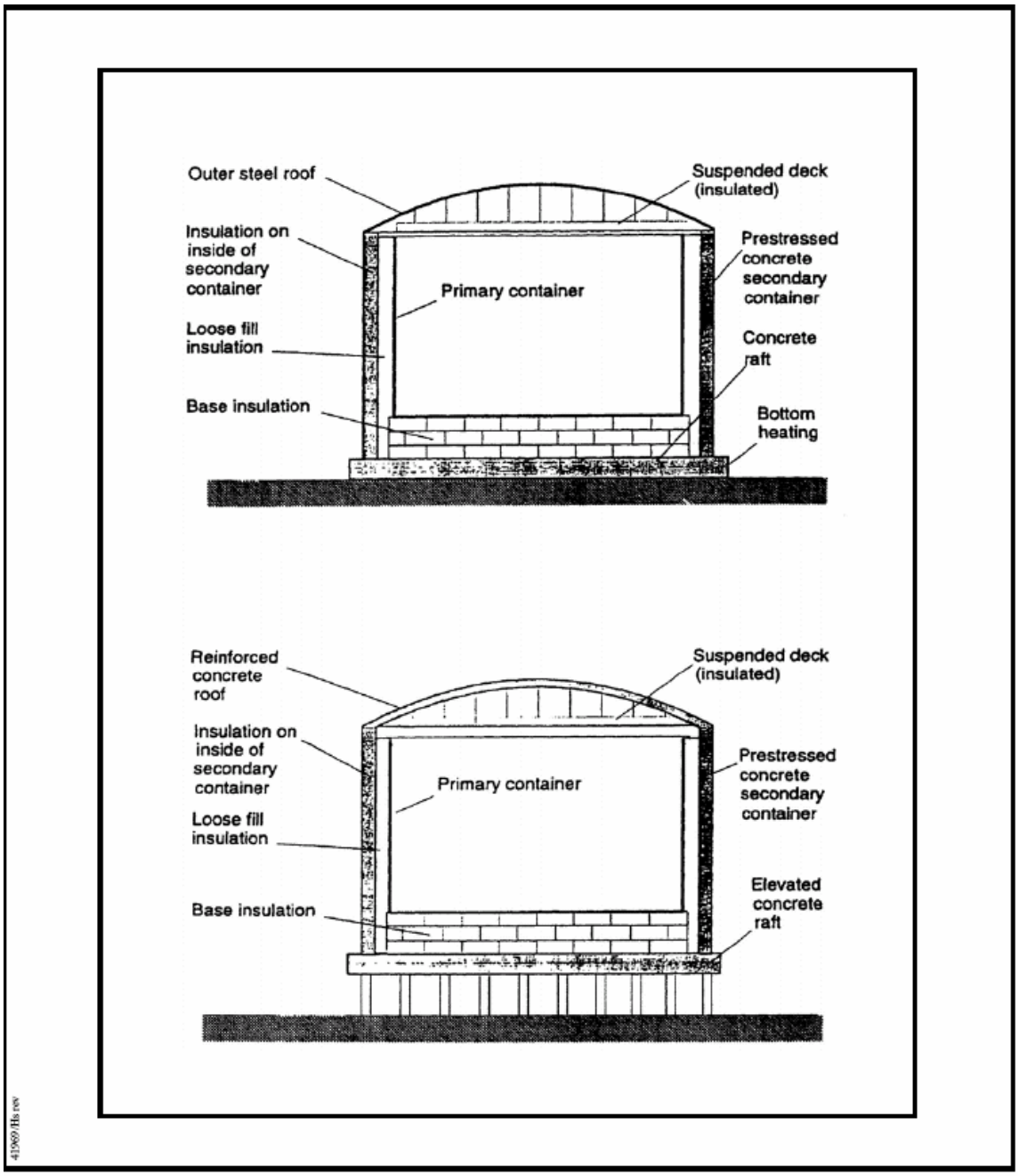

Figure H-4
Examples of Full Containment Tanks

During the review of earlier LNG terminal proposals, a number of issues have surfaced concerning the applicability of existing codes and regulations to full containment tank. Specifically, the term "full containment" does not appear in U.S. codes or standards for LNG facilities, including the Federal Safety Standards in 49 CFR 193, NFPA 59A, or American Petroleum Institute 620. As a result some have made the assumption that to design and construct a full containment tank in accordance with the EN 1473 will satisfy the U.S. code and standards.

For example, it has been suggested that thermal exclusion zones are not required for a full containment tank because EN 1473 does not consider a tank fire scenario for full containment tanks with a pre-stressed concrete wall and concrete roof. The staffs of the FERC and DOT do not agree because Part 193 does not exclude full containment tanks from thermal exclusion zone requirements. As a result, a thermal exclusion zone analysis is required for an LNG storage tank fire at the top of the secondary container (see section 4.12.4).

Further, EN 1473 does not specify a minimum distance to the property line for full containment tanks because no tank fire scenario is considered. However, NFPA 59A, 2001 edition, requires a separation of 0.7 times the diameter from the property line. The proposed tanks for the Calhoun Point Comfort Project would meet the separation requirement.

Another issue regarding the full containment design is that the tank outer wall (secondary containment) serves as the impoundment, a concept allowed under Parts 193.2161 and 193.2167, and under the "exception" in figure 2.2.2.6 of NFPA 59A, 2001 edition. A specific concern is the dual function of the concrete secondary container: it serves both the operational function of holding the insulation and gas pressure, and a safety function of containing liquid in the event of an inner tank failure. Conversely, in single and double containment tanks, independent systems provide operational and safety functions. While recognition must be given to the benefits of a concrete secondary container with respect to external events, such as projectiles or small aircraft, its ability to provide the dual functions while retaining its integrity has not been convincingly supported for all scenarios. This becomes increasingly important as proposed site acreage is reduced and buffer zones between adjacent properties are minimized. As such, FERC staff considers prudent design practice to provide some form of barrier to prevent liquid from flowing to an unintended area (i.e., outside the plant property) in the event that the storage tank primary and secondary containers fail.

Concerns have also been expressed that the barrier could be considered a containment and prohibit certain equipment being located within the barrier and/or may conflict with other parts of the various codes with respect to hazardous and electrical code classifications. Other concerns are that the barrier could be considered an impounding area that would require new thermal and vapor cloud calculations. The purpose of the barrier is to prevent liquid from flowing off the plant property, and it is not the intent to define a containment or impounding area for thermal radiation or flammable vapor exclusion zone calculations or other code requirements.

Calhoun Point Comfort originally proposed a common impoundment system around the single containment tanks. This mechanically stabilized earthen berm would be constructed to an elevation ranging from about 15 to 28 feet from the finished grade level. This berm would encompass an area measuring approximately 704 feet by 1,426 feet and would completely surround both tanks. This would not change for the full containment tank modification. The southeastern portion of this impoundment would have a lower elevation than the tank area,

allowing any spill to drain away from both tanks into this lower half. This area would be 361 feet wide by 1,426 feet long with an average height of 12.5 feet. A square sub-impoundment would be located within this lower half and would measure 150 feet wide by 150 feet long with a depth of 4 feet. Including the volume provided by the lower half and the sub-impoundment, the entire berm surrounding the tanks would provide 169,404,128 gallons of spill containment. When full, both storage tanks would hold a combined total of 91,206,928 gallons of LNG. The structure's volumetric capacity would contain both LNG tanks' maximum liquid capacity. This tertiary earthen berm would confine LNG on the project site in the event of any hypothetical catastrophic event.

4.12.4 Siting Requirements – Thermal and Dispersion Exclusion Zones

Regulatory Requirements

The LNG facilities proposed in this project must comply with the siting requirements of 49 CFR 193, Subpart B. On March 30, 2000, the DOT revised 49 CFR 193 to incorporate NFPA 59A (1996 edition) into the LNG regulations. On April 9, 2004, the DOT further revised 49 CFR 193 to incorporate the 2001 edition of NFPA 59A. The following sections specifically address off-site hazards:

Part 193.2001, Scope of part, excludes any matter other than siting provisions pertaining to marine cargo transfer systems between the marine vessel and the last manifold or valve immediately before a storage tank.

Part 193.2051, Scope, states that each LNG facility designed, replaced, relocated or significantly altered after March 31, 2000, must be provided with siting requirements in accordance with Subpart B and NFPA 59A, 2001 edition. In the event of a conflict with NFPA 59A, 2001 edition, then Part 193 prevails.

Part 193.2057, Thermal radiation protection, requires that each LNG container and LNG transfer system have thermal exclusion zones based on three radiation flux levels in accordance with Section 2.2.3.2 of NFPA 59A, 2001 edition.

Part 193.2059, Flammable vapor-gas dispersion protection, requires that each LNG container and LNG transfer system have a dispersion exclusion zone in accordance with Sections 2.2.3.3 and 2.2.3.4 of NFPA 59A, 2001 edition.

For the following LNG facilities that are proposed in this project, we have identified the applicable siting requirements from Part 193 and NFPA 59A, 2001 edition:

- Two 1,006,000-barrel (160,000 m^3) full containment LNG storage tanks - Parts 193.2057 and 2059 require the establishment of thermal and flammable vapor exclusion zones for LNG tanks. NFPA 59A Section 2.2.3.2 specifies four thermal exclusion zones based on the design spill and the impounding area. NFPA 59A Sections 2.2.3.3 and 2.2.3.4 specify a flammable vapor exclusion zone for the design spill which is determined with Section 2.2.3.5.

- One LNG ship unloading berth and a marine cargo transfer system consisting of a total of four marine unloading arms, three 16-inch-diameter liquid transfer arms and one 16-inch-

diameter vapor return arm; and a 36-inch-diameter transfer line to carry LNG to the onshore storage tanks - Parts 193.2001, 2057, and 2059 require thermal and flammable vapor exclusion zones for the transfer system. NFPA 59A does not address LNG transfer systems.

- Four 5,500-gpm in-tank pumps (two per tank with a spare pump tube); and four low pressure and four high pressure sendout pumps, each capable of discharging 3,217 and 4,133 gpm, respectively - Parts 193.2057 and 2059 require thermal and flammable vapor exclusion zones. NFPA 59A Section 2.2.3.2 specifies the thermal exclusion zone and Section 2.2.3.4 specifies the flammable vapor exclusion zone based on the design spill.

- Twelve submerged combustion vaporizers - Same requirements as for LNG pumps.

The incorporation of the NFPA 59A requirements into Part 193 has resulted in some confusion and possible misinterpretation in applying the siting requirements. Parts 193.2057 and 2059 require exclusion zones for LNG transfer systems, which are defined to include transfer piping. However, NFPA 59A only requires exclusion zones for "transfer areas" which are defined as the part of the plant where liquids are introduced or removed from the facility such as truck loading or ship unloading areas. The definition of transfer area in NFPA 59A specifically excludes permanent plant piping such as cargo transfer lines. Additionally, NFPA 59A Section 2.2.3.1 specifically excludes transfer area at the water edge of marine terminals. When the DOT incorporated NFPA 59A into its regulations, it removed the requirement for impounding systems around transfer piping (old Part 193.2149). In the preamble to the final rule, the DOT determined that the most likely sources of leaks within LNG plant are LNG storage tanks, cargo transfer areas, and vaporizers and process equipment, which are all addressed in NFPA 59A Section 2.2.1.2. The result is that while Part 193 retains exclusion zones for LNG transfer systems, neither Part 193 nor NFPA 59A requires the impoundment from which to base the calculations. We do not believe that this was the intent, nor do we believe that omitting containment for transfer piping is a sound engineering practice. The FERC staff will continue to require containment for all LNG transfer piping within a plant site.

The incorporation of NFPA 59A also changed the way in which design spills and impoundment capacities may be determined. Under Section 2.2.2.2, the capacity of impounding areas for vaporization, process, or LNG transfer areas must equal the greatest volume during a 10-minute period from any single <u>accidental leakage source</u> or during a shorter time period based upon demonstrable surveillance and shutdown provisions acceptable to the authority having jurisdiction. Similar criteria appear in Section 2.2.3.5 for determining the design spill used in thermal and flammable vapor exclusion zone calculations. Prior to the incorporation of NFPA 59A, the design spill in Part 193 assumed the <u>rupture of a single transfer pipe</u> with the greatest overall flow capacity, for not less than 10 minutes (old Part 193.2059(d)). As a result, the spill <u>rate</u> for vaporization, process, or LNG transfer areas may be assumed to be an "accidental leakage source" rather than a full pipe rupture; however, the spill <u>duration</u> must be 10 minutes unless the authority having jurisdiction (i.e., DOT), determines that a shorter time is acceptable. Again, given the confusion in applying the two requirements, the FERC staff will continue to utilize the 10-minute spill criteria at the maximum flow possible for containment sizing. This will ensure that impoundments are sized for a catastrophic failure, while recognizing that less conservative spill scenarios may be appropriate to calculate exclusion zones. In giving recognition to the integrity of all-welded transfer piping, the determination of

the single accidental leakage source should be based on an evaluation of all small diameter attachments to the transfer piping for instrumentation, pressure relief, recirculation, etc., and any flanges that may be used at valves or other equipment, in order to determine the largest spill rate. This approach is the result of discussions with DOT concerning the basis for design spills and application to exclusion zone determinations for proposals before the Commission.

Impoundment Systems and Design Spills

Calhoun Point Comfort had originally proposed to install two single containment LNG storage tanks located within a common impoundment system. After review of the original proposal, FERC staff requested Calhoun Point Comfort to provide measures to effectively prevent fire exposure from leakage in one tank affecting an adjacent tank. Subsequently Calhoun Point Comfort re-evaluated its tank design and submitted a revised full containment storage tank design. Calhoun Point Comfort is proposing to retain the configuration of the LNG storage tank spill impoundment area as originally proposed for the single containment tanks.

Each proposed full containment storage tank (Tank 111 and 112) would have a working volumetric capacity of 160,000 m^3 and a gross volumetric capacity of 180,000 m^3 (1,008,000-barrel). The calculations of thermal and flammable exclusion zones for the proposed LNG facility are based on the dimensions of the proposed impoundment systems and the spill volumes specified by Part 193 and NFPA 59A, 2001 edition. Part 193.2181 specifies that the impoundment serving a single LNG storage tank must have a volumetric capacity of 110 percent of the LNG tank's maximum liquid capacity.

Calhoun Point Comfort's proposed LNG storage tank impoundments would be full containment storage tanks. The outer concrete tank would have an inside diameter of 262 feet with an apex at approximately 183 feet high. Each LNG storage tank's maximum liquid capacity would be 45,603,464 gallons. The volumetric capacity of the concrete wall would be 54,708,388 gallons and would exceed the 110 percent requirement by 4,544,578 gallons. The site would also be surrounded by an irregularly shaped, mechanically stabilized earthen berm ranging from 15 feet to 28 feet in height. This berm would encompass an area measuring approximately 704 feet by 1,426 feet and would completely surround both tanks. The southeastern portion of this impoundment would have a lower elevation than the tank area, allowing any spill to drain away from both tanks into this lower half. This area would be 361 feet wide by 1,426 feet long with an average height of 12.5 feet.

A square sub-impoundment would be located within this lower half and would measure 150 feet wide by 150 feet long with a depth of 4 feet. The lower half of the impoundment and the square sub-impoundment would provide 48,135,831 gallons and 586,473 gallons of spill capacity, respectively. The lower half of the impoundment, including the square sub-impoundment, would entirely contain the total contents of one LNG storage tank.

Including the volume provided by the lower half and the sub-impoundment, the entire berm surrounding the tanks would provide 169,404,128 gallons of spill containment. When full, both storage tanks would hold a combined total of 91,206,928 gallons of LNG. LNG spill containment would also be provided at several other locations around the facility. These LNG spill containment structures would consist of concrete slabs, surrounded by a 3-foot-high concrete retaining wall, and graded to direct LNG into sloped trenches and concrete sumps.

Two identical sumps would be located to capture any LNG spills along the pipe racks that connect the unloading dock to the storage tanks. Both of the sumps would be 40 feet wide by 80 feet long with a usable depth of 25 feet. The capacity of each would be 598,442 gallons. The first of these, the Dock Area Sump, would be west of the marine unloading platform outside of the LNG storage tank impoundment berm. The other sump, the Process Area Sump, would be east of the marine unloading platform in proximity to the natural gas liquids and vaporization area. The largest 10-minute spill which could occur in either of these areas would be from the 36-inch-diameter marine unloading line. This spill would be 572,688 gallons and would be contained by either the Dock Area or Process Area sump, depending on the location of the spill.

The area surrounding the vaporizer trains and the natural gas liquids recovery systems would be curbed so that any spilled LNG would be directed into two identical LNG Vaporization Area Sumps. These sumps would be 15 feet wide by 15 feet long with a usable depth of 29 feet and a capacity of 48,810 gallons. The largest 10-minute spill in this area would be from the second stage vaporizer suction piping, a spill of 40,919 gallons. This would be contained by either LNG Vaporization Area Sump.

The calculation of thermal and flammable vapor exclusion zones for the proposed LNG facility are based on the dimensions of the proposed spill containment systems and the design spills according to 49 CFR 193 and NFPA 59A, 2001 edition. In accordance with Section 2.2.3.5 of NFPA 59A, 2001 edition, the design spill for an LNG storage tank with no penetrations below the liquid level is defined as the largest flow from any single line that could be pumped into the impounding area with the tank withdrawal pumps considered to be operating at full rated capacity over a 10-minute period. For the proposed design, this would be a guillotine rupture of the discharge header for the in-tank pumps. Since each pump is rated at 5,500 gallons per minute and there are two pumps per tank, the resulting 10-minute design spill would be 110,000 gallons. This spill would be completely contained by the square sub-impoundment located in the lower half of the LNG storage tank impoundment.

Section 2.2.3.5 also defines design spills for impounding areas serving only vaporization, process, or LNG transfer areas as the flow from any single accidental leakage source for a 10-minute duration. After a review of the piping and instrumentation diagrams for small diameter attachments, staff determined the design spill for the Dock Area Sump and Process Area Sump to be the rupture of a 6-inch-diameter drain connection to the marine unloading line. This 10-minute design spill would generate a volume of 130,481 gallons and would be contained in the either the Dock Area Sump or the Process Area Sump.

Similarly, the design spill for the LNG Vaporization Area Sumps would result from a rupture of a 4-inch-diameter connection to the low-pressure pump discharge line. This 10-minute design spill would result in a volume of 30,070 gallons and would be contained by either of the LNG Vaporization Area Sumps.

Table 4.12.4-1 presents the impounding areas and spill size volumes used to determine adequate impounding capacity, as well as the design spills used in the thermal radiation and flammable gas dispersion modeling.

TABLE 4.12.4-1 **Impoundment Areas**			
Source	**Spill Size (gallons)**	**Impoundment System**	**Impoundment Size (gallons)**
Impoundment sizing spills:			
LNG Storage Tank	45,603,464	Concrete Tank Wall	54,708,388
Unloading Line	572,688	Process Area Sump or Dock Area Sump	598,442
2nd Stage SCV Suction	40,919	LNG Vaporization Area Sumps	48,810
Design spills:			
Tank - Pump withdrawal header	110,000	Sub-impoundment	586,473
Unloading Line - 6-inch connection	130,481	Process Area Sump or Dock Area Sump	598,442
Low Pressure Pump Discharge - 4-inch connection	30,070	LNG Vaporization Area Sumps	48,810

Thermal Exclusion Zone

If a large quantity of LNG is spilled in the presence of an ignition source, the resulting LNG pool fire could cause high levels of thermal radiation. Exclusion distances for various flux levels were calculated according to 49 CFR 193.2057 and Section 2.2.3.2 of NFPA 59A, 2001 edition, using the "LNGFIRE III" computer program model developed by the Gas Research Institute. NFPA 59A, 2001 edition, establishes certain atmospheric conditions (0 mph wind speed, 70°F, and 50 percent relative humidity) which are to be used in calculating the distances. However, Part 193.2057 supersedes these requirements and stipulates that wind speed, ambient temperature, and relative humidity which produce the maximum exclusion distances must be used, except for conditions that occur less than 5 percent of the time based on recorded data for the area. For its analysis, Calhoun Point Comfort selected the following ambient conditions to produce the maximum distances: wind speed of 25.0 mph; ambient temperature of 34°F; and 70 percent relative humidity. These conditions yield longer distances than the 0 mph wind speed, 70°F ambient temperature, and 50 percent relative humidity specified in NFPA 59A, 2001 edition.

Under Title 49, Code of Federal Regulations, Section 193.2057, the LNG storage tank impoundment must have a thermal exclusion zone in accordance with NFPA 59A, 2001 edition. Thermal radiation distances were calculated for 1,600 to 10,000 British thermal units per square foot per hour (Btu/ft^2-hr) incident flux levels for an LNG storage tank impoundment fire. The model was run for a full containment tank with roof failure and fire at a diameter of 262 feet and a height of 135 feet. Target height was set at ground level (0 feet). Furthermore, thermal radiation distances were also determined for the 1,600-Btu/ft^2-hr incident flux level centered on the Dock Area Sump, Process Area Sump, and the two LNG Vaporization Area Sumps. Figure 4.12-1 shows the 1,600 Btu/ft^2-hr thermal radiation exclusion zones for the LNG storage tanks, Tank Impoundment Sump, Dock Area Sump, and Process Area Sump.

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Figure 4.12-1

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The 3,000 Btu/ft^2-hr and 1,600 Btu/ft^2-hr exclusion zones from the full containment tanks would extend approximately 382 feet and 540 feet, respectively, over the MSC on the northwest side of the proposed site and the 1,600 Btu/ft^2-hr zone from the full containment tanks would also extend approximately 223 feet over Cox Bay on the south side of the proposed site. In addition, the 1,600 Btu/ft^2-hr zone from the square sub-impoundment would extend approximately 350 feet over Cox Bay. For these reasons, we have included a recommendation in section 4.12.6, *Emergency Response and Evacuation Planning*, to ensure boaters would be warned in the unlikely event that a potential exists for fire in any of these impoundments.

Table 4.12.4-2 presents the maximum distances for incident flux levels ranging from 1,600 to 10,000-Btu/ft^2-hr, as calculated by FERC staff. We believe Calhoun Point Comfort's proposed terminal would satisfy the thermal exclusion zone requirements of 49 CFR 193.2057.

TABLE 4.12.4-2

Thermal Exclusion Zones

Source	Exclusion Area NFPA 59A Section 2-2.3.2(a)	Incident Flux (Btu/ft^2 hr) (a/)	Exclusion Zone (feet)
LNG Storage Tank Impoundment	Outdoor assembly area occupied by 50 or more people.	1,600	923
LNG Storage Tank Impoundment	Off-site structures used for occupancies or residences.	3,000	742
LNG Storage Tank Impoundment	Property line that can be built upon.	10,000	429
LNG Storage Tank Impoundment Sump	Property line that can be built upon.	1,600	668
Dock Sump and Process Area Sump	Property line that can be built upon.	1,600	286
Vaporization Area Sumps	Property line that can be built upon.	1,600	104

a/ The 1,600 Btu/ft^2-hr flux level is associated with an exposed person experiencing burns within about 30 seconds. At 3,000 Btu/ft^2-hr, an exposed person would experience burns within 10 seconds; however, a wooden structure would not be expected to burn and affords protection to sheltered persons. At 10,000 Btu/ft^2-hr, clothing and wood can ignite spontaneously.

Vapor Dispersion Zone

A large quantity of LNG spilled without ignition would form a flammable vapor cloud that would travel with the prevailing wind until it either dispersed below the flammable limits or encountered an ignition source. Sections 2.2.3.3 and 2.2.3.4 of NFPA 59A, 2001 edition, and Part 193.2059 require that provisions be made to minimize the possibility of flammable vapors from reaching a property line that can be built upon and that would result in a distinct hazard. Part 193.2059 requires that dispersion distances be calculated for a 2.5 percent average gas concentration (one half the lower flammability limit [LFL] of LNG vapor) under meteorological conditions which result in the longest downwind distances at least 90 percent of the time. Alternatively, maximum downwind distances may be estimated for stability Class F, a wind speed of 4.5 mph, 50 percent relative humidity, and the average regional temperature. The section allows the use of the DEGADIS Dense Gas Dispersion Model, or the FEM3A model, to compute dispersion distances. Design spills into impounding areas serving LNG containers,

transfer systems, and piping are to be determined in accordance with Section 2.2.3.5 of NFPA 59A, 2001 edition. In accordance with Section 2.2.3.3 of NFPA 59A, 2001 edition, an average concentration of methane in air of 50 percent of the LFL cannot cross the property line from a design spill into each tank impoundment. In this case, compliance with Section 2.2.3.3 would also meet the requirements of Section 2.2.3.4 of NFPA 59A, 2001 edition.

In performing the vapor dispersion analysis required by 49 CFR 193.2059, Calhoun Point Comfort selected a wind speed of 4.5 mph, an atmospheric temperature of 71°F, a relative humidity of 50 percent, and atmospheric stability Class F. A ground temperature of 71°F was also assumed. In its analysis, Calhoun Point Comfort modeled a spill of the full flow from the marine unloading line into the square sub-impoundment within the storage tank berm. Using SOURCE5 and DEGADIS, Calhoun Point Comfort calculated a distance of 633 feet to the 2.5 percent average gas concentration isopleth. However, this analysis assumed very effective vapor retention within the storage tank berm, resulting in no vapor escaping for a period of over 6 hours after the spill. We do not believe this to be a reasonable assumption.

Consequently, FERC staff calculated flammable vapor dispersion distances using Calhoun Point Comfort's atmospheric conditions for the sub-impoundment with the berm artificially set to 0 feet. This allows the scenario to be modeled without accounting for any vapor retention by the storage tank berm. As previously discussed, the design spill for each LNG storage tank would be a rupture of the discharge header for the in-tank pumps. This would be a spill of 110,000 gallons and would be contained by the square sub-impoundment located in the lower half of the LNG storage tank impoundment. According to staff's calculations, vapor overtopping would occur within 14 seconds. The DEGADIS results indicate a distance of 1,667 feet to the 2.5 percent average gas concentration isopleth. The dispersion distances calculated by FERC staff extends beyond the plant property line into the waters surrounding the site (see figure 4.12-2). However, this is a conservative estimate. The actual dispersion distance would be shorter as the berm would provide some vapor retention.

Staff also performed a vapor dispersion analysis for the Dock Area Sump, Process Area Sump, and the two LNG Vaporization Area Sumps with SOURCE5 and DEGADIS. The 130,481 gallon design spill would be contained by either the Dock Area Sump or the Process Area Sump. DEGADIS indicates a distance of 694 feet to the 2.5 percent average gas concentration isopleth for this design spill (see figure 4.12-2). The 30,070 gallon design spill would be contained by either LNG Vaporization Area Sump. In this case, DEGADIS indicates a distance of 465 feet to the 2.5 percent average gas concentration isopleth.

Although the flammable vapor gas dispersion exclusion zones associated with these design spills would extend off-site into the MSC and Cox Bay, there are no prohibited land uses within them. We believe the vapor dispersion exclusion zones for the proposed project would comply with the regulations in 49 CFR 193.2007 and 193.2059. Furthermore, a recommendation has been added in section 4.12.6, *Emergency Response and Evacuation Planning*, to ensure that boaters would be warned in the unlikely event that LNG vapor may disperse over the waters surrounding the site.

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Figure 4.12-2

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4.12.5 LNG Carrier Safety

Since 1959, LNG has been transported by ship without a major release of cargo or a major accident involving an LNG ship. Over the last 45 years, LNG carriers have made 44,000 voyages worldwide. Starting in 1971, LNG began arriving at the Distrigas facility in Everett, Massachusetts. To date, more than 680 cargoes, with volumes ranging from 60,000 to 125,000 m^3, have been delivered into the Port of Boston without incident. During 2005, a total of 241 cargoes of LNG was imported into the United States. For 36 years, LNG shipping operations have been safely conducted in the United States.

4.12.5.1 History

During the 44,000 voyages that have been completed since the inception of LNG maritime transportation, there has not been a serious accident at sea or in a port which resulted in a spill due to rupturing of the cargo tanks. However, insurance records, industry sources, and public websites identify a number of incidents involving LNG vessels, including minor collisions with other vessels of all sizes, groundings, minor LNG releases during cargo unloading operations, and mechanical/equipment failures typical of large vessels. Some of the more significant LNG vessel incidents are described below:

- ***Pollenger*** had an LNG spill onto the steel cover of cargo tank number one during unloading at Everett, Massachusetts in April 1979. The spill caused cracking of the steel plate.
- ***El Paso Paul Kayser*** grounded on a rock in June 1979 in the Straits of Gibraltar during a loaded voyage from Algeria to the United States. Extensive bottom damage to the ballast tanks resulted; however, the cargo tanks were not damaged, and no cargo was released. The complete cargo of LNG was subsequently transferred to another LNG ship and delivered to its U.S. destination.
- ***LNG Taurus*** grounded in December 1980 near the entrance to Taboata Harbor, Japan. The grounding resulted in extensive bottom damage, but the cargo tanks were not affected. The ship was refloated and the cargo unloaded.
- ***Isabella*** had LNG spill onto its deck due to a cargo tank overflow in June 1985, causing severe cracking of the steelwork. The spill had been attributed to a cargo valve failure during discharging of cargo.
- ***Tellier*** was blown from its docking berth at Skikda, Algeria in February 1989 during severe winds causing damage to the loading arms and the ship and shore piping. The cargo loading had been secured just before the wind struck, but the loading arms had not been drained. Consequently, the LNG remaining in the loading arms spilled onto the deck causing fracture of some plating.
- ***Mostefa Ben Boulaid*** had LNG spill onto its deck during loading operations in Algeria in 2002. The spill, which is believed to have been caused by overflow rather than a mechanical failure, caused significant brittle fracturing of the steelwork. The ship was required to discharge its cargo, after which it proceeded to dock for repair.

- ***Khannur*** had a cargo tank overfill into the ship's vapor handling system on September 10, 2001 during unloading at Everett, Massachusetts. Approximately 100 gallons of LNG were vented and sprayed onto the protective decking over the cargo tank dome, resulting in several cracks. After re-inspection by the Coast Guard, the Khannur was allowed to discharge its LNG cargo.
- ***Norman Lady*** was struck by the USS Oklahoma City nuclear submarine while rising to periscope depth near the Strait of Gibraltar in November 2002. The 87,000 m^3 LNG tanker, which had just unloaded its cargo at Barcelona, Spain, sustained only minor damage to the outer layer of its double hull but no damage to its cargo tanks.
- ***Tenaga Lima*** grounded on rocks while proceeding to open sea east of Mopko, South Korea due to strong current in November 2004. The shell plating was torn open and fractured over an approximate area of 20 feet by 80 feet, and internal breaches allowed water to enter the insulation space between the primary and secondary membranes. The ship was refloated, repaired and returned to service.
- ***Golar Freeze*** moved away from its docking berth during unloading on March 14, 2006 in Savannah, Georgia. The powered emergency release couplings on the unloading arms activated as designed and transfer operations were shut down.

4.12.5.2 Vessel Construction

In 1980, at the initial peak of LNG import activity in the United States, the Coast Guard published the report *Liquefied Natural Gas and Liquefied Petroleum Gas – Views and Practices – Policy and Safety*. The report summarized the Coast Guard's extensive research into the safety hazards of LNG and its view that "...the nature of both LNG and LPG presents an acceptable risk for transportation in maritime commerce." This is due to the fact that LNG ships are well constructed, robust vessels designed to withstand low-energy type incidents that are prevalent in harbors and during docking operations. Moreover, safety measures, both equipment and training, are planned and designed into these LNG ships to prevent or control all types of potential incidents. The Sandia National Laboratory reached a similar conclusion in 2005 in its report.

The world's LNG ship fleet currently exceeds 218 carriers. Currently, all of the ships in the LNG fleet operate under a foreign flag with foreign crews. The LNG ships used to import LNG to the United States would be constructed and operated in accordance with the International Maritime Organization (IMO) *Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk*, the SOLAS, and 46 CFR Part 154, which contain the U.S. safety standards for vessels carrying bulk liquefied natural gas. Foreign flag LNG ships are required to possess a valid IMO Certificate of Fitness and a Coast Guard Certificate of Compliance.

As required by the IMO conventions and design standards, hold spaces and insulation areas on an LNG carrier are equipped with gas detection and low temperature alarms. These devices monitor for leaks of LNG into the insulation between primary and secondary LNG cargo tank barriers. In addition, hazard detection systems are also provided to monitor the hull structure adjacent to the cargo tank, compressor rooms, motor rooms, cargo control rooms, enclosed spaces in the cargo area, specific ventilation hoods and gas ducts, and air locks.

LNG carriers are equipped with a firewater system with the ability to supply at least two jets of water to any part of the deck in the cargo area and parts of the cargo containment and tank covers above-deck. A water spray system is also available for cooling, fire prevention, and crew protection in specific areas. Furthermore, certain areas of LNG carriers are fitted with dry chemical powder-type extinguishing systems and CO_2 smothering systems for fighting fires.

In 1993, amendments to the IMO's Code for the *Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk* require all tankers to have monitoring equipment with an alarm facility which is activated by detection of over-pressure or under-pressure conditions within a cargo tank. In addition, the cargo tanks are heavily instrumented, with gas detection equipment in the hold and inter-barrier spaces, temperature sensors, and pressure gauges. Fire protection must include the following systems:

- a water spray (deluge) system that covers the accommodation house control room and all main cargo valves;
- a traditional firewater system that provides water to fire monitors on deck and to fire stations found throughout the ship;
- a dry chemical fire extinguishing system for hydrocarbon fires; and
- a carbon dioxide system for protecting machinery including the ballast pump room, emergency generators, and compressors.

As a result of September 11, 2001, the IMO agreed to new amendments to the 1974 SOLAS addressing port facility and ship security. The *International Ship and Port Facility Security (ISPS) Code* was adopted in 2003 by the IMO. This code requires both ships and ports to conduct vulnerability assessments and to develop security plans. The purpose of the code is to: prevent and suppress terrorism against ships; improve security aboard ships and ashore; and reduce the risk of passengers, crew, and port personnel on board ships and in port areas, for vessels and cargoes. All LNG vessels as well as other cargo vessels 300-gross tons and larger, and ports servicing those regulated vessels, must adhere to these IMO and SOLAS standards. Some of the IMO requirements are as follows:

For the ships, these requirements must include:

- ships must develop security plans and have a Vessel Security Officer (VSO);
- ships must be provided with a ship security alert system. These alarms transmit ship-to-shore security alerts to a competent authority designated by the Administration, which may include the company, identifying the ship, its location, and indicating that the security of the ship is under threat or has been compromised;
- ships must have a comprehensive security plan for international port facilities, focusing on areas having direct contact with ships; and
- ships may have certain equipment onboard to help maintain or enhance the physical security of the ship.

For the port facilities, the requirements must include:

- the port facility must have a security plan and a Facility Security Officer (FSO); and
- certain security equipment may be required to maintain or enhance the physical security of the facility.

Both ships and ports must include the following:

- monitoring and controlling access;
- monitoring activities of people and cargo;
- ensuring security communications and that they are readily available; and
- completion of a Declaration of Security that is signed by the FSO and VSO.

4.12.5.3 Hazards

The history of LNG shipping has been free of major incidents, and none have resulted in significant quantities of cargo being released (see section 4.12.5.1). No incidents have occurred at existing LNG terminals during the 50 years of operation that resulted in any significant quantities of cargoes being released. However, the possibility of an LNG spill from a ship over the duration of the proposed project must be considered. Historically, the events most likely to cause a substantial release of LNG were a ship casualty such as:

- a vessel colliding with an LNG ship in transit;
- an LNG ship alliding[8] with the terminal or a structure in Matagorda and Lavaca Bays;
- a vessel alliding with an LNG ship while moored at the terminal; or
- a grounding sufficiently severe to puncture an LNG cargo tank.

The attacks on September 11, 2001, have made the public keenly aware of additional risks that must be considered in the evaluation of marine safety and security:

- a deliberate attack on an LNG ship by a terrorist group.

To result in a spill of LNG, any of the above events would need to occur with sufficient impact to breach an LNG carrier's double hull and cargo tanks. All LNG ships used to deliver LNG to this proposed project would have double hull construction, with the inner and outer hulls separated by about 10 feet. Furthermore, the cargo tanks are normally separated from the inner hull by a layer of insulation approximately 1-foot thick.

As a result, many grounding incidents severe enough to cause a cargo spill on a single bottom oil tanker would be unable to penetrate both inner and outer hulls of an LNG ship. An earlier Federal Power Commission (predecessor to the FERC) study estimated that the double bottom of an LNG ship would be sufficient to prevent cargo tank penetration in about 85 percent of the cases that penetrated a single bottom oil tanker. Previous incidents with LNG carriers have

[8] "Allision" is the action of dashing against or striking upon a stationary object (e.g., the running of one ship upon another ship that is docked) – distinguished from "collision," which is used to refer to two moving ships striking one another.

primarily involved grounding, and none of these have resulted in the breach of the double hull and subsequent release of LNG cargo.

The probability of an LNG ship sustaining cargo tank damage in a collision would depend on several factors: the displacement and construction of both the struck and striking vessels; the velocity of the striking vessel and its angle of impact with the struck vessel; and the location of the point of impact. The previous Federal Power Commission study estimated the additional protection afforded by the double hull would be effective in low energy collisions, overall it would prevent cargo tank penetration in about 25 percent of the cases that penetrated a single hull oil tanker.

In 1995, to assist the Coast Guard in San Juan, Puerto Rico, EcoEléctrica L.P. prepared an analysis of the damage that could result from an oil tanker striking an LNG ship at berth (FERC, 1996). The analysis assumed a 125,000 m^3 LNG ship and an 82,000 dead weight ton tanker carrying number 6 fuel oil without tug assistance. The analysis determined the minimum striking speed to penetrate the cargo tanks of an LNG ship for a range of potential collision angles. The resulting minimum striking speeds are presented in table 4.12.5.3-1 for the two principal cargo systems.

TABLE 4.12.5.3-1

Minimum Striking Speed to Penetrate LNG Cargo Tanks

Angle of Impact	Minimum Striking Speed (knots)	
	Spherical Tanks	Membrane Tanks
Greater than 60 Degrees	4.5	3
45 Degrees	6.3	4
30 Degrees	9	6
15 Degrees	18	12

For membrane tanks, the critical beam-on striking speed is 3.0 knots, and for spherical tanks, the critical on-beam speed is 4.5 knots. For both containment types, lower angles of impact result in much greater minimum striking speeds to penetrate LNG cargo tanks. In the July/August 2002 issue of the "*LNG Journal*," the Society of International Gas Tanker & Terminal Operators General Manager provides a table that shows the critical speed necessary for a 20,000-ton vessel to puncture the outer hull of an LNG carrier is 7.3 knots. For a 93,000-ton ship, the impact speed is 3.2 knots. In neither case does such an impact result in damage to the LNG cargo containment system nor result in release of LNG.

The Sandia Report included an LNG cargo tank breach analysis using modern finite element modeling and explosive shock physics modeling to estimate a range of breach sizes for credible accidental and intentional LNG spill events. The analysis of accidental events found that groundings, collisions with small vessels and low speed (less than 7 knots) collisions with large vessels striking at 90 degrees could cause minor ship damage but would not result in a cargo spill. This is due to the protection provided by the double hull structure, the insulation layer and the primary cargo tank of an LNG vessel. High speed (12 knots) collisions with large vessels striking at 90 degrees were found to potentially cause cargo tank breach areas of 0.5 to 1.5 square meters.

In the event of a collision or allision of sufficient magnitude to rupture an LNG cargo tank, it is likely that sparks or flames would ignite the flammable vapors at the spill site. In a grounding of sufficient magnitude to rupture an LNG cargo tank, the damage would occur under water and the potential for ignition would be less than for collisions or allisions. In this case, an LNG spill would rapidly vaporize on water and form a potentially flammable cloud. If not ignited, the flammable vapor cloud would drift downwind until the effects of dispersion would dilute the vapors below the lower flammable limit for methane. The maximum range of potentially flammable vapors (i.e., the distance to the lower flammable limit) is a function of the volume of LNG spilled, the rate of the spill, and the prevailing meteorological conditions. If the flammable vapor cloud encountered an ignition source, the cloud would burn back to the spill site.

The final EIS for the Calcasieu LNG Project (Lake Charles, LA) (September 1976) analyzed the maximum range of a flammable vapor cloud and hazardous radiation levels from an instantaneous one-tank spill. As was consistent with risk analyses at that time and for nearly 25 years thereafter, the instantaneous spillage of one cargo tank was considered to be the "worst case" scenario. Physical constraints on maximum vessel speeds and maximum depths of penetration required to rupture one LNG cargo tank render the possibility of an instantaneous release of more than one cargo tank to be implausible. This is not to imply that the loss of multiple cargo tanks could never occur, but that the extent of the hazard would not exceed that of the instantaneous spillage of one tank.

For an instantaneous one-tank spill with ignition, the final EIS for the Calcasieu LNG Project estimated that a hazardous thermal radiation level of 5,300 Btu/hr-ft^2 would extend 3,595 feet from the center of the spill. For an instantaneous one-tank spill without ignition, the final EIS for the Yukon Pacific LNG Project (FERC, March 1995) estimated that potentially flammable vapors could travel up to 3.3 miles with a 10-mph wind and typical atmospheric stability.

In October 2001, the use of a one-tank instantaneous release as the "worst case" scenario was re-examined by Quest Consultants, Inc (Quest) as part of an effort by the DOE to determine the hazards associated with reopening the Distrigas LNG import terminal following the terrorist attacks of September 11, 2001. It was determined that time-release spills through 1-meter and 5-meter diameter holes would more accurately simulate credible "worst case" damage scenarios. Maximum flammable vapor cloud and radiation hazards were calculated for the two spill scenarios. For a spill on water with ignition, the maximum distance to a radiant flux level of 1,500 Btu/ft^2-hr was estimated to be 1,770 feet. For a spill on water without ignition, a flammable vapor cloud of 2.5 miles was estimated. In November 2003, in response to comments concerning its October 2001 study, Quest clarified that its study only applied to LNG spills resulting from a collision with a large ship in Boston's Outer Harbor where waves would restrict the spreading of LNG on water.

Since the Quest study, there has been an emergence of studies by various parties to define the "worst case" scenario that would result from a deliberate, terrorist attack on an LNG vessel and the subsequent release of cargo. Distances have been estimated to range from 1,770 to 4,200 feet for a thermal radiation level of 1,500 Btu/ft^2-hr. Part of the reason for the apparent discrepancies is the lack of large-scale historical incidents, and the need to extrapolate small-scale field test data to a worst case event. This inevitably leads to differing conservative assumptions among the various parties. For example, some models calculate a time-release cargo discharge through

1-meter or 5-meter diameter holes, while others assume that the cargo tank empties instantaneously.

As a result, the FERC commissioned a study by ABSG Consultants to search and review the literature on experimental LNG spills and on consequence methodologies that are applicable to modeling incidents of LNG spills on water. Further, the goal of the study was to identify appropriate methods for estimating flammable vapor and thermal radiation hazard distances for potential LNG vessel cargo releases during transit and while at berth. The resulting study, *Consequence Assessment Methods for Incidents Involving Releases from Liquefied Natural Gas Carriers*, was released for public comment on May 14, 2004. On June 18, 2004, the FERC staff's responses to comments on the consequence assessment methods were issued. In addition, the model was updated to include a lower limit on the characteristic wind speed. As discussed in greater detail in the staff's responses, various components of the consequence assessment methodologies were revised based on comments received. The revised methodology provides procedures for calculating: (1) the rate of release of LNG from a cargo tank penetration for various sized holes; (2) the spreading of an unconfined LNG pool on water for both continuous spills and rapid (nearly instantaneous) releases; (3) the rate of vapor generation from an unconfined spill on water; (4) thermal radiation distances for LNG pool fires on water; and (5) and flammable vapor dispersion distances.

A detailed evaluation of the consequences of a terrorist attack on a modern membrane LNG tanker was prepared by Lloyds Register North America for the Weaver's Cove LNG Project. The study evaluated the consequences of attacks on an LNG tanker by missiles and explosives. Finite element analysis was used to evaluate the effect of various sized charges on both the outer and inner hulls. A 1-meter diameter hole of the inner hull at the waterline was found to be the "worst case" scenario for hazard consequence assessments. This finding is consistent with the attack on the double hull oil tanker *Limberg* which caused greater than a 5-meter diameter hole on the outer hull, but only minor damage to the inner hull. A failure modes and effects analysis was used to understand internal LNG release characteristics and a residual strength analysis used to investigate damage scenarios for a loaded LNG tanker.

As discussed above, the Sandia Report included an LNG cargo tank breach analysis using modern finite element modeling and explosive shock physics modeling to estimate a range of breach sizes for credible accidental and intentional LNG spill events. For intentional scenarios, the size of the cargo tank hole depends on the location of the ship and source of threat. Intentional breach areas were estimated to range from 2 to 12 m^2. In most cases, an intentional breaching scenario would not result in a nominal hole of more than 5 to 7 m^2, which is a more appropriate range to use in calculating potential hazards from spills.

The Sandia Report also included guidance on risk management for intentional spills, based on the findings that the most significant impacts to public safety and property exist within approximately 500 meters (1,640 feet) of a spill due to thermal hazards from a fire, with lower public health and safety impacts beyond 1,600 meters (5,250 feet). Large, unignited LNG vapor releases were found to be unlikely, but could extend to 2,500 meters (8,200 feet) for a nominal intentional spill.

Cascading damage due to brittle fracture from exposure to cryogenic liquid or fire-induced damage to foam insulation was evaluated and, while possible under certain conditions, is not

likely to involve more than two or three cargo tanks. Cascading events are not expected to increase the overall fire hazard by more than 20 to 30 percent (1,920 to 2,080 meters (6,300 to 6,825 feet)), but would increase the expected fire duration. Rapid phase transitions are possible for large spills but the effects would be localized near the spill source and should not cause extensive structural damage.

As part of the waterway suitability review process, the Coast Guard uses criteria from the Sandia Report to define the outer limits of the hazard zones for assessing potential risks associated with the proposal. The Zones of Concern used in the analysis are listed below:

- Zone 1 - impacts on structures and organisms are expected to be significant within 500 meters (1,640 feet). The outer perimeter of Zone 1 is the distance to thermal hazards of 37.5 kW/m^2 (12,000 Btu/ ft^2-hr) from a pool fire.

- Zone 2 - impacts would be significant but reduced, and damage from radiant heat levels are expected to transition from severe to minimal between 500 and 1,600 meters (1,640 and 5,250 feet). The outer perimeter of Zone 2 is the distance to thermal hazards of 5 kW/m^2 (1,600 Btu/ ft^2-hr) from a pool fire.

- Zone 3 - impacts on people and property from a pool fire or an unignited LNG spill that does not ignite are expected to be minimal between 1,600 meters (5,250 feet) and a conservative maximum distance of 3,500 meters (11,500 feet). The outer perimeter of Zone 3 should be considered the vapor cloud dispersion distance to the LFL from a worst case unignited release. Impacts to people and property could be significant if the vapor cloud reaches an ignition source and burns back to the source.

The severity of impacts within Zones 1 through 3 would depend on the location of the incident relative to a specific area, the scope of the incident, and whether the released LNG ignited or dispersed. This could be a significant impact, being most severe in Zone 1 and decreasing outward through Zones 2 and 3. However, because of the implementation of safety and security measures during marine transit, the likelihood of a marine LNG spill is remote and not considered a reasonably foreseeable event.

Based on the breach sizes identified in the Sandia Report, the methodology described in the ABSG Consulting study, and revised in the FERC staff's responses to comments, was also used to calculate the thermal radiation and flammable vapor dispersion distances. In the case of the penetration of the largest cargo tank of a 140,000 m^3 LNG ship, a potential spill of 23,000 m^3 is estimated for the volume of LNG above the waterline. The estimated pool spread results and thermal radiation hazard distances are identified in table 4.12.5.3-2 below. Thermal radiation calculations are based on an ambient temperature of 50°F, a relative humidity of 50 percent, and a 20-mile per hour wind speed.

TABLE 4.12.5.3-2 **LNG Spills on Water**					
LNG Release and Spread					
Hole Area	0.8 square meters	1.5 square meters	5 square meters	7 square meters	12 square meters
Hole Diameter	1.0 meter	1.4 meters	2.5 meters	3.0 meters	3.9 meters
Spill Time	94.0 minutes	48.0 minutes	15.0 minutes	10.4 minutes	6.2 minutes
Pool Fire Calculations					
Maximum Pool Radius	341 feet	476 feet	817 feet	938 feet	1,102 feet
Fire Duration	94.1 minutes	48.1 minutes	15.2 minutes	10.7 minutes	6.5 minutes
Distance to:					
1,600 BTU/ft^2-hr	2,164 feet	2,790 feet	4,182 feet	4,652 feet	5,250 feet
3,000 BTU/ft^2-hr	1,690 feet	2,169 feet	3,232 feet	3,591 feet	4,047 feet
10,000 BTU/ft^2-hr	1,031 feet	1,312 feet	1,934 feet	2,143 feet	2,409 feet
12,000 BTU/ft^2-hr	947 feet	1,205 feet	1,775 feet	1,967 feet	2,211 feet

Flammable vapor dispersion calculations were based on an ambient temperature of 70ºF, 50 percent relative humidity, a 4.5-mph wind speed and atmospheric stability Class F. Based on a 1-meter diameter hole, an unignited release would result in an estimated pool radius of 421 feet. The unignited vapor cloud would extend to 9,776 feet to the LFL and 14,377 feet to one-half the LFL. It is important to identify certain key assumptions of conditions that must exist in order to achieve the maximum vapor cloud distances. First it would be necessary for an event to create a 1-meter diameter hole by penetrating the outer hull, the inner hull, and cargo containment without ignition. Far more credible is that the event creating a 1-meter diameter hole would also result in a number of ignition sources which would lead to an LNG pool fire and subsequent thermal radiation hazards. It is also unlikely that a flammable vapor cloud could achieve its maximum distance over land surfaces without encountering an ignition source, and subsequently burning back to the source. Flammable vapor dispersion for larger holes was not performed since, realistically, the cloud would not even extend to the maximum distance for a 1-meter diameter hole before encountering an ignition source.

The results of these calculations are in agreement with the Zones of Concern used by the Coast Guard in assessing the waterway suitability and are in agreement with the Sandia report. These intentional breach scenarios provide guidance to the Coast Guard in developing the operating restrictions for LNG ships movements in the waterway, as well as in establishing potential impact areas for emergency response and evacuation planning. By focusing on the "worst case" scenario for LNG transportation, there is a tendency to dismiss the potential hazards for other fuels and products commonly transported on our waterways. Some of the previously identified studies that calculate long hazard distances for LNG cargo fires also estimate similarly long distances for gasoline, propane, and jet fuel cargo fires. Also, it should not be assumed that the hazard distances identified are the assured outcome of an LNG vessel accident or attack, given the conservatisms in the models and the level of damage required to yield such large scale

releases. Further, these estimated "worst case" scenarios should not be misconstrued as defining an exclusionary zone. Rather the average most probable "worst case" scenarios provide guidance in developing the operating restrictions for LNG vessel movements in the MSC, as well as in establishing potential impact areas for emergency response and evacuation planning.

Currently, the MSC has a minimum width of 200 feet and a depth of 36 feet, limiting the size of LNG carriers which could be received by the facility. A vessel maneuvering study by Moffatt & Nichols analyzed the inbound transit of a fully loaded 90,000 m^3 LNG carrier with a loaded draft of 34 feet using bathymetric data of the MSC from 2003. Based on this study, Calhoun Point Comfort states that the MSC at its current depth and width would be able to safely accommodate LNG carriers up to 90,000 m^3 in capacity. Calhoun Point Comfort would design the terminal and unloading berth for LNG ships with capacities up to 220,000 m^3. The limited information available regarding the design of future 220,000 m^3 LNG ships suggests that the draft of the larger ships would remain the same due to the limited draft of the channel, while the length and width of the larger ships would increase. Preliminary information shows that the larger class ships would have five cargo tanks instead of four as on the 140,000 m^3 ships. For a 220,000 m^3 LNG ship compared to the results for a 140,000 m^3 LNG ship, the estimated distance to the 1,600 Btu/ft^2-hr zone would be less than 5 percent farther and the fire duration would be extended by about 39 percent. Therefore, in order to allow the Coast Guard to determine the continued suitability of the waterway for LNG marine traffic, **we recommend that**:

- **<u>Prior to accepting</u> ships greater than 140,000 m^3 in capacity, Calhoun Point Comfort should provide the necessary information to demonstrate that the transient hazard areas identified in the EIS are applicable. Calhoun should file this information with the Secretary for review and written approval of the Director of OEP. This information should also be provided to the Coast Guard.**

4.12.5.4 LNG Vessel Transit to the Calhoun Point Comfort LNG Project

Imported LNG could be obtained from exporting terminals throughout the world and delivered by LNG ships to the proposed terminal. Exporting countries include Algeria, Australia, Brunei, Indonesia, Malaysia, Nigeria, Oman, Qatar, Trinidad, and United Arab Emirates. In 2003, LNG imports to the United States included: 72 percent from Trinidad, 12 percent from Nigeria, 10 percent from Algeria, 3 percent from Qatar, 2 percent from Oman, and 1 percent from Malaysia. At this time, Calhoun Point Comfort has not confirmed the source(s) of LNG supplies.

From open seas and the wider Gulf of Mexico, LNG ships are navigated by their own Captain towards the Texan coast via a series of Safety Fairways. These shipping lanes are designated as clear routes by marine authorities to assist ships in maintaining clearance from the many offshore oil and gas structures present in coastal waters.

Once arriving at the Texas coast, LNG ships would transit about 22 miles from the Gulf of Mexico to the proposed LNG terminal along the MSC. All ships in the MSC are required to have a Matagorda Pilot (Pilot). If the Coast Guard issues an LOR, as described in section 1.3 "Permits, Approvals, and Regulatory Requirements," finding the waterway suitable for LNG marine traffic, the LNG ship would board a Pilot approximately 3.5 miles southeast of the Matagorda jetties. The Pilots are presently the controlling body in terms of scheduling,

monitoring of weather conditions, establishing working conditions, and declaring channel closure days based on inclement weather. After boarding the LNG ship, the Pilot would navigate the vessel through the narrowest part of the MSC - the Jetties Channel – which is the land cut in the Matagorda Peninsula. From there, vessels would travel in a straight line along the MSC until reaching the Port where the vessel would swing in readiness for berthing.

Although the MSC is transited both day and night, large ships, such as an LNG carrier, are restricted to one-way traffic as coordinated by the Pilots. If the Coast Guard issues an LOR finding the waterway suitable for LNG marine traffic, the LNG ship would normally transit, arrive, and enter the port during early daylight hours and would be assisted by the two larger tractor tugs in the approach to the LNG terminal. Final marine operating procedures would be developed in partnership between Calhoun Point Comfort, the Pilots and the Port, but it would be common for tugs to rendezvous with inward bound LNG ships some time prior to the swinging area.

The berth would be aligned such that the LNG vessels would be turned by the tugs and backed onto berth. Docking, LNG offloading, and undocking would take less than 24 hours. The LNG ship would depart during daylight hours on the second day.

Cities and population areas that would be within the Zones of Concern are discussed in section 4.8.1 of this EIS. There are no nuclear power plants or tunnels within the Zones of Concern. In addition, the LNG ships would not pass under any bridges during transit. See figure 4.4-1 sheets 1 through 4 for a depiction of critical infrastructure with the Zones of Concern.

The State Highway 35 Bridge across Lavaca Bay falls within Zone 3 (see figure 4.4-1 sheet 4). In case the response time is inadequate to stop traffic from entering the bridge, traffic on the bridge could serve as a source of ignition to the vapor cloud. In this case, people and vehicles on the bridge would be at risk from a flash fire. The greatest risk to people would occur during morning and afternoon commute times, since many people in Port Lavaca work at Alcoa, Formosa Plastics, Formosa Hydrocarbons, or other industrial employers on the east side of the bridge. Calhoun LNG's emergency response plan would include notification systems to the Calhoun County Sheriff Department and Police Departments for both the City of Point Comfort and City of Port Lavaca. These measures would include traffic control of major arteries such as Highway 35 causeway. In addition, the bridge itself could be exposed to high heat and flame impingement in the unlikely event of a flash fire. Depending on the duration and intensity of the event, the bridge could be largely undamaged or significantly impacted.

LNG vessels would cross several major pipelines in the bay. From normal operations, there is very low probability that operations would affect the pipelines. These pipelines are required to be buried a minimum of 10 feet below major navigation channels. If the MSCIP goes forward, the depth of these pipelines will be checked by the COE, and the pipelines would be lowered from their current placement if necessary. In the case of a catastrophic accident or terrorist incident in the MSC, the LNG ship would likely have to be directly over a pipeline for the pipeline to suffer damage from the incident, and even then the likelihood of damage to the pipeline would be remote. It is believed that all of the major pipelines in the bay that are crossed by the MSC are natural gas pipelines, except the two 8-inch-diameter liquid product lines which connect the Port with the Ineos facility located near Seabreeze. Some of the local gathering lines

from platforms in the bay could also contain liquid hydrocarbons (condensate or crude oil). Several of these gathering lines are also crossed by the MSC, and thus would be crossed by the transit of LNG vessels. Risk to these small gathering lines is minimal from normal operations and incidents to the LNG ships.

There are several major industrial sites within the Zones of Concern. Most of these are industries within the confines of the Port property, such as Ineos Nitrile and Texas Liquid Fertilizer, or nearby, such as Alcoa Point Comfort or Formosa Hydrocarbons. Except for the LNG terminal itself, most of the area encompassed by Zone 1 at the turning basin and at the dock is unmanned workspace. The control room for the Port is outside of Zone 1, as is the main office for the Port itself. Zone 2 would encompass Alcoa, and Zone 3 would extend to Formosa Hydrocarbons. The only other major industrial facility within a Zone of Concern is the Matagorda Gas Plant, which is just northwest of Magnolia Beach, and would be in Zone 3.

4.12.5.5 Requirements for LNG Ship Operations in Matagorda Ship Channel

The Coast Guard exercises regulatory authority over LNG facilities that affect the safety and security of port areas and navigable waterways under Executive Order 10173; the Magnuson Act (50 USC § 191); the Ports and Waterways Safety Act of 1972, as amended (33 USC § 1221, et seq.); and the Maritime Transportation Security Act of 2002 (46 USC § 701). The Coast Guard is responsible for matters related to navigation safety, vessel engineering and safety standards, and all matters pertaining to the safety of facilities or equipment located in or adjacent to navigable waters up to the last valve immediately before the receiving tanks. The Coast Guard also has authority for LNG facility security plan review and compliance verification as provided in Title 33 CFR Part 105, and siting as it pertains to the management of vessel traffic in and around the LNG facility.

The Coast Guard regulations, in 33 CFR 127, apply to the marine transfer area of waterfront facilities between the LNG ship and the last manifold or valve located immediately before a storage tank. Title 33 CFR 127 regulates the design, construction, equipment, operations, inspections, maintenance, testing, personnel training, firefighting, and security of LNG waterfront facilities. The safety systems, including communications, emergency shutdown, gas detection, and fire protection, must comply with the regulations in 33 CFR 127. Under 33 CFR 127.019, Calhoun Point Comfort would be required to submit two copies of its Operations and Emergency Manuals to the Captain of the Port for examination.

Title 33 CFR 127 separates cargo transfer operations into three distinct phases: Preliminary Transfer Inspection (Section 127.315); Declaration of Inspection (Section 127.317); and LNG Transfer (Section 127.319). These different sections require specific actions to be completed prior to and during the transfer. Additionally, there are specific actions required in the case of a release of LNG (Section 127.321).

As required by its regulations (Section 127.009), the Coast Guard is responsible for issuing an LOR as to the suitability of the waterway for LNG marine traffic with respect to the following items:

- information submitted under Section 127.007:
  - the physical location of the facility;
  - a description of the facility;
  - the LNG vessels' characteristics and the frequency of LNG shipments to or from the facility; and
  - charts showing waterway channels and identifying commercial, industrial, environmentally sensitive, and residential areas in and adjacent to the waterway used by the LNG vessels en route to the facility, within 25 kilometers (15.5 miles) of the facility.
- density and character of marine traffic;
- locks, bridges, or other manmade obstructions in the waterway; and
- the following factors adjacent to the facility:
  - depth of water;
  - tidal range;
  - protection from high seas;
  - natural hazards, including reefs, rocks, and sandbars;
  - underwater pipes and cables; and
  - distance of berthed vessels from the channel and the width of the channel.

The NVIC 05-05 provides Coast Guard Captains of the Port/Federal Maritime Security (MARSEC) Coordinators, members of the LNG industry, and port stakeholders with guidance on assessing the suitability of a waterway for LNG marine traffic that takes into account conventional navigation safety/waterway management issues contemplated by the existing LOI/LOR process, but in addition, will also take completely into account maritime security implications. In accordance with this guidance, each LNG project applicant is to submit a WSA to the cognizant Captain of the Port. The WSA process addresses the transportation of LNG from an LNG tanker's entrance into U.S. territorial waters, through its transit to and from the LNG receiving facility, including operations at the vessel/facility interface. In addition, the WSA should address the navigational safety issues and port security issues introduced by the proposed LNG operations. The NVIC 05-05 also provides specific guidance on the timing and scope of the WSA.

The process of preparing the LOR begins when an applicant submits an LOI to the Captain of the Port. In accordance with 33 CFR 127.007, Calhoun Point Comfort submitted an LOI to the Coast Guard on March 15, 2005 (see Appendix G).

Calhoun Point Comfort Waterway Suitability Assessment

On January 19, 2006, Calhoun Point Comfort submitted a WSA for the proposed project to the Captain of the Port Coast Guard Sector Corpus Christi. The Coast Guard, with input from the Area Maritime Security Committee, local law enforcement, and emergency response organizations, has completed a review of Calhoun Point Comfort's WSA in accordance with the guidance in NVIC 05-05. The WSA review focused on the navigation safety and maritime security risks posed by LNG marine traffic, and the measures needed to responsibly manage these security risks.

Coast Guard Waterway Suitability Report

Based on the WSA review and consultations, the Coast Guard advised the FERC in its WSR dated June 19, 2006, that to make the Matagorada Bay suitable for the LNG marine traffic associated with the Calhoun Point Comfort Project, specific risk mitigation measures would be necessary. These measures were further delineated in a follow-up letter dated June 26, 2007, and include, among others, the following conditions:

- Transit Management Plan - A TMP which addresses specific issues and details related to LNG vessel transits to and from the LNG facility must be developed in cooperation with local stakeholders and reviewed/approved by the Captain of the Port.

- Communications Interoperability - All agencies involved in the vessel's navigation and security regime must have interoperable communications. Additionally, procedures must be specified and incorporated into the TMP for notification and communication with owners/operators of certain critical infrastructure located along the transit route.

- Law Enforcement Vessel Escort - While an LNG vessel is navigating its loaded inbound transit, an armed, multi-vessel escort may be required around the moving LNG vessel, as determined by a risk assessment at the time of transit. Escorts must be conducted by those with appropriate jurisdictional authority. For environmental analysis purposes, the number of armed escort vessels will range from zero to six.

- Shoreline Surveillance & Monitoring - The monitoring of shoreline and adjacent waterways shall be accomplished using a blend of electronic and crewed shore-side, waterborne, and aerial assets as described below. Appropriate Memorandums of Agreement (MOAs) between the Coast Guard and all entities involved will have to be developed.
    - Surveillance Patrols - State and local law enforcement agencies will provide landside security patrols for surveillance along certain portions of the waterfront prior to and during an LNG vessel's transit.
    - Aerial Reconnaissance - Aircraft may be used to monitor the shoreline ahead of the vessel's transit, with the capability of transmitting real-time information to security vessels or other assets involved in transit security.
    - Pre-staging of Surveillance Assets - Sufficient landside and waterborne law enforcement assets which are capable of being dispatched to investigate anomalies reported during reconnaissance of the transit route must be pre-staged.

- Video Surveillance System - The TMP must include integration of a video surveillance system of the vessel while moored at the terminal.

- Measures for Non-Empty Outbound Transits - If for any reason the LNG vessel must carry a significant amount of cargo during its outbound transit, all security measures recommended during inbound transit also shall be undertaken during the vessel's loaded outbound transit.

- Shore-Side Firefighting - Shore-side firefighting resources and training will need to be augmented in order to provide basic protection services to communities along the transit route.

- In-Transit Firefighting - A plan must be developed for managing underway firefighting, including provisions for command and control of tactical fire fighting decisions as well as financial arrangements for provision of mutual aid and identification of suitable locations for conducting fire fighting operations along the transit route.

- Public Notification System and Procedures - Adequate means to notify the public along the transit route, including ongoing public education campaigns, emergency notification systems (such as reverse 911 and siren systems), and drills and training are required. Education programs must be tailored to meet the various needs of all users of the waterway including commercial and recreational boaters, local businesses, local residents and tourists.

- Facility Security Measures - The LNG facility will be subject to the security regulations outlined in 33 CFR Part 105 and will be required to submit a FSP to Coast Guard approval. The facility will undergo (at a minimum) an annual Coast Guard security inspection. The facility shall also develop a plan to provide for appropriate security measures from the start of construction through implementation of the Coast Guard approved FSP.

- Tug Escort - A minimum of two commercial tug boats shall be provided to accompany the LNG vessel in transit from the designated sea buoy to the LNG facility.

- Divers for Pier Security Sweeps - On a case-by-case basis, divers may be required to conduct underwater security sweeps of the LNG pier. If deemed necessary by the Captain of the Port, divers shall be arranged for and provided by the facility owner.

- Anti-Boat Barriers - Anti-boat barriers may be provided in the vicinity of berthed LNG vessels and deployed whenever an LNG vessel is moored at the terminal. The barrier should be positioned to protect the vessel while not infringing upon federally controlled waters.

- Vessel and Facility Inspections - The LNG facility and LNG vessels serving the facility will be subject to (at a minimum) annual Coast Guard inspections to ensure compliance with federal and international safety, security, and pollution regulations. In addition, the LNG vessels and facility are typically required to undergo a pre-arrival inspection and are monitored during transfer operations.

After completion of the final EIS, the Coast Guard will complete its review and issue an LOR to address the suitability of the waterway for LNG transport. If the Coast Guard issues an LOR finding the waterway suitable for LNG marine traffic with conditions, the necessary security measures would be further developed into the detailed LNG Vessel TMP, which would become the basis for appropriate security measures for each Maritime Security threat level. This plan would clearly spell out roles, responsibilities, and specific procedures for an LNG ship transiting the MSC to the proposed Calhoun Point Comfort LNG terminal, as well as for all agencies

involved in implementing security and safety during the operation. Prior to the LNG ship being granted permission to enter the shipping channels, both the vessel and facility would be required to be in full compliance with the Maritime Transportation Security Act and International Ship and Port Facility Security Code, and the security protocols to be established by the Captain of the Port in the LNG Vessel TMP. The plan may include security measures such as: Coast Guard and other law enforcement agency vessels enforcing safety and security zones around the LNG ships while in transit and mooring at the terminal; shoreside surveillance and monitoring; and other prevention/mitigation strategies.

We recognize that the LNG Vessel TMP would be a dynamic document that would be prepared well before import operations would commence, and that the port's overall security picture may change over that time period. New port activities may commence, infrastructure may be added, or population density may change. Improvements in technology to detect, deter and defend against intentional acts may also develop. Therefore, **we recommend that:**

- **Calhoun Point Comfort should, until commencement of construction, annually review its waterway suitability assessment relating to LNG vessel traffic for the project; update the assessment to reflect changing conditions which may impact the suitability of the waterway for LNG marine traffic; and provide the updated assessment to the cognizant Captain of the Port/Federal Maritime Security Coordinator (COTP/FMSC) for review and validation and if appropriate, further action by the COTP/FMSC relating to LNG vessel traffic. In addition, Calhoun Point Comfort should provide copies of this information, including the status of appropriate MOAs for shoreline surveillance and monitoring and the plans for anti-boat barrier deployment, to the FERC staff.**

In addition, Calhoun Point Comfort would provide security for the terminal according to a Facility Security Plan that must be prepared under 33 CFR 105. This plan would need to be approved by the Coast Guard Captain of the Port. The requirements of this plan may include:

- a Facility Security Assessment to identify site vulnerabilities, possible security threats, consequences of an attack, and facility protective measures;
- procedures for responding to security incidents;
- a designated FSO responsible for implementing and periodically updating the Facility Security Plan and Assessment;
- scalable security measures to provide increasing levels of security at increasing MARSEC levels;
- security exercises at least once each calendar year and drills at least every three months; and
- mandatory reporting of all breaches of security and security incidents.

Security at the facility would be provided by both active and passive systems. The entire site would be surrounded by a protective enclosure (i.e., a fence) with sufficient strength to deter unauthorized access. The enclosure would also be illuminated with not less than 2.2 lux between sunset and sunrise. Intrusion detection systems and day/night camera coverage would identify

unauthorized access. A separate security staff would conduct periodic patrols of the plant, screen visitors and contractors. The security staff may also assist in maintaining security of the marine terminal during cargo unloading. Calhoun Point Comfort would be required to submit their Facility Security Plan to the Captain of the Port for approval 60 days prior to commencement of operations. In order to ensure that the responsibilities of Calhoun Point Comfort's security staff enhance overall security, **we recommend that:**

- **<u>Prior to commissioning</u>, Calhoun Point Comfort coordinate, as needed, with the Coast Guard to define the responsibilities of Calhoun Point Comfort's security staff in supplementing other security personnel and in protecting the LNG tankers and terminal.**

4.12.5.6 Impact of Vessel Security Requirements

The potential impacts of the proposed LNG vessel traffic for Calhoun Point Comfort on other commercial and recreational boaters is addressed in relation to several general security requirements: 1) a moving safety zone for inbound LNG vessels; 2) a security zone around a moored LNG vessel; and 3) other measures as deemed appropriate by the Coast Guard.

If the Coast Guard issues an LOR finding the waterway suitable for LNG marine traffic with the conditions referenced in the WSR, the Coast Guard may promulgate a moving safety/security zone that would affect other vessels. Pursuant to such a regulation, no vessel would be allowed to enter the safety/security zone without first obtaining permission from the Coast Guard Captain of the Port. If the Coast Guard issues an LOR finding the waterway suitable for LNG marine traffic with conditions, it is anticipated that the LNG ships would transit about 22 miles along the MSC to the Calhoun LNG terminal. For the majority of this trip, an LNG vessel would travel at an average speed of 8 to 10 knots. Based on these assumed speeds, it would take about 2.5 hours for LNG ships to complete the trip to the LNG terminal. Additional time would be required to maneuver the LNG ship into the berth. Minimum visibility conditions would have to be satisfied before the LNG ship would be allowed to proceed inbound from the Gulf of Mexico, ensuring that the Coast Guard could adequately monitor the safety zone.

If a moving safety/security zone during transit, a fixed security zone at the terminal, and one-way traffic in designated areas were implemented, they would affect other commercial and recreational traffic using the channel. The magnitude of the effect would also be influenced by other factors, such as the amount of time it takes to obtain a pilot and other competing ship traffic in the federal navigation channel.

If the proposed LNG terminal is constructed, and if the Coast Guard issues an LOR finding the waterway suitable for LNG marine traffic with the conditions described above under *Coast Guard Waterway Suitability Report*, as many as 120 LNG ships for the Calhoun LNG terminal could potentially move in and out of the MSC every year. This is an increase in vessel traffic of 44 percent for large vessels per year currently transiting these waterways. Other shipping activities would be moderately affected by this increase in traffic; however, based on the relatively modest current level of shipping activity, the impact is not expected to be substantial.

FERC has received comments on other LNG terminal proposals expressing concern about the cost of applying additional security measures and the potential burden on local taxpayers.

Additional funding for state and local resources would be provided by Calhoun Point Comfort. Funding for security and management costs are discussed further in section 4.12.6 under *Emergency Response and Evacuation Planning*.

While the LOR would address the suitability of the MSC for LNG ship transportation, it would not constitute a final authority to commence LNG operations. In addition, the Coast Guard may establish a safety and security zone under 33 CFR 165 for LNG vessels in transit and while docked. Only personnel or vessels authorized by the Captain of the Port would be permitted in the safety and security zone.

4.12.6 Emergency Response and Evacuation Planning

Prior to commencing operations, Calhoun Point Comfort would be required, according to 49 CFR Part 193.2509, to prepare final emergency procedures manuals that provide for: (a) responding to controllable emergencies and recognizing an uncontrollable emergency; (b) taking action to minimize harm to the public including the possible need to evacuate the public; and (c) coordination and cooperation with appropriate local officials. Specifically, Section 193.2509(b)(3) requires, "Coordinating with appropriate local officials in preparation of an emergency evacuation plan…"

While the exclusion zones evaluated for the onshore facility in section 4.12.4 and for marine spills in section 4.12.5 provide guidance on the maximum extent of potential hazards, they should not be assumed to represent the evacuation zone for *every* potential incident. As with any other fuel or hazardous material, the actual severity of the incident would determine what area needs to be evacuated, if any, rather than a worst-case maximum zone. It is anticipated that the emergency evacuation plans would identify evacuation distances based upon increasing severity of events.

On several LNG import terminal proposals, a number of organizations and individuals commented on the need to consider emergency response procedures. Subsequently, Section 3A(e) of the Natural Gas Act, added by Section 311 of the Energy Policy Act of 2005, stipulated that in any Order authorizing an LNG terminal, the Commission shall the LNG terminal operator to develop an Emergency Response Plan in consultation with the Coast Guard and state and local agencies. The FERC must approve the Emergency Response Plan prior to any final approval to begin construction. Therefore, **we recommend that:**

- **Calhoun Point Comfort develop an Emergency Response Plan (including evacuation) and coordinate procedures with the Coast Guard, state, county, and local emergency planning groups, fire departments, state and local law enforcement, and appropriate federal agencies. This plan should include at a minimum:**

  a. **designated contacts with state and local emergency response agencies;**

  b. **scalable procedures for the prompt notification of appropriate local officials and emergency response agencies based on the level and severity of potential incidents;**

  c. **procedures for notifying residents and recreational users within areas of potential hazard;**

d. **evacuation routes for residents and other public use areas that are within any transient hazard areas along the route of the LNG vessel transit;**

e. **locations of permanent sirens and other warning devices; and**

f. **an "emergency coordinator" on each LNG vessel to activate sirens and other warning devices.**

The Emergency Response Plan should be filed with the Secretary for review and approval by the Director of OEP <u>prior to initial site preparation</u>. Calhoun Point Comfort should notify FERC staff of all planning meetings in advance and should report progress on the development of its Emergency Response Plan at <u>3-month</u> intervals.

The FERC has also received comments on other LNG terminal proposals expressing concern that the local community would have to bear some of the cost of ensuring the security and emergency management of the LNG facility and the LNG vessels while in transit and unloading at the berth. In addition, Section 3A(e) specifies that the Emergency Response Plan shall include a Cost-Sharing Plan that contains a description of any direct cost reimbursements the applicant agrees to provide to any state and local agencies with responsibility for security and safety at the LNG terminal and in proximity to vessels that serve the facility. To allow the FERC an opportunity to review the plan, **we recommend that**:

- **The Emergency Response Plan should include a Cost-Sharing Plan identifying the mechanisms for funding all project-specific security/emergency management costs that would be imposed on state and local agencies. In addition to the funding of direct transit-related security/emergency management costs, this comprehensive plan should include funding mechanisms for the capital costs associated with any necessary security/emergency management equipment and personnel base. The Cost-Sharing Plan should be filed with the Secretary for review and written approval by the Director of OEP <u>prior to initial site preparation</u>.**

4.12.7 Conclusions on Marine Safety

LNG vessels have safely transited another Gulf Coast Waterway, the Calcasieu Ship Channel in Louisiana, for the past 20 years and worldwide for 50 years. Based on the extensive operational experience of LNG shipping and the structural design of an LNG carrier, the likelihood of a cargo containment failure and subsequent LNG spill from a vessel casualty - collision, grounding, or allision - is highly unlikely. For intentional spills, the impacts to public safety and property could exist within the Zones of Concern. The severity of impacts within the zones would depend on the location of the incident relative to a specific area, the scope of the incident, and whether the released LNG is ignited or dispersed. However, if the Coast Guard issues an LOR finding the waterway suitable for LNG marine traffic with the conditions referenced under *Coast Guard Waterway Suitability Report*, the Coast Guard would control the transit of the LNG vessel through the waterway and while unloading cargo. The security provisions and operational controls that would be imposed by the Coast Guard, and the local pilots, to direct movement of LNG vessels would maintain the risk of a marine LNG spill, either with or without ignition, at acceptable levels. Therefore, the Calhoun Point Comfort Project would be unlikely to result in

significant impact within the Zones of Concern because it is unlikely that a substantial cargo release would occur.

4.12.8 Terrorism and Security Issues

The security requirements for the onshore component of the proposed project are governed by 49 CFR 193, Subpart J - Security. This subpart includes requirements for conducting security inspections and patrols, liaison with local law enforcement officials, design and construction of protective enclosures, lighting, monitoring, alternative power sources, and warning signs. Requirements for maintaining safety of the marine terminal are in 33 CFR 127. Requirements for maintaining security of the marine terminal are in 33 CFR 105.

In the aftermath of the terrorist attacks that occurred on September 11, 2001, terrorism has become a very real issue for the facilities under the Commission's jurisdiction. The FERC, like other federal agencies, is faced with a dilemma in how much information can be offered to the public while still providing a significant level of protection to the facility. Consequently, the FERC has removed energy facility design plans and location information from its website to ensure that sensitive information filed under CEII is not readily available (RM02-4-000 and PL02-1-000 issued February 20, 2003).

Since September 11, 2001, the FERC has been involved with other federal agencies in developing a coordinated approach to protecting the energy facilities of the United States. The FERC continues to coordinate with these agencies, specifically with the Coast Guard to address this issue. The Coast Guard now requires arriving ships to provide them with a 96-hour advance notice of arrival that includes key information about the vessel and its crew which allows the Coast Guard to conduct a terrorism risk assessment and put in place appropriate mitigation before the ship reaches the ship channel. In addition, interstate natural gas companies are actively involved with several industry groups to chart how best to address security measures in the current environment. A Security Task Force has been created and is addressing ways to improve pipeline security practices, strengthen communications within the industry and the interface with government, and extend public outreach efforts.

In September 2002, the DOT issued non-public guidelines to LNG operators that direct them to develop new security procedures for onshore facilities. Operators were required to prepare a security plan within six months that responds to the five threat levels defined by the Office of Homeland Security. The DOT conducts subsequent on-site reviews of the security procedures.

On October 22, 2003, the Coast Guard issued a series of six final rules, which promulgated the maritime security requirements of the Marine Transportation Security Act of 2002: Implementation of National Maritime Security Initiatives; Area Maritime Security; Vessel Security; Facility Security; Continental Shelf Facility Security; and the Automatic Identification System. The entire series of rulemakings establishes a new subchapter H in 33 CFR. In support of the rulemakings, the Coast Guard applied a risk-based decision making process to comprehensively evaluate the relative risks of various target and attack mode combinations and scenarios for those vessel types and port facilities that pose a risk of a security incident. This approach provides a more realistic estimation of risk than a simple “worst-case outcome” assessment. Risk management principles acknowledges that while risk generally cannot be

eliminated, it can be reduced by adjusting operations to lower consequences, threats, or vulnerability, recognizing that it is easier to reduce vulnerabilities by adding security measures.

On December 29, 2003, all terminal owners or operators subject to 33 CFR 105 were required to submit a *Facility Security Assessment and Facility Security Plan* to the Coast Guard Captain of the Port for review and approval. The Facility Security Plans were required to be implemented no later than July 1, 2004 or for facilities constructed after July 1, 2004, 60 days prior to operations. Some of the principal owner or operator responsibilities include:

- designating a FSO with a general knowledge of current security threats and patterns, risk assessment methodology, and the responsibility for implementing the Facility Security Plan and Assessment and performing an annual audit for the life of the project;
- conducting a Facility Security Assessment to identify site vulnerabilities, possible security threats and consequences of an attack, and facility protective measures;
- developing a Facility Security Plan based on the Facility Security Assessment, with procedures for responding to transportation security incidents, notification and coordination with local, state, and federal authorities, prevent unauthorized access; measures and equipment to prevent or deter dangerous substances and devices; training; and evacuation;
- implementing scalable security measures to provide increasing levels of security at increasing MARSEC levels for facility access control, restricted areas, cargo handling, vessel stores and bunkers, and monitoring;
- conducting security exercises at least once each calendar year and drills at least every three months; and
- reporting of all breaches of security and security incidents.

Increased security awareness has occurred throughout the industry and the nation. President Bush established the Office of Homeland Security with the mission of coordinating the efforts of all executive departments and agencies to detect, prepare for, prevent, protect against, respond to, and recover from terrorist attacks within the United States. The Commission, in cooperation with other federal agencies and industry trade groups, has joined in the efforts to protect the energy infrastructure, including the more than 300,000 miles of interstate natural gas transmission pipeline and associated LNG facilities.

Safety and security are important considerations in any Commission action. The attacks of September 11, 2001 have changed the way pipeline operators as well as regulators must consider terrorism, both in approving new projects and in operating existing facilities. However, the likelihood of future acts of terrorism or sabotage occurring at the proposed LNG import terminal, or at any of the myriad natural gas pipeline or energy facilities throughout the U.S. is unpredictable given the disparate motives and abilities of terrorist groups. The continuing need to construct facilities to support the future natural gas pipeline infrastructure is not diminished from the threat of any such unpredictable acts.

4.12.9 Pipeline Reliability and Safety

The transportation of natural gas by pipeline involves some risk to the public in the event of an accident and subsequent release of gas. The greatest hazard is a fire or explosion following a major pipeline rupture.

Methane, the primary component of natural gas, is colorless, odorless, and tasteless. It is not toxic, but is classified as a simple asphyxiate, possessing a slight inhalation hazard. If breathed in high concentration, oxygen deficiency can result in serious injury or death.

Methane has an ignition temperature of 1,000°F and is flammable at concentrations between 5.0 percent and 15.0 percent in air. Unconfined mixtures of methane in air are not explosive. However, a flammable concentration within an enclosed space in the presence of an ignition source can explode. It is buoyant at atmospheric temperatures and disperses rapidly in air.

Safety Standards

The DOT is mandated to provide pipeline safety under Title 49, U.S.C. Chapter 601. The Pipeline and Hazardous Materials Safety Administration (PHMSA), Office of Pipeline Safety (OPS), administers the national regulatory program to ensure the safe transportation of natural gas and other hazardous materials by pipeline. It develops safety regulations and other approaches to risk management that ensure safety in the design, construction, testing, operation, maintenance, and emergency response of pipeline facilities. Many of the regulations are written as performance standards which set the level of safety to be attained and allow the pipeline operator to use various technologies to achieve safety. PHMSA ensures that people and the environment are protected from the risk of pipeline incidents. This work is shared with state agency partners and others at the federal, state, and local level. Section 5(a) of the Natural Gas Pipeline Safety Act provides for a state agency to assume all aspects of the safety program for intrastate facilities by adopting and enforcing the federal standards, while Section 5(b) permits a state agency that does not qualify under Section 5(a) to perform certain inspection and monitoring functions. A state may also act as DOT's agent to inspect interstate facilities within its boundaries; however, the DOT is responsible for enforcement action. The majority of the states have either 5(a) certifications or 5(b) agreements, while nine states act as interstate agents.

The DOT pipeline standards are published in Parts 190-199 of Title 49 of the CFR. Part 192 of 49 CFR specifically addresses natural gas pipeline safety issues.

Under a Memorandum of Understanding on Natural Gas Transportation Facilities (Memorandum) dated January 15, 1993 between the DOT and the FERC, the DOT has the exclusive authority to promulgate federal safety standards used in the transportation of natural gas. Section 157.14(a)(9)(vi) of the FERC's regulations require that an applicant certify that it will design, install, inspect, test, construct, operate, replace, and maintain the facility for which a certificate is requested in accordance with federal safety standards and plans for maintenance and inspection, or shall certify that it has been granted a waiver of the requirements of the safety standards by the DOT in accordance with Section 3(e) of the Natural Gas Pipeline Safety Act. The FERC accepts this certification and does not impose additional safety standards other than the DOT standards. If the Commission becomes aware of an existing or potential safety problem, there is a provision in the Memorandum to promptly alert DOT. The Memorandum

also provides for referring complaints and inquiries made by state and local governments and the general public involving safety matters related to pipeline under the Commission's jurisdiction.

The FERC also participates as a member of the DOT's Technical Pipeline Safety Standards Committee which determines if proposed safety regulations are reasonable, feasible, and practicable.

The pipeline and aboveground facilities associated with the Calhoun LNG Project must be designed, constructed, operated, and maintained in accordance with the DOT Minimum Federal Safety Standards in 49 CFR 192. The regulations are intended to ensure adequate protection for the public and to prevent natural gas facility accidents and failures. Part 192 specifies material selection and qualification, minimum design requirements, and protection from internal, external, and atmospheric corrosion.

Part 192 also defines area classifications, based on population density in the vicinity of the pipeline, and specifies more rigorous safety requirements for populated areas. The class location unit is an area that extends 220 yards on either side of the centerline of any continuous 1-mile length of pipeline. The four area classifications are defined as follows:

Class 1 Location with 10 or fewer buildings intended for human occupancy.

Class 2 Location with more than 10 but less than 46 buildings intended for human occupancy.

Class 3 Location with 46 or more buildings intended for human occupancy or where the pipeline lies within 100 yards of any building, or small well-defined outside area occupied by 20 or more people during normal use.

Class 4 Location where buildings with four or more stories aboveground are prevalent.

Class locations representing more populated areas require higher safety factors in pipeline design, testing, and operation. Pipelines constructed on land in Class 1 locations must be installed with a minimum depth of cover of 30 inches in normal soil and 18 inches in consolidated rock. Class 2, 3, and 4 locations, as well as drainage ditches of public roads and railroad crossings, require a minimum cover of 36 inches in normal soil and 24 inches in consolidated rock. All pipelines installed in navigable rivers, streams, and harbors must have a minimum cover of 48 inches in soil or 24 inches in consolidated rock.

Class locations also specify the maximum distance to a sectionalizing block valve (e.g., 10.0 miles in Class 1, 7.5 miles in Class 2, 4.0 miles in Class 3, and 2.5 miles in Class 4). Pipe wall thickness and pipeline design pressures, hydrostatic test pressures, maximum allowable operating pressure, inspection and testing of welds, and frequency of pipeline patrols and leak surveys must also conform to higher standards in more populated areas. The majority of the proposed pipeline route would cross open land that is sparsely populated. About 25.8 miles of proposed pipeline route would be located in Class 1 areas and the remaining 1.3 miles would be in a Class 3 area. No portions of the proposed route would be located in Class 2 or 4 areas. In addition, all pipeline interconnects, and pipeline facilities within the fenced enclosures of the meter stations, launcher and receiver, and MLVs would be designed and constructed to meet Class 3 requirements.

If a subsequent increase in population density adjacent to the right-of-way indicates a change in class location above existing design for the pipeline, Calhoun Point Comfort would reduce the maximum allowable operating pressure or replace the segment with pipe of sufficient grade and wall thickness, if required to comply with the DOT code of regulations for the new class location.

In 2002, Congress recently passed an act to strengthen the Nation's pipeline safety laws. The pipeline Safety Improvement Act of 2002 (HR 3609) was passed by Congress on November 15, 2002, and signed into law by the President in December 2002. Since December 17, 2004, gas transmission operators are required to develop and follow a written integrity management program that contains all the elements described in Section 192.911 and addresses the risks on each covered transmission pipeline segment. Specifically, the law establishes an integrity management program which applies to all high consequence areas (HCAs). The DOT (68 FR 69778, 69 FR 18228, and 69 FR 29903) defines HCAs as they relate to the different class zones, potential impact circles, or areas containing an identified site as defined in Section 192.903 of the DOT regulations.

OPS published a series of rules from August 6, 2002 to May 26, 2004 (69 FR 29903), that defines HCAs where a gas pipeline accident could do considerable harm to people and their property and requires an integrity management program to minimize the potential for an accident. This definition satisfies, in part, the Congressional mandate in 49 USC 60109 for OPS to prescribe standards that establish criteria for identifying each gas pipeline facility in a high-density population area.

The HCA may be defined in one of two ways. In the first method an HCA includes:

- current Class 3 and 4 locations;
- any area in Class 1 or 2 where the potential impact radius[9] is greater than 660 feet and there are 20 or more buildings intended for human occupancy within the potential impact circle;[10] or
- any area in Class 1 or 2 where the potential impact circle includes an identified site.[11]

In the second method, an HCA includes any area within a potential impact circle which contains:

- 20 or more buildings intended for human occupancy; or
- an identified site.

[9] The potential impact radius is calculated as the product of 0.69 and the square root of the maximum allowable operating pressure of the pipeline in psi multiplied by the pipeline diameter in inches.

[10] The potential impact circle is a circle of radius equal to the potential impact radius.

[11] An identified site is an outside area or open structure that is occupied by 20 or more persons on at least 50 days in any 12-month period; a building that is occupied by 20 or more persons on at least five days a week for any 10 weeks in any 12-month period; or a facility that is occupied by persons who are confined, are of impaired mobility, or would be difficult to evacuate.

Once a pipeline operator has determined the HCAs on its pipeline, it must apply the elements of its integrity management program to those segments of the pipeline within the HCAs. The DOT regulations specify the requirements for the integrity management plan at Section 192.911. The HCAs have been determined based on the relationship of the pipeline centerline to other nearby structures and identified sites. Of the 27.1 miles of proposed pipeline route, Calhoun Point Comfort has identified approximately 2.9 miles that would be classified as a HCA. The pipeline integrity management rule for HCAs requires inspection of the entire pipeline in HCAs every seven years.

Part 192 prescribes the minimum standards for operating and maintaining pipeline facilities, including the requirement to establish a written plan governing these activities. The proposed pipeline would be continuously monitored and controlled via computer and local logic controllers at the manned control center at the LNG terminal site. A locally based, full-time staff would be assigned to operate and maintain the natural gas pipeline. The staff would be fully trained in pipeline operations, maintenance, and normal, abnormal, and emergency procedures.

The pipeline would be patrolled and inspected on the ground on a periodic basis per DOT requirements or better. The frequency of these inspections would be affected by activity along the pipeline route such as construction or possible encroachment. These inspections would identify conditions indicative of pipeline leaks, evidence of pipeline damage or deterioration, damage to erosion controls, loss of cover, third-party activities or conditions which may presently or in the future affect pipeline integrity, safety, or operation of the pipeline. The pipeline system would participate in the state "One Call" system.

Under Section 192.615, each pipeline operator must also establish an emergency plan that includes procedures to minimize the hazards in a natural gas pipeline emergency. Key elements of the plan include procedures for:

- receiving, identifying, and classifying emergency events, gas leakage, fires, explosions, and natural disasters;
- establishing and maintaining communications with local fire, police, and public officials, and coordinating emergency response;
- emergency shutdown of system and safe restoration of service;
- making personnel, equipment, tools, and materials available at the scene of an emergency; and
- protecting people first and then property, and making them safe from actual or potential hazards.

Part 192 requires that each operator must establish and maintain liaison with appropriate fire, police, and public officials to learn the resources and responsibilities of each organization that may respond to a natural gas pipeline emergency, and to coordinate mutual assistance. The operator must also establish a continuing education program to enable customers, the public, government officials, and those engaged in excavation activities to recognize a gas pipeline emergency and report it to appropriate public officials. Calhoun Point Comfort would provide the appropriate training to local emergency service personnel before the pipeline is placed in

service. No additional specialized local fire protection equipment would be required to handle pipeline emergencies.

Pipeline Accident Data

Since February 9, 1970, 49 CFR 191 has required all operators of transmission and gathering systems to notify the DOT of any reportable incident and to submit a report on form F7100.2 within 20 days. Reportable incidents are defined as any leaks that:

- caused a death or personal injury requiring hospitalization;
- required taking any segment of transmission line out of service;
- resulted in gas ignition;
- caused estimated damage to the property of the operator, or others, or both, of a total of $5,000 or more;
- required immediate repair on a transmission line;
- occurred while testing with gas or another medium; or
- in the judgment of the operator was significant, even though it did not meet the above criteria.

The DOT changed reporting requirements after June 1984 to reduce the amount of data collected. Since that date, operators must only report incidents that involve property damage of more than $50,000, injury, death, release of gas, or that are otherwise considered significant by the operator. Table 4.12.9-1 presents a summary of incident data for the 1970 to 1984 period, as well as more recent incident data for 1986 through 2005, recognizing the difference in reporting requirements. The 14.5-year period from 1970 through June 1984, which provides a larger universe of data and more basic report information than subsequent years, has been subject to detailed analysis, as discussed in the following sections.[12]

TABLE 4.12.9-1

Natural Gas Service Incidents by Cause

Cause	Incidents per 1,000 Miles of Pipeline (percentage)	
	1970-1984	**1986-2005**
Outside Force	0.70 (53.8)	0.10 (38.5)
Corrosion	0.22 (16.9)	0.06 (23.1)
Construction or Material Defect	0.27 (20.8)	0.04 (15.4)
Other	0.11 (8.5)	0.06 (23.1)
Total	**1.30**	**0.26**

[12] Jones, D.J., G.S. Kramer, D.N. Gideon, and R.J. Eiber, 1986. "An Analysis of Reportable Incidents for Natural Gas Transportation and Gathering Lines 1970 Through June 1984." NG-18 Report No. 158, Pipeline Research Committee of the American Gas Association.

During the 14.5-year period, 5,862 service incidents were reported over the more than 300,000 total miles of natural gas transmission and gathering systems nationwide. Service incidents, defined as failures that occur during pipeline operation, have remained fairly constant over this period with no clear upward or downward trend in annual totals. In addition, 2,013 test failures were reported. Correction of test failures removed defects from the pipeline before operation.

Additional insight into the nature of service incidents may be found by examining the primary factors that caused the failures. Table 4.12.9-1 provides a percentage distribution of the causal factors as well as the annual frequency of each factor per 1,000 miles of pipeline in service.

The dominant incident cause is outside forces, constituting 53.8 percent of all service incidents. Outside forces incidents result from the encroachment of mechanical equipment such as bulldozers and backhoes; earth movements due to soil settlement, washouts, or geologic hazards; weather effects such as winds, storms, and thermal strains; and willful damage. Table 4.12.9-2 shows that human error in equipment usage was responsible for approximately 75 percent of outside forces incidents. Since April 1982, operators have been required to participate in "One Call" public utility programs in populated areas to minimize unauthorized excavation activities in the vicinity of pipelines. The "One Call" program is a service used by public utilities and some private sector companies (e.g., oil pipelines and cable television) to provide preconstruction information to contractors or other maintenance workers on the underground location of pipes, cables, and culverts. The 1986 through 2005 data (as shown on table 4.12.9-1) show that the portion of incidents caused by outside forces has decreased to 38.5 percent.

TABLE 4.12.9-2

Outside Forces Incidents by Cause (1970-1984)

Cause	Percent
Equipment Operated by Outside Party	67.1
Equipment Operated by or for Operator	7.3
Earth Movement	13.3
Weather	10.8
Other	1.5

The pipelines included in the data set in table 4.12.9-2 vary widely in terms of age, pipe diameter, and level of corrosion control. Each variable influences the incident frequency that may be expected for a specific segment of pipeline.

The frequency of service incidents is strongly dependent on pipeline age. While pipelines installed since 1950 exhibit a fairly constant level of service incident frequency, pipelines installed before that time have a significantly higher rate, partially due to corrosion. Older pipelines have a higher frequency of corrosion incidents, since corrosion is a time-dependent process. Further, new pipe generally uses more advanced coatings and cathodic protection to reduce corrosion potential.

Older pipelines have a higher frequency of outside forces incidents partly because their location may be less well known and less well marked than newer lines. In addition, the older pipelines contain a disproportionate number of smaller diameter pipelines, which have a greater rate of

outside forces incidents. Small diameter pipelines are more easily crushed or broken by mechanical equipment or earth movements.

Table 4.12.9-3 clearly demonstrates the effectiveness of corrosion control in reducing the incidence of failures caused by external corrosion. The use of both an external protective coating and a cathodic protection system, required on all pipelines installed after July 1971, significantly reduces the rate of failure compared to unprotected or partially protected pipe. The data shows that bare, cathodically protected pipe actually has a higher corrosion rate than unprotected pipe. This anomaly reflects the retrofitting of cathodic protection to actively corroding spots on pipes.

TABLE 4.12.9-3

External Corrosion by Level of Control (1970-1984)

Corrosion Control	Incidents per 1,000 Miles per Year
None-bare Pipe	0.42
Cathodic Protection Only	0.97
Coated Only	0.40
Coated and Cathodic Protection	0.11

Impacts on Public Safety

The service incident data summarized in table 4.12.9-1 include pipeline failures of all magnitudes with widely varying consequences. Approximately two-thirds of the incidents were classified as leaks, and the remaining third classified as ruptures, implying a more serious failure.

Table 4.12.9-4 presents the average annual fatalities that occurred on natural gas transmission and gathering lines from 1970 to 2005. Fatalities between 1970 and June 1984 have been separated into employees and nonemployees, to better identify a fatality rate experienced by the general public. Of the total 5.0 nationwide average, fatalities among the public averaged 2.6 per year over this period. The simplified reporting requirements in effect after June 1984 do not differentiate between employees and nonemployees. However, the data show that the total annual average for the period 1984 through 2005 decreased to 3.6 fatalities per year. Subtracting two major offshore incidents in 1989, which do not reflect the risk to the onshore public, yields a total annual rate of 2.8 fatalities per year for this period.

TABLE 4.12.9-4

Annual Average Fatalities - Natural Gas Transmission and Gathering Systems a/, b/

Year	Employees	Nonemployees	Total
1970-June 1984	2.4	2.6	5.0
1984-2005 c/	-	-	3.6
1984-2005 c/	-	-	2.8 d/

a/ 1970 through June 1984 - American Gas Association, 1986.
b/ DOT Hazardous Materials Information System.
c/ Employee/nonemployee breakdown not available after June 1984.
d/ Without 18 offshore fatalities occurring in 1989 – 11 fatalities resulted from a fishing vessel striking an offshore pipeline and seven fatalities resulted from explosion on an offshore production platform.

The nationwide totals of accidental fatalities from various manmade and natural hazards are listed in table 4.12.9-5 in order to provide a relative measure of the industry-wide safety of natural gas pipelines. Direct comparisons between accident categories should be made cautiously however, because individual exposures to hazards are not uniform among all categories. Nevertheless, the average 2.6 public fatalities per year is relatively small considering the more than 300,000 miles of transmission and gathering lines in service nationwide. Furthermore, the fatality rate is approximately two orders of magnitude (100 times) lower than the fatalities from natural hazards such as lightning, tornadoes, floods, earthquakes, etc.

The available data show that natural gas pipelines continue to be a safe, reliable means of energy transportation. Based on approximately 301,000 miles in service, the rate of public fatalities for the nationwide mix of transmission and gathering lines in service is 0.01 per year per 1,000 miles of pipeline. Using this rate, the Calhoun LNG Project might result in a public fatality every 3,690 years. This would represent a slight increase in risk to the nearby public.

TABLE 4.12.9-5

Nationwide Accidental Deaths a/

Type of Accident	Fatalities
All Accidents	90,523
Motor Vehicles	43,649
Falls	14,985
Poisoning	9,510
Fires and Burns	3,791
Drowning	3,488
Suffocation by Ingested Object	3,206
Tornado, Flood, Earthquake, etc. (1984-93 average)	181
All Liquid and Gas Pipelines (1986-2003 average) b/	22
Gas Transmission and Gathering Lines, Nonemployees Only (1970-84 average) c/	2.6

a/ All data, unless otherwise noted, reflects 1996 statistics from the U.S. Department of Commerce, Bureau of the Census, "Statistical Abstract of the United States 118th Edition."
b/ U.S. Department of Transportation, Office of Pipeline Safety, www.ops.dot.gov/stats.
c/ American Gas Association, 1986.

4.13 CUMULATIVE IMPACTS

The CEQ defines cumulative impacts as the "impacts on the environment which result from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (federal or non-federal) or person undertakes such other actions." Although the individual impact of each individual project may be minor, the additive or synergistic impacts from multiple projects could be significant. Impacts subject to cumulative effects analysis for the Calhoun LNG Project were identified by determining the environmental impact issues associated with the proposed action, establishing the geographic scope of the study area, establishing the timeframe of the analysis, and identifying other past, present, or future actions that have affected, or could affect, the resources of concern.

For this analysis, we looked at potential impacts from known projects existing or proposed along the MSC, within Lavaca Bay, and adjacent to the Port. Existing environmental conditions in the project area reflect changes based on past activities. In 1931, the causeway over Lavaca Bay was

constructed and linked the area to the south Texas highway system. Natural gas and oil was discovered near Port Lavaca during the mid-1930s and private farming became commercialized during the 1950s. Alcoa opened its Point Comfort Operations in 1947. Other major industries in the project area included Hartzog Shipyard, U.S. Cold Storage Company, and fishing and shrimping. By 1958, Calhoun County had 11 manufacturers and 77 mineral related enterprises. In 1963, the Port of Port Lavaca–Point Comfort was designated a U.S. customs port of entry and in 1965 the MSC was completed to Point Comfort. During the 1960s and 1970s, National Starch (a manufacturer of vinyl acetate) began operation, Witco manufactured pitch oil at its plant in Point Comfort, and Vistron Corporation was in operation. The Formosa Plastics Corporation of Taiwan established a petrochemical factory at Point Comfort in 1988.

Existing conditions in much of the general project area, particularly along the pipeline route, consists of flat agricultural and range land. The area in the immediate vicinity of the proposed LNG terminal, and the Port, has been developed for industrial activities. As such, the coastal marsh and subtidal habitats in Lavaca Bay have been disturbed by previous industrial development.

Construction of the Calhoun LNG Project would result in both short- and long-term, minor to moderate environmental impacts. Impacts associated with construction of the pipelines generally are short-term and minor because resources in the project area that would be affected during construction can generally be restored or allowed to revegetate back to their original condition following pipeline installation. Some long-term impacts occur, however, when resources cannot be restored back to original conditions (e.g., cleared forest lands), or when resources are permanently affected due to operational and maintenance requirements (e.g., development of the proposed LNG terminal facilities and maintenance requirements along the proposed pipeline rights-of-way).

The environmental impact analysis contained in this EIS indicates that pipeline construction and operation activities for the Calhoun LNG Project would result in short-term and minor impacts associated primarily with construction across waterbodies and wetlands, fish and other wildlife habitats, recreation, socioeconomics, transportation, and noise. Long-term impacts associated with construction of the LNG terminal and pipeline-related aboveground facilities are considered more significant and may include both the temporary and permanent clearing of vegetation and maintenance of the permanent pipeline rights-of-way. Although these types of impacts were not considered significant for the Calhoun LNG Project, they were considered on a cumulative impact basis in association with the review of other LNG terminal and pipeline projects proposed or approved for the area. Environmental resources such as geology, soils, and cultural would not be measurably affected by the proposed Project, and therefore, have not been considered in this cumulative effects analysis.

Table 4.13-1 provides a list of activities and projects considered in our cumulative impact analysis. Projects included in our analysis are those known or reasonably foreseeable future projects with potential impacts to the same resources for which some effect has been evaluated for the proposed Project. Following is a brief description of the Matagorda Ship Channel Deepening and Widening Project, Indianola Beach Restoration Project, Formosa Plastics Power Plant Project, and E.S. Joslin Power Plant Project, in addition to the proposed Calhoun LNG Project, that are included in our analysis.

TABLE 4.13-1

Existing, Approved, or Proposed Activities/Projects that Could Contribute to Cumulative Impacts Associated with Construction of the Calhoun LNG Project

Activity/Project	Description	Timeframe
Manufacturing/Refining	Manufacturing, storage, and transportation of petroleum and chemical products.	Ongoing
Dredging	Maintenance dredging of the Matagorda Ship Channel and Lavaca Bay.	Periodic
Recreation	Fishing, boating, and bird watching.	Ongoing
Shipping	Commercial traffic on the Matagorda Ship Channel and through the Port of Port Lavaca–Point Comfort.	Ongoing
Matagorda Ship Channel Deepening and Widening Project	Deepen the 22-mile-long ship channel from 36 feet to 45 feet and widen from 200 feet to 350 or 400 feet.	By 2015
Indianola Beach Restoration Project	Construct a shoreline stabilization project to protect State Route 316, the La Salle Historic Landmark, and marshes west of the road along the Indianola-Magnolia Beach shoreline.	Undetermined
Formosa Plastics Power Plant Project	Construct and operate two circulating fluidized bed steam electric generating units capable of producing up to 300 megawatts of electricity.	2006-2009
E.S. Joslin Power Plant Project	Repower and upgrade the existing turbine from 261 to 303 megawatts.	2006-2009

Table 4.13-2 depicts the resources that would be affected by construction and operation of the projects identified in table 4.13-1. Construction schedules of the future projects depend on factors such as economics, funding, and politics, but all are expected, if approved for development, to be constructed in the same general timeframe associated with the Calhoun LNG Project. Projects and activities included in this analysis are generally those of comparable magnitude and nature of impact with the proposed action, and are located within the same vicinity as the proposed Project.

Matagorda Ship Channel Deepening and Widening Project

On August 16, 2004, the Galveston District of the COE issued a *Notice of Studies and Initial Public Scoping Meeting for Matagorda Ship Channel, Texas Feasibility Study* (Matagorda Project). The study would analyze and evaluate alternatives to reconfigure the MSC jetties to improve navigation safety, deepen and widen the 22-mile-long ship channel to improve navigational efficiency and safety, and perform environmental restoration through the beneficial use of dredged material. On March 24, 2006 the COE issued a Notice of Intent to prepare a draft EIS for the Matagorda Project. The project would result in the dredging of about 48.9 mcy of new work dredged material, and about 316 mcy of maintenance dredged material during the 50-year planning period. The CCND is the non-federal sponsor for the project. The Matagorda Project would include:

- deepening the MSC from the currently authorized depth of 36 feet to between 36 feet and 46 feet; and
- widening the MSC at various locations, including turning basis, by an additional 200 to 300 feet.

TABLE 4.13-2

Resources of Concern that Could be Impacted by Construction or Development of Existing, Approved, or Proposed Activities in the Vicinity of the Calhoun LNG Project

Project	Primary Environmental Impact								
	Water Resources	Wetlands	Wildlife/ Vegetation	Aquatic Resources	Land Use and Recreation	Socio-economics	Land Transporta-tion	Marine Transporta-tion	Air and Noise Quality
Manufacturing/Refining	X	X	X	X	X	X	X	X	X
Dredging	X	X	X	X	X			X	X
Recreation	X		X	X	X	X	X		
Shipping	X			X				X	X
Matagorda Ship Channel Deepening and Widening	X	X	X	X	X			X	X
Indianola Beach Restoration	X			X	X				
Formosa Plastics Power Plant	X	X		X	X			X	X
E.S. Joslin Power Plant	X								X

Indianola Beach Restoration Project

On September 19, 2005, the Galveston District of the COE issued a *Public Notice* for the Indianola Beach Restoration Project, Permit Application No. 22787-01 (Indianola Project). The project would be located along the Indianola-Magnolia Beach shoreline along the west shore of Matagorda Bay. The CCND proposes to construct a shoreline stabilization project to protect State Route 316, the La Salle Historic Landmark, and marshes west of State Route 316. The CCND has constructed Phase I of the project and is proposing to extend the project in Phase II.

Due to funding considerations, two separate methods are being considered for this project: Method 1 includes placing sand along the shoreline between a series of rock groins which would use about 35,000 cubic yards of sand and 6,050 cubic yards of rock. This method would involve filling 10.3 acres of beach area and 1.8 acres of rock groins for a total impact of about 12.1 acres. Method 2 includes placing sand along the shoreline between a series of rock groins for a portion of the project, and using an articulated-concrete-mattress revetment system. The articulated-concrete-mattress-revetment system would be about 5,610 square yards (yds^2) in size, including about 1,980 yds^2 underwater. This method would involve filling about 9.0 acres, including 7 acres of beach area, 1.5 acres of rock groins, and 0.5 acres for the articulated-concrete-mattress-revetment system. The SHPO believes that no impact to historic properties would occur and preliminary indications are that no known threatened and/or endangered species or their critical habitat would be affected by the project. The COE's initial determination is that the proposed action would not have a substantial adverse impact on EFH or federally managed fisheries in the Gulf of Mexico; however, a final determination regarding the need for mitigation measures is subject to review by and coordination with the NOAA Fisheries.

Formosa Plastics Power Plant Project

Formosa Plastics Corporation would construct and operate a generating facility at a leased site near the Point Comfort Turning Basin in Point Comfort, Texas. The generating facility would consist of two circulating fluidized bed steam electric generating units capable of producing up to 300 megawatts of electricity. Pulverized low sulfur, sub-bituminous coal and petroleum coke would be the primary fuels. Natural gas would be used to start up the generating units. In addition to installation of the generating units, a rotary railcar dumping facility, ship/barge unloading facility, fuel and limestone conveyors, feeders, crushers, storage buildings and silos, fly and bottom ash handling equipment, cooling towers, and water treatment storage tanks would be installed at the site. The project would be a Major Stationary source and trigger requirements for a PSD permit for NO_x, SO_2, PM_{10}, VOC, CO, sulfuric acid, and fluorides.

E.S. Joslin Power Plant Project

The CCND would repower and upgrade existing turbines at the E.S. Joslin Power Plant in Point Comfort, Texas from 261 to 303 megawatts. The existing natural gas fired boiler would be replaced with a petroleum coke boiler which would use a circulating fluidized bed capable of obtaining lower emission levels of NO_x, SO_2, and mercury. A limestone and coal unloading area and transfer, storage, and handling facilities would also be installed at the power plant site. Natural gas would continue to be used for start ups and during maintenance of solids handling equipment.

4.13.1 Water Resources

The proposed Calhoun LNG Project would include the CCND's dredging of a new turning basin within the Port and dredging of Calhoun Point Comfort's ship berth adjacent to the MSC in the Port. In addition, the construction of the proposed pipeline would require the crossing of 65 waterbodies.

Potential cumulative effects on marine water resources would occur from dredging that would be required for the proposed Project and the Matagorda Project, and shoreline fill and related disturbance required for the Indianola Project. The Matagorda Project would involve dredging to expand or maintain the channel(s); about 20 to 30 mcy of material would be dredged from the channel. Increased turbidity and sedimentation from initial dredging during the construction of new channels, the CCND's new turning basins, and Calhoun Point Comfort's ship berth, in addition to future maintenance dredging, would temporarily decrease water quality in the immediate vicinity of each project. If dredging associated with the proposed Project or the shoreline work proposed for the Indianola Project were to occur concurrently with the Matagorda Project, the reduction in water quality could be exacerbated. However, the negative effects of dredging in and adjacent to the existing MSC would be temporary, and water quality would be expected to return to ambient conditions soon after completion of activities.

As discussed in section 4.3.2, impacts from construction of the pipeline across waterbodies would generally be temporary, and the waterbodies would not experience long term impact during operation of the Project.

4.13.2 Wetlands and Submerged Aquatic Vegetation

Collectively the proposed Calhoun LNG Project, Matagorda Project, and Indianola Project would permanently impact tidal flats and salt marsh, submerged aquatic vegetation, and freshwater wetlands. Each of the project proponents would be required by the terms and conditions of their respective Section 404 permits to provide compensatory mitigation for unavoidable wetland impacts. Calhoun Point Comfort and the proponents for the other projects would mitigate the loss of wetlands as required by the COE's Section 404 permit requirements that would ultimately be needed for the projects to proceed. The construction and operation of the proposed Project, along with the other potential projects and activities, could result in a cumulative reduction in the amount of wetlands in the vicinity of the Project. However, mitigation for wetlands affected by the proposed Project and the other projects listed would be required by the COE and could result in a net increase and/or improvement in the regional coastal marsh resource. Dredged material placement for these projects could, in fact, result in the creation of shallow emergent wetlands in the Lavaca Bay area.

As discussed in section 4.4.1, impacts from the pipeline on wetlands would generally be temporary, and none of the wetlands would be permanently drained or filled for operation of the Project.

4.13.3 Vegetation and Wildlife

When projects are constructed at or near the same time, the combination of construction activities could have a cumulative impact on vegetation and wildlife living in the immediate

area. Clearing and grading and other construction activities associated with the project, along with other area construction projects, would result in the removal of vegetation, alteration of wildlife habitat, displacement of wildlife, and other secondary effects such as increased population stress, predation, forest fragmentation, and establishment of invasive plant species.

The construction of multiple large industrial projects at or near the same time can result in a significant amount of land clearing activities that could have a cumulative impact on forest resources in the immediate area of the projects. However, the site proposed for Calhoun Point Comfort's LNG terminal and the Formosa Plastics and E.S. Joslin power projects are devoid of large stands of trees. The proposed LNG terminal would affect 73 acres of terrestrial habitat identified as disturbed, undeveloped, manmade industrial. The Formosa Plastics and E.S. Joslin power projects would be constructed on existing industrial land. For the small amounts of native upland vegetation that would be lost by the combined construction of these projects, similar habitats are widely distributed nearby. During construction activities, mobile species would be able to relocate to adjacent habitat and then reoccupy open project lands after they have been restored. Therefore, we believe cumulative impacts on terrestrial wildlife would be short-term and not significant.

4.13.4 Aquatic Resources

The proposed Project, Matagorda Project, and the Indianola Project would impact shallow water and bottom habitat within Matagorda and Lavaca Bays as a result of dredging proposed to deepen and widen the MSC, the CCND's new turning basin, and Calhoun Point Comfort's ship berth. As a result of this dredging, shallow bottom habitat would be converted to deeper water, and maintained as such through periodic maintenance dredging. Dredging would also result in impacts to shallow water habitat during dredged material placement. Most other impacts associated with dredging would be short-term, such as localized increased turbidity during dredging operations.

Designated EFH would also be affected by the proposed Project and the Matagorda and Indianola Projects. Of the total potential acreage of impacted EFH, by far the largest contributor to the loss is the Matagorda Project. Some of this loss of EFH would be offset by the beneficial utilization of dredged material to create intertidal wetlands. Creation of shallow marsh habitat from dredged material disposal could provide important nursery habitat for early life stage development and production of shrimp and estuarine fisheries in the area. Impact on EFH as a whole would be addressed for each individual project, and impact on vegetated components of EFH (submerged aquatic vegetation and salt marsh) would be addressed through compensatory mitigation during Section 404 permitting.

4.13.5 Land Use, Recreation, and Visual Resources

The proposed Project would incrementally add to the cumulative impact on land uses in the project area. The majority of this additional impact would be permanent. The proposed LNG terminal site would be on manmade industrial land and the Formosa Plastics and E.S. Joslin power projects would be constructed on existing industrial land. The DMPAs that would be used by the Calhoun LNG Project are within Lavaca Bay. Along the proposed pipeline route, most land uses would be allowed to revert to prior uses following construction. Some land uses would be restricted or prohibited on the new permanent pipeline rights-of-way, such as construction of

aboveground structures. Cumulatively, a significant portion of land would be converted to industrial use; however, a significant portion of this land was already classified for industrial use or consisted of manmade, dredged materials; therefore cumulative changes in land use would not be significant.

Fishing, boating, and bird watching activities occur within, and from the shores of, Matagorda and Lavaca Bays. The proposed projects could have cumulative negative affects on recreational activities associated with boating and fishing, primarily during the period of active construction and dredging. Dredging causes temporary turbidity that may have short-term impacts on local fisheries; however, proposed dredging projects would benefit recreational boating by improving channel configurations. The potential increase of up to about 120 LNG vessels per year from the proposed Project could also have an impact on recreational boating. The proposed Project, Formosa Plastics Power Plant Project, and E.S. Joslin Power Plant Project are all located on lands dedicated to industrial uses and are not near beaches, parks, or other developed recreational facilities. The activities associated with the Indianola Project would enhance the beach area. Therefore, we do not believe that the projects would have a cumulative impact on recreation.

With the exception of the Matagorda and Indianola Projects, the projects would have some cumulative visual impact on the immediate surroundings. For the pipeline, the construction work areas would be restored, as near as possible, to pre-construction contours and revegetated. Once revegetation is complete, there would be no significant cumulative alteration of the landscape in the region. The LNG storage tanks that would be constructed for the proposed Project, as well as facilities constructed at the site of the Formosa Plastics Power Plant would create significant new visual features in the landscape. However, cumulatively, these features would be consistent with existing industrial features and activities at existing facilities within the Port, and would not significantly alter the visual landscape of the area.

4.13.6 Socioeconomics

Construction of the projects listed in table 4.13-1 would generate temporary construction jobs, with many of these workers residing locally. The influx of non-local laborers could represent an increase in the percent for the total population of Calhoun and Jackson Counties (assuming half the construction workers are non-local). The potentially vacant or rental units available in the two counties would offer enough housing for non-local workers. Likewise, the counties have the necessary infrastructure to provide public services and utilities to support the projects. No identified minority or low-income populations would be disproportionately impacted by the projects.

There would be positive cumulative economic benefits from these projects. Taxes generated from operation of the Calhoun LNG Project, Formosa Plastics Power Plant Project, and E.S. Joslin Power Plant Project would provide an overall increase annually. Permanent employment would also increase as a result of the operation of these projects, with the cumulative benefit of potentially lowering local unemployment rates.

4.13.7 Transportation

4.13.7.1 Land Transportation

Combined, the Calhoun LNG Project, Formosa Plastics Power Plant Project, and E.S. Joslin Power Plant Project would increase daily vehicle trips during peak construction periods. If all three projects were to be constructed at the same time, traffic would increase on FM 1593 and State Route 35. However, exact coincidence of the timing of all projects is unlikely and could be mitigated by staggering shift startup across the construction sites to minimize traffic congestion and reduce potential cumulative impacts to a level that is not significant. In addition, operation of these projects would result in an increase in daily vehicle trips entering and exiting the terminal and plant sites. Potential cumulative impacts on transportation systems are expected to be temporary and short-term.

4.13.7.2 Marine Transportation

In addition to the Calhoun LNG Project, estimates of potential increased traffic by large ships are available for facilities at the CCND's Port. Based on available information, the planned or proposed projects along the MSC would result in an increased number of ship calls per year to this channel. During fiscal year 2004, about 1,230 deep-draft vessels and inland barges utilized the MSC. This resulted in about 103 vessel and barge trips per month. During fiscal year 2005, there was a slight decrease in vessel and barge traffic along the MSC, about 1,180 deep-draft vessels and inland barges utilized the channel during this period for an average of about 99 vessels and barges trips per month. Calhoun Point Comfort reported that, according to the CCND, the Port is operating a 50 percent occupancy rate. Calhoun Point Comfort's LNG terminal would have the capacity to unload up to about 120 LNG ships per year, or up to 12 ships per month. This would represent a 10 percent increase in ship traffic along the MSC and at the Port.

During the 35 month construction period for the terminal, Calhoun Point Comfort estimates that about 293 barges would supply construction material and equipment to the site thereby, resulting in an increase of about 9 barge trips per month. In addition, one dredging barge would be at the turning basin and ship berth site during the last 6 months of construction. With the traffic management and mitigation measures discussed in section 4.12.5.2, construction of the LNG terminal and the operation of LNG ships should have a similar impact as other large vessels, and should cause no more disruption than the vessel traffic increases planned by other channel users.

4.13.8 Air Quality and Noise

Construction of the proposed projects would involve the use of heavy equipment that produces noise, air contaminants, and dust. Operation of the projects and some of the reasonably foreseeable projects would also contribute cumulatively to ongoing air emissions. As shown in table 4.13.8-1 operation of the Calhoun LNG terminal would account for a small percentage of the proposed new project emissions.

Each of the individual projects would need to apply to the TCEQ for an air quality permit, which may require controls to limit the emission of certain criteria pollutants or hazardous air pollutants.

TABLE 4.13.8-1

Estimated Yearly Emissions from Operations of the Calhoun LNG, Formosa Plastics, and E.S. Joslin Power Projects (tons)

Projects	NO_2	CO	SO_2	PM_{10}	VOC
Sources					
Calhoun LNG Terminal	147.90	119.04	3.35	27.12	27.16
Formosa Plastics Power Project	920.00	1,972.00	1,084.00	476.00	68.00
E.S. Joslin Power Project	448.00	1,741.00	902.00	174.00	70.00
Total New Projects	**1,515.90**	**3,832.04**	**1,989.35**	**677.12**	**165.16**
Percent Total of Calhoun LNG Terminal	**9.8**	**3.1**	**0.2**	**4.0**	**16.4**

Noise produced during construction of the listed projects could create short-term annoyances to some residences, and could have short-term impacts on some aquatic species, nesting birds and other wildlife in the area. Noise impacts during the construction phase would be localized and would attenuate quickly as the distance from the noise source increases. These impacts would be temporary and would only occur during construction of the projects. Therefore, cumulative noise impacts associated with construction of all of the projects are not anticipated to be significant, even in the unlikely event that multiple projects occur at the same time and in the same location.

4.13.9 Reliability and Safety

Impacts on reliability and public safety would be mitigated through the implementation of applicable federal, state, and local rules and regulations for each individual project. The specific rules and regulations that apply to each individual project would ensure that the applicable design standards are implemented to protect the public and to prevent accidents and failures. The LNG terminal facilities would be sited, designed, constructed, operated, and maintained in compliance with the federal safety standards summarized in table 2.8.1-1. The pipelines and aboveground facilities associated with the Calhoun LNG Terminal and Pipeline Project would be designed, constructed, operated, and maintained in accordance with DOT Minimum Federal Safety Standards in Title 49 CFR Part 192.

Several of the present or reasonably foreseeable future projects, including the proposed project, would involve cargo terminals that could be expected to ship hazardous materials. Accidents involving such materials represent a potential impact on public safety. Continued growth in international commerce is likely to result in increased quantities of hazardous materials being shipped to and from the region.

It is difficult to evaluate the cumulative risk that such growth represents or has represented. In addition, it is difficult to measure the cumulative risk for an intentional attack on the Port of Port Lavaca–Point Comfort or the LNG facility. The addition of the LNG facility and its associated LNG vessels would not significantly change the risk of an intentional attack in the MSC. It is reasonable to assume that the rate of ship accidents (including those involving the release of hazardous materials) is likely to rise with more vessel traffic, which could cumulatively increase the risk of an accident having an impact on public safety. As discussed in section 4.12.6, the Matagorda Bay Pilots manage vessel traffic to ensure safe transit in the MSC. The Coast Guard would also enforce a moving safety zone and moored vessel security zone around LNG ships.

These and other operational controls by the Coast Guard and Matagorda Bay Pilots would minimize the risk of accidents involving LNG ships. Furthermore, the implementation of federal, state, and local rules and regulations concerning security and the results of the WSA with its associated operations and Emergency Response Plan would minimize the risk to the LNG ship and terminal.

Emergency response time is a key aspect of public health and safety. No significant cumulative impacts on emergency services are expected because sufficient emergency services and facilities exist in the area to accommodate the cumulative projects. No significant cumulative impacts on emergency services are expected during operation of the proposed project. Section 4.12.5 includes our recommendation that Calhoun Point Comfort prepare an Emergency Response Plan and coordinate procedures with local emergency planning group's fire departments, state and local law enforcement, the Coast Guard, and other appropriate federal agencies to be used in the event of an incident. Calhoun Point Comfort would be required to prepare a comprehensive plan that identifies the cost sharing mechanisms for funding these emergency response costs. With the implementation of the coordination procedures in the Emergency Response Plan and the funding of additional emergency management equipment and personnel, no cumulative impacts would be expected on emergency response services during operation of the proposed project.

4.13.10 Conclusions about Cumulative Impacts

A determination of significance for the cumulative impacts for a specific resource is problematic because well-defined threshold values are typically undetermined. However, the majority of cumulative impacts we have identified for the proposed Project would be temporary and minor. Consequently, their addition to other reasonably foreseeable impacts in the region does not result in an overall permanent increase of impacts. There would be several notable permanent impacts, however. The conversion of about 249 acres of open water habitat to uplands, marsh, or oyster reef as a result of the proposed dredged material placement, combined with similar conversions of bay bottom habitat from other past, present, and reasonably foreseeable dredging projects in Matagorda and Lavaca Bays, would be a permanent impact on the bay systems. The permanent conversion of woodlands and scrub/shrub communities to an herbaceous community along the proposed pipeline route in combination with other past, present, or reasonably foreseeable future projects, could potentially fragment some wildlife habitat. Additionally, the proposed Project would contribute to increased ship traffic within Matagorda and Lavaca Bays.

Although the proposed Project and Matagorda Projects would result in the degradation of some wetland habitats, compensatory mitigation programs for each of these projects would be designed to provide a net benefit to the ecosystem. As many of the Project stakeholders have commented on, the proposed Project would cumulatively benefit the local economy through job creation and wages, purchases of goods and materials, tax revenues, and by providing a new source of competitively priced natural gas.

South Texas Project, Unit 2

Pressurized Water Reactor

12 MI SSW of Bay City, TX

Docket Number: 050-00499

Operating License: Issued - 03/28/1989, Expires - 12/15/2028

Operator: STP Nuclear Operating Co.

For questions about this facility, contact the NRC Public Affairs Office in Region 4

Facility Performance Information:	Current Performance Summary Inspection Reports Escalated Enforcement Actions Issued
Electrical Output:	1265 MWe
Reactor Vendor/Type:	Westinghouse Four-Loop
Containment Type:	Dry, Ambient Pressure
More Reactor Information:	Current Power Reactor Status Report Reactor Quick Links Other Reactors in Texas NRC Emergency Preparedness and Response FEMA's State Offices and Agencies of Emergency Management EXIT Plant Specific Items of Interest

License Renewal
- Overview
- Process
- Regulations
- Guidance
- Public Involvement
- Commission Papers
- Status
- Introduction

Home > Nuclear Reactors > Operating Reactors > Licensing > Renewal > Applications

Status of License Renewal Applications and Industry Activities

On this page:

- Plant Applications for License Renewal
  - Completed Applications
  - Applications Currently Under Review
  - Future Submittals of Applications
- Owners' Groups
- Industry Activities
- Related Information

Plant Applications for License Renewal

Completed Applications:

(includes Application, Review Schedule, Supplemental Environmental Impact Statement, and Safety Evaluation Report)

- Calvert Cliffs, Units 1 and 2
- Oconee Nuclear Station, Units 1, 2 and 3
- Arkansas Nuclear One, Unit 1
- Edwin I. Hatch Nuclear Plant, Units 1 and 2
- Turkey Point Nuclear Plant, Units 3 and 4
- North Anna, Units 1 and 2, and Surry, Units 1 and 2
- Peach Bottom, Units 2 and 3
- St. Lucie, Units 1 and 2
- Fort Calhoun Station, Unit 1
- McGuire, Units 1 and 2, and Catawba, Units 1 and 2
- H.B. Robinson Nuclear Plant, Unit 2
- R.E. Ginna Nuclear Power Plant, Unit 1
- V.C. Summer Nuclear Station, Unit 1
- Dresden, Units 2 and 3, and Quad Cities, Units 1 and 2
- Farley, Units 1 and 2
- Arkansas Nuclear One, Unit 2
- D.C. Cook, Units 1 and 2
- Millstone, Units 2 and 3
- Point Beach, Units 1 and 2
- Browns Ferry, Units 1, 2, and 3
- Brunswick, Units 1 and 2
- Nine Mile Point, Units 1 and 2
- Monticello
- Palisades
- James A. FitzPatrick
- Wolf Creek, Unit 1
- Harris, Unit 1
- Oyster Creek
- Vogtle, Units 1 and 2
- Three Mile Island, Unit 1
- Beaver Valley, Units 1 and 2
- Susquehanna, Units 1 and 2

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Applications Currently Under Review:

- Pilgrim 1, Unit 1 - Application received January 27, 2006
- Vermont Yankee - Application received January 27, 2006
- Indian Point, Units 2 and 3 - Application received April 30, 2007
- Prairie Island, Units 1 and 2 - Application received April 15, 2008
- Kewaunee Power Station - Application received August 14, 2008
- Cooper Nuclear Station - Application received September 30, 2008
- Duane Arnold Energy Center - Application received October 1, 2008
- Palo Verde, Units 1, 2, and 3 - Application received December 15, 2008
- Crystal River, Unit 3 - Application received December 18, 2008
- Hope Creek - Application received August 18, 2009
- Salem, Units 1 and 2 - Application received August 18, 2009
- Diablo Canyon, Units 1 and 2 - Application received November 24, 2009
- Columbia Generating Station - Application received January 20, 2010

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Some links on this page are to documents in our Agencywide Documents Access and Management System (ADAMS), and others are to documents in Adobe Portable Document Format (PDF). ADAMS documents are provided in either PDF or Tagged Image File Format (TIFF). To obtain free viewers for displaying these formats, see our Plugins, Viewers, and Other Tools page. If you have questions about search techniques or problems with viewing or printing documents from ADAMS, please contact the Public Document Room staff.

Future Submittals of Applications:

Fiscal Year	No.	Renewal Application	Applicant	Letter of Intent (ADAMS Accession No.)	Submission Date
2010	1	Seabrook Station, Unit 1	FPL Energy Seabrook, LLC	ML073381282	Apr. to June 2010
	2	Davis-Besse Nuclear Power Station, Unit 1	FirstEnergy Nuclear Operating Company	ML062290261	Aug. 2010
2011	1	South Texas Project, Unit 1 and Unit 2	STP Nuclear Operating Company	ML081770299	Oct. to Dec. 2010
	2	Grand Gulf Nuclear Station, Unit 1	Entergy Nuclear, Inc.	ML092450109	July 2011
	3	Limerick Generating Station, Unit 1 and Unit 2	Exelon Generation Company, LLC	ML091210103	Sept. 2011
2012	1	Callaway Plant, Unit 1	AmerenUE	ML083370203	Oct. to Dec. 2011
2013	1	Strategic Teaming and Resource Sharing (STARS) No. 7	Un-named	ML080590377	Oct. to Dec. 2012
	2	Waterford Steam Electric Station, Unit 3	Entergy Nuclear, Inc.	ML092450109	Jan. 2013
	3	Sequoyah Nuclear Plant, Unit 1 and Unit 2	Tennessee Valley Authority	ML092220377	Apr. to June 2013
	4	Strategic Teaming and Resource Sharing (STARS) No. 6	Un-named	ML062550111	July to Sept. 2013
	5	Un-named	Exelon Generation Company, LLC	ML091210103	July 2013
	6	Perry Nuclear Power Plant, Unit 1	FirstEnergy Nuclear Operating Company	ML062290261	Aug. 2013

2015	1	River Bend Station, Unit 1	Entergy Nuclear, Inc.	ML092450109	Jan. 2015
	2	Un-named	Exelon Generation Company, LLC	ML091210103	July 2015
2017	1	Un-named	Exelon Generation Company, LLC	ML091210103	Apr. 2017

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Owners' Groups

Babcock & Wilcox -- The Babcock & Wilcox Owners Group, representing five operating B&W plants, has formulated a generic license renewal program. The B&W Owners Group has submitted generic license renewal reports on the reactor coolant system piping, the pressurizer, the reactor pressure vessel, and reactor vessel internals.

Westinghouse -- The Westinghouse Owners Group also has programs for license renewal and has submitted technical reports on the aging management activities for the reactor coolant system supports, the pressurizer, the Class I piping, the containment structure, and the reactor vessel internals.

General Electric -- The Boiling Water Reactor Owners Group submitted a generic technical report on the containment structure and is currently concentrating their efforts on reports related to the vessel internals program.

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Industry Activities

Nuclear Energy Institute (NEI) -- Industry representatives also participate in working groups and technical committees, coordinated by the Nuclear Energy Institute, to address generic technical and process issues, and to develop additional guidance related to scoping and aging management programs. The NRC has established a formal feedback process by which the resolution of the generic renewal issues and lessons learned during the review of the initial renewal applications is documented and included in revisions to the implementation guidance. These activities are expected to improve the efficiency and effectiveness of future license renewal reviews.

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Related Information

Slides for Vermont Yankee and Pilgrim License Renewal Application.

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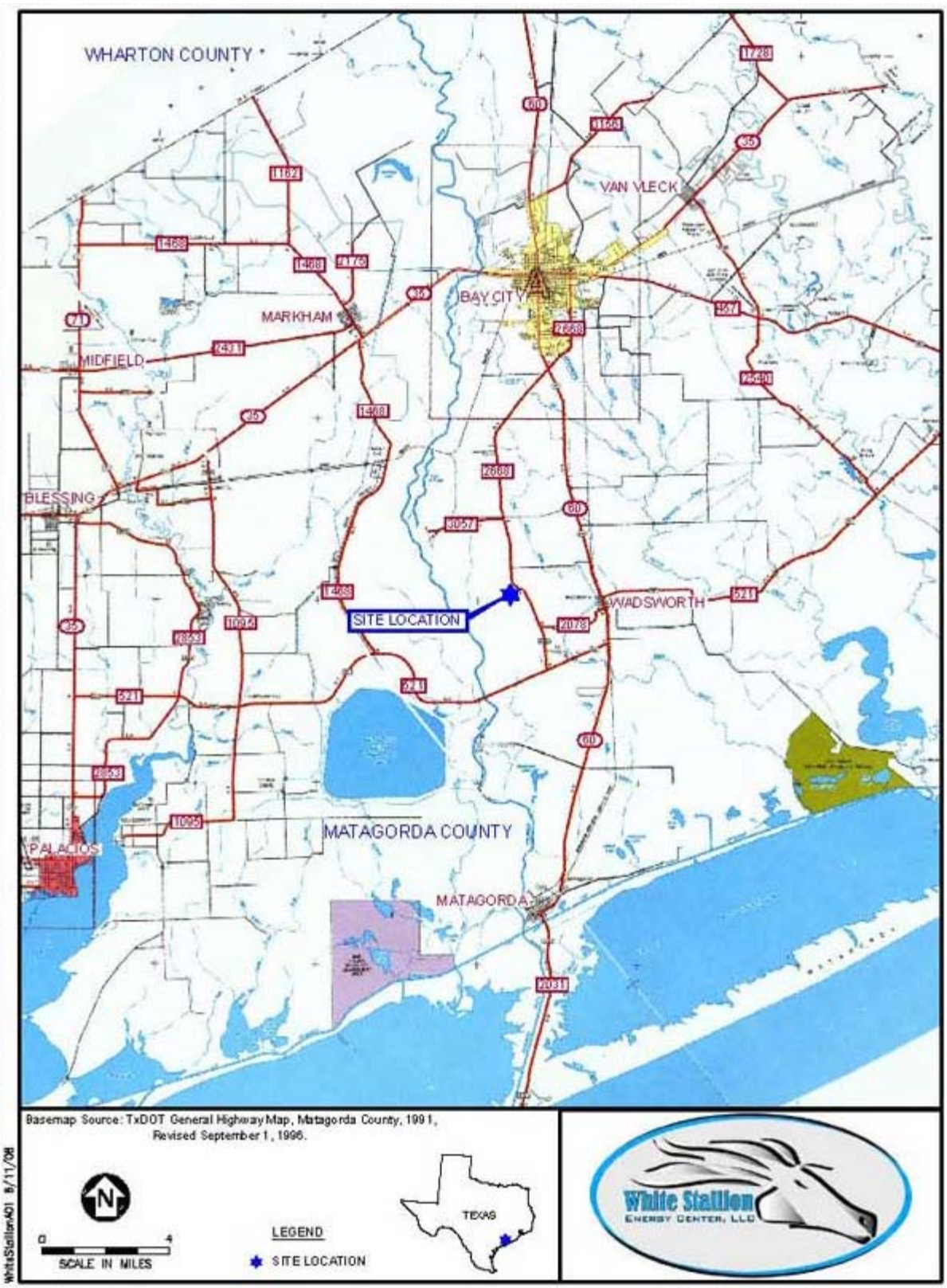
Wednesday, February 03, 2010

Generating Clean Energy for Texas' Future

Location:

The project site is a 1200-acre tract 1 mile south of the Port of Bay City in Matagorda County, TX, ideally situated between FM 2668 and the Lower Colorado River.



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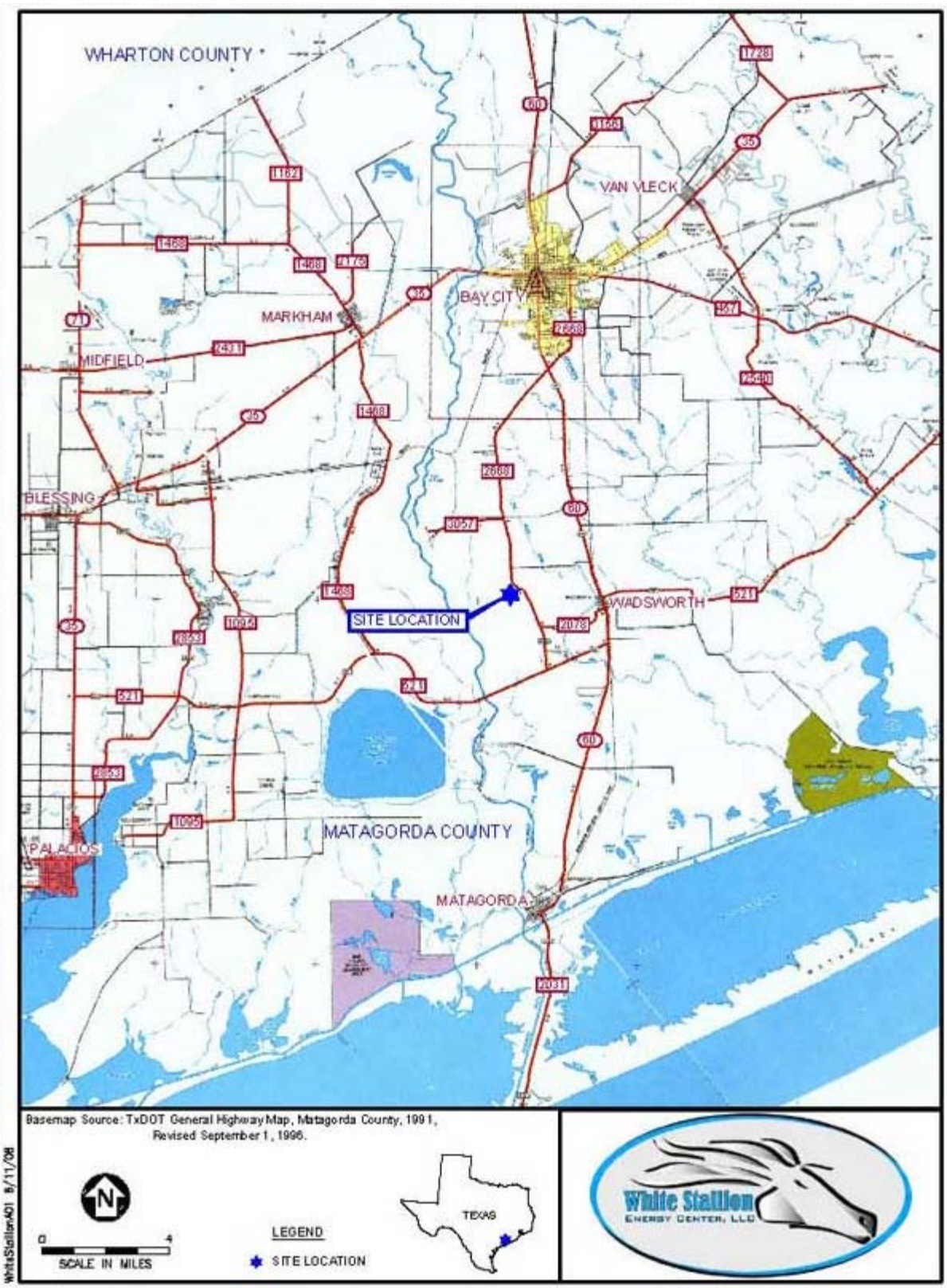

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White Stallion Energy Center, LLC

Generating Clean Energy for Texas' Future

Project Description:

White Stallion Energy Center is a 1320 Megawatt, base-load, solid fueled electric power generating station utilizing the **most environmentally advanced, cleanest, commercially proven, emission lowering technology available.**

As a result, the plant is much cleaner than earlier versions of solid fueled generation. The circulating fluidized bed (CFB) boiler design removes sulfur dioxide during the combustion process by adding limestone into the boiler. The low combustion design temperature prevents the formation of much of the nitrogen oxides and a Selective Non-Catalytic Reducer removes virtually all of the remainder. Mercury and particulate emissions are captured by "bag houses" and by other new technology unavailable on older Texas power plants. The project will be fueled by pet coke, a byproduct of oil refining produced in the region in a blend with high quality bituminous coal imported into Texas. These fuels can be delivered by rail, barge, or truck. An application for water has been submitted to LCRA.

The project will produce enough electricity to supply 650,000 homes throughout the South Texas region. As electricity prices have risen dramatically in Texas this summer, and as they continue to rise due to the demand to fuel the huge on-going economic growth of our State, White Stallion Energy Center will provide a lower cost alternative to natural gas fired generation in Texas, and at significantly reduced cost versus all popular possible technology alternatives.

Click the following links to view pictures of a similar plant under construction. PHOTO 1 PHOTO 2

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